GEOLOGINEN TUTKIMUSLAITOS

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N:o 163

ON MIGMATITES AND ORE MINERALIZATIONS IN THE PERNAJA DISTRICT, SOUTHERN FINLAND

BY

OKE VAASJOKI

WITH 24 FIGURES AND 3 TABLES IN TEXT, ONE PLATE AND ONE MAP

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Helsinki 1953. Valtioneuvoston kirjapaino

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PREFACE

The basic field studies were carried out in the summers of 1948 and 1949 and supplemented by shorter trips in the area during 1950—51. The laboratory research was done mainly during the period of 1949—51.

I owe my primary dept of gratitude to Dr. Aarno Kahma, my chief, who has taken constant interest in this work and generously helped make the practical arrangements for the performance of my studies in the Pernaja district.

Dr. Pentti Eskola, professor of geology at the University of Helsinki and my teacher for many years, was the first to read the manuscript of this paper. For his valuable criticism I wish to express my appreciation.

Dr. Ahti Simonen, State Geologist at the Geological Survey of Finland, has contributed to the progress of this study with much counsel and he also critically read the manuscript. His constructive suggestions I want to acknowledge especially. I am greatly indepted to Dr. Aarne Laitakari, Director of the Geological Survey of Finland, for his permission to use the laboratory facilities of the establishment and to have this study published by the Geological Survey. To the Michael Hisinger Foundation I am very grateful for the financial aid given me.

It gives me pleasure to address my thanks to Mr. Veijo Yletyinen and Mr. Olavi Waldén for assistance in the field, to Mr. H. B. Wiik, M. A., for the chemical analyses herein presented and to Mrs. Toini Mikkola, M. A., for assisting in optical determinations. I likewise wish to acknowledge the help of Miss Karin Dahl, who has drawn the map and pictures.

Finally, credit is due to Mr. Paul Sjöblom, M. A., for correcting the English of my manuscript.

Geological Survey of Finland, December 1952.

Oke Vaasjoki.

INTRODUCTION

Since 1607 small silver-bearing ore prospects have been known around Koskenkylä, in the parish of Pernaja, and from time to time during the period of over 300 years prospecting of various kinds has gone on in the area. The results of the earliest geological mapping of the area have been published by Moberg (1884). A report by Gylling (1887), including several sketch maps and a short description of the general geology of the area, mentions sixteen ore prospects as having been discovered in gneissose rocks. It is known for a fact that in 1751—53 and in 1764 mining operations were undertaken at Hopeavuori (Silverberg) and Forsö, but without satisfactory results.

A fairly large boulder containing considerable amounts of galena, arsenopyrite and other sulphides excited the latest interest in the Koskenkylä region in 1948. The sons of a displaced Karelian farmer, Mr. K. Hovi, found the boulder while clearing land for a new farm approximately one kilometer south-southeast of Hopeavuori. However, the subsequent geological and geophysical investigations in the Koskenkylä area, carried out by the Geological Survey of Finland, appeared to rule out the possibility of mining on a commercial scale.

At the outset it was thought that the mineralizations resulted from hydrothermal effects caused by rapakivi, which forms the eastern boundary to the whole area investigated in Pernaja. The rock belongs to the extensive rapakivi massif of Viipuri (Wahl 1925). However, the paragenic properties of the ores and the geological set-up at Koskenkylä differ essentially from those demonstrated as being typical of the ore occurrences that are assumed to be associated with the formation of the rapakivi granites, namely: The occurrence of Pitkäranta, in Eastern Finland (Trüstedt 1907) [1], and Josva Mine, in Southern Greenland (Wegmann 1938). On the other hand, within the Svecofennidic zone of Southern Finland several small ore prospects can be listed that have paragenic properties and field conditions similar to the mineralizations at Koskenkylä *e.g.*, at Pakila (Kulonpalo 1946), Lauttasaari and Santahamina, to mention a few of the localities near Helsinki registered during the last few years. Analogous formations in Central Sweden are also known (Magnusson 1936, pp. 350—352), *i.e.* in areas certainly without any connection with rapakivi formations. The author accordingly reasoned that the mineralizations at Koskenkylä belong to the last-mentioned category of sulphide formations.

[1]) Since 1944 the area belongs to Russia.

Because the rapakivi has not been considered as a probable ore-bearer, study of the rapakivi has consequently played minor role in this connection. Neither has the investigation of supracrustal rocks been of extraordinary importance to the ultimate purpose of this paper. However, they are presented at sufficient length to serve correlative works, which may be carried out in future on the Svecofennidic supracrustal rocks. Primary interest thus centered on the geology of the widely superimposed Archean infracrustal rocks and the resulting problems, *i.e.* the main topics of this paper, may be stated as follows:

a. The succession of granite-like rocks in the Pernaja district.

b. The emplacement of the ore mineralizations as related to that of granite-like rocks.

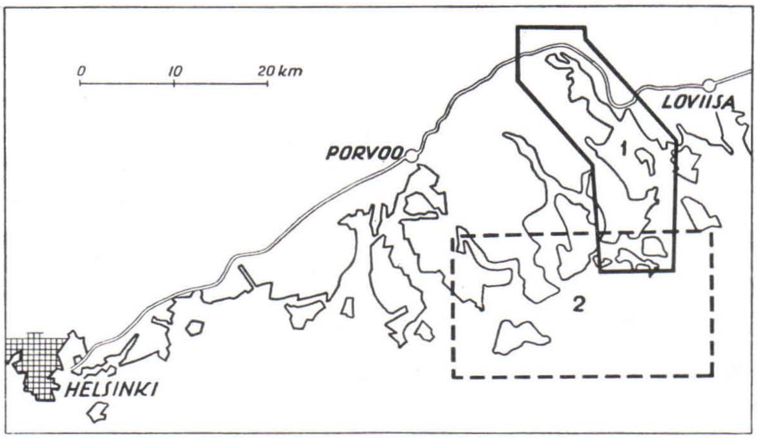

Fig. 1. Location of the area investigated 1. The Pernaja District, 2. The Pellinge Region studied by Sederholm.

During the extended investigation, the mapping was finally carried down to the southern archipelago of the Gulf of Pernaja (Fig. 1). This area partly includes formations earlier described by Sederholm in his memoir on the Pellinge region (1923). The field investigation of the area Våtskär—Sundarö —Stadsland forms merely a network of scattered observations, because a detailed mapping of the abundant outcrops of the numerous small islands would have taken too much time. Altogether, the area now in question is covered by Sederholm's study, which accordingly has suggested most of the field excursions of the present author in the southern archipelago.

The area south of Koskenkylä is a terrain of migmatic rocks. At the outset, therefore, a method was chosen for drawing a map to illustrate appropriately the probable formational relations and not only to reproduce the mixed first impression gained in the field. In this endeavor attention was drawn to a detailed study of the structural patterns of migmatic rocks in the Pernaja district (p. 21). The method applied more or less spontaneously afforded also a logical approach to the problems at hand.

The investigations of migmatic rocks in Southern Finland carried out by Sederholm (1923, 1927 and 1934) have been fundamental to the progress of the present study. The corrections of some of the results presented by Sederholm from the Pellinge area concern mainly the stratigraphical scheme. This is apparently a natural consequence of the ever-increasing amount of stratigraphical facts collected in the Svecofennidic zone since Sederholm's time. The investigation carried out by Wegmann and Kranck (1931) in the area east of Helsinki has been of great informative value to the present author, especially when dealing with tectonic problems. It was here, as Wegmann most definitely pointed out, that a significant dependence between manner of movement and generation of granitic rocks prevails.

Using conclusions based mainly on the inductive field evidence in this particular area, the author has not made any detailed chemical study of the rocks. For the same reason the author has deliberately avoided wider discussion of granitization and metasomatism in the light of the many diverging viewpoints represented in the modern literature.

THE SUPRACRUSTAL SERIES

VOLCANICS AND PYROCLASTIC SEDIMENTS

PLAGIOCLASE PORPHYRITES AND ACID VOLCANIC ROCKS

A common type in the Koskenkylä schists is a blastoporphyritic, darkish rock usually containing only a few phenocrysts of plagioclase. The rock closely resembles the blastoporphyritic volcanics in southern Pernaja, or the metabasalts of Sundarö according to Sederholm's stratigraphical scheme (1923, p. 72).

The rock of Koskenkylä contains plagioclase (An_{30-35}) and hornblende ($2V\,\alpha = 60°$; $c \wedge \gamma = 19°$) in almost equal amounts. Quartz and biotite are present in varying proportions, the latter being to a great extent a product of an alteration of hornblende. As accessories there are small grains of oxidic ore and sphene. The groundmass and a part of the phenocrysts have been entirely recrystallized.

The plagioclase porphyrite occurs within two well exposed zones in the eastern branch of the schist formation ȧt Koskenkylä. Near the main road to Helsinki, ½ kilometer to the west from the Koskenkylä bridge, coarser-grained and strongly deformed rock of the same group occurs, showing some special features as related to other plagioclase porphyrites in the area.

The phenocrysts of plagioclase are about 0.5—1.5 centimeters long. The main constituents in the groundmass are hornblende, plagioclase (An_{30-35}), quartz, biotite and chlorite, the latter only in minor quantities as an alteration product of biotite. Some apatite and grains of oxidic ore occur as accessories. The light-colored constituents are entirely recrystallized. Apparently a secondary increase of quartz has taken place (Pl. I, Fig. 1.).

The coarse porphyritic bed, approximately 30 meters wide, borders conformably to the tuffaceous schists striking N 70°E and dipping 60°N. In the direction of the schistosity numerous narrow injection pegmatites occur, especially in the tuffs. Towards the southern contact the coarse porphyritic rock grades into a fine-grained variety, while the phenocrysts become longer though decrease in quantity. The decrease in the amount of phenocrysts might be due to gravitative differentiation, as suggested by Edelman (1949) in regard to an evidently corresponding phenomenon in the Gullkrona area, Southern Finland. In the present case, however, the phenomenon as described is rather local in character and probably signifies only a gradational contact between tuff and porphyrite material.

As to appearance and mineralogical composition, the plagioclase porphyrites of Koskenkylä are almost exact counterparts of the meta-andesites (Sederholm 1923) which occur in contact with granodiorites at Hästholmen, south of Våtskär. Microscopical examination of the blastoporphyritic rocks from Koskenkylä and Hästholmen reveal that the latter is more nearly primary in texture. The chemical analyses of both rocks are included in Table 1.

No acidic lavas have been noted in the Koskenkylä area. In the Våtskär area, about ½ kilometer to the south from the aforementioned contact at Hästholmen, some reddish-brown, aphanitic, acidic schists occur within the meta-andesitic zone. Having a strike parallel to that of the meta-andesites, these schists form a single bed up to 100 meters in width.

The main component is recrystallized quartz. It seems that during the metamorphic action larger phenocrysts of quartz were elongated and partly mobilized in such a manner that the mineral gives to the rock a texture resembling that of fragmented stratification. Quite subordinate components are small amounts of plagioclase, amphibole, chlorite, needles of cummingtonite, epidote, apatite and grains of oxidic ore.

The primary origin of these rocks cannot be reliably ascertained but the names dacite or rhyolite might be tentatively used, rather than terms applicable to rocks of purely sedimentary origin. In his map Sederholm has not distinguished between these rocks and the meta-andesite south of Våtskär. However, in the text (1923, p. 70) he refers to some quartzite formations found on the western shore of Sundarö. These formations might form a continuation of the acidic beds observed at Hästholmen. The present author, however, had no opportunity to verify this possibility.

URALITE PORPHYRITES

Particularly in the zone east of the main road between Koskenkylä and the village of Pernaja, the plagioclase porphyrites contain intercalations of more basic beds, with dark, spot-like phenocrysts of hornblende.

Hornblende ($2V\alpha = 65°$; $c \wedge \gamma = 20°$) has resulted by recrystallization of primary pyroxenes, which still exist in places among the phenocrysts. The groundmass is completely recrystallized, comprising prismatic hornblende and small irregular grains of basic plagioclase. The flow structure visible under the microscope may be partly a relict feature of primary lava flow.

The blastoporphyritic rocks are distinctly separable from the basic tuffites. According to Sederholm, there should exist in the Pellinge area different kinds of uralite porphyrites produced during separate epochs of volcanic activity. The slight discrepancies in the appearance of these rocks, as found at Koskenkylä, however, must be merely a consequence of a different stage of metamorphism.

TUFFITES AND AGGLOMERATES

The pyroclastic sediments are dominant among the Koskenkylä schists. The western branch of the ramifying schist zones is for the main part composed of agglomeratic rocks, whereas in the eastern branch the westernmost border seems to be only a uniform zone of agglomerates. After it there follow intercalations between tuffs and lava beds, until the agglomeratic structures entirely disappear.

The plain tuffaceous beds are best exposed in the eastern branch of the schists in immediate contact with agglomerates. Well-preserved tuffites belonging to the same zone occur farther, near Kudasberg, north-northwest of Koskenkylä. The rock is darkish, fine-grained and megascopically strongly schistose.

The main mineral components are plagioclase (An_{40-42}) and green hornblende ($2V\alpha = 66°$; $c \wedge \gamma = 10°$). Apatite, sphene, zircon and oxidic ore are accessories. Some pyroxene occurs as occasional remnants in scores of hornblende and biotite. The hornblende is strongly biotitized and chloritized. The salic minerals are partly recrystallized. Recrystallized quartz is small-grained and bright, whereas the older generation is coarser, cataclastically broken and possesses a distinct undulatory extinction (Pl. I, Fig. 2).

On the east side of the main road, east of the Hovi farmhouse, banded tuffaceous beds were noted, in which the border between dark and light layers is remarkably sharp. The layers are from one to several centimeters wide, and the dark portions probably are of a chemical composition similar to the basic tuffites in the area. A typical constituent of these layers is coarse-grained hornblende ($2V\alpha = 65°$; $c \wedge \gamma = 15°$). The light bands mainly comprise epidote, variable amounts of plagioclase, and some quartz. It should be noticed that the composition of plagioclase varies from An_{30-35} to almost pure albite. Small remnants of chloritized hornblende associated with abundant grains of oxidic ore have been met with.

Within the eastern border of the volcanic series, in the immediate vicinity of the rapakivi contact, large outcrops of dark, very fine-grained schist were found. In field appearance the rock closely resembles phyllites, showing a kind of stratification. Microscopical examination reveals that the structural resemblance is due to: a. vein-like quartz in approximate alignment with the foliation of the dark minerals, and b. very fine bands of quartz, although no real stratification is present.

Table 1. Analyses of the Volcanics in the Pernaja District.

	1		2		3		4	
	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.
SiO_2	50.78	8 455	52.28	8 751	54.13	9 012	59.39	9 888
TiO_2	.75	94	.87	109	1.41	176	.92	115
Al_2O_3	18.08	1 774	20.75	2 036	16.57	1 625	17.83	1 749
Fe_2O_3	2.80	175	2.35	147	2.25	141	.69	43
FeO	5.33	742	5.20	724	7.06	982	6.01	836
MnO	.11	16	.10	14	.09	13	.04	6
MgO	5.72	1 419	2.70	670	4.94	1 225	2.29	568
CaO	10.80	1 926	8.18	1 458	6.38	1 137	6.44	1 148
Na_2O	3.12	503	3.82	616	3.64	587	1.28	207
K_2O	1.00	106	1.55	165	2.34	248	2.81	298
P_2O_5					.15	11	.07	5
H_2O+	1.06		1.66		1.41		1.76	
H_2O-					.06		.06	
	99.55		99.46		100.43		99.59	

Niggli numbers

	1	2	3	4
si	123.8	145.8	148.1	201.8
al	25.9	34.1	26.7	35.7
fm	37.0	28.5	41.0	30.5
c	28.2	24.4	18.6	23.4
alk	8.9	13.1	13.7	10.3
k	.17	.21	.30	.59
mg	.56	.38	.49	.36
c/fm	.76	.88	.45	.77

1. Plagioclase porphyrite, Öster Rysskär, Pernaja. Analyst E. Mäkinen (Sederholm 1923, p. 36).
2. Meta-andesite, Ägghällan, Pernaja. Analyst E. Mäkinen (Sederholm 1923, p. 74).
3. Plagioclase porphyrite, Koskenkylä, Pernaja. Analyst M. Tavela.
4. Fine-grained tuffite, Koskenkylä, Pernaja. Analyst H. B. Wiik.

The main components in the rock are partly recrystallized plagioclase (An_{35}) and biotite, which, rich in iron, has been greatly chloritized. The epidote occurs as an essential accessory mineral, sometimes as large crystals in association with quartz veins. The light minerals compose 62 % of the rock. (Pl. I, Fig. 3).

The quartz, occurring in definite layers, was probably enriched by the primary tuffite material. The quartz of thin veins might be introduced by later hydrothermal solutions from an external source. In view of its high content of lime (Table 1, 4) the rock may be classified as a fine-grained modification of the tuffites of the Koskenkylä area. The real tuffite character is also obvious upon comparing the composition of the rock with that of other tuffitic rocks described from the Svecofennidic zone (Simonen 1953).

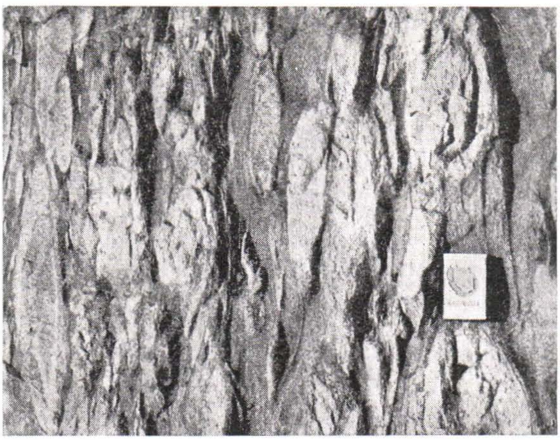

Fig. 2. Agglomerate near Ahlers, Koskenkylä.

Near the house of Ahlers, approximately in the middle of the Koskenkylä area, a structurally well-preserved agglomeratic bed was found (Fig. 2). The pebbles are rounded and strongly elongated in the direction of the strike of the schists. The size of the usually greenish pebbles varies from a few centimeters to thirty centimeters in length. On the weathered surface the pebbles show evidence of having had a primarily porphyritic texture. Microscopical examination does not disclose the textural properties, because a strong epidotization has entirely obscured the primary habit of the minerals.

In addition to plagioclase and epidote, the other chief constituents of the pebbles are hornblende, mostly altered to chlorite, and some quartz. Grains of oxidic ore and sphene occur as accessories. The chief components in the dark-colored, schistose matrix are green hornblende and plagioclase (An_{25}), which approximately corresponds to the composition of the plagioclase of the tuffaceous schists. Epidote and chlorite exist in much smaller amounts in the matrix than in the pebbles. In places both ingredients of the agglomeratic rock have been penetrated by veins of rather coarse-grained quartz.

The agglomeratic formation of Ahlers seems to be very similar to those which, according to Sederholm, belong to the oldest schists of Sundarö at Viasholm and Sundarö (1923, p. 75). However, he preferred to call these rocks conglomerates, especially the one at Viasholm, because he supposed the material to have been washed by water and transported from some distance. The tuffites at Koskenkylä show a distinct tendency to selective sedimentation, as revealed by the variation of primarily coarse and fine-grained beds. As expected the agglomerates have undergone the same process and the resulting formation may thus be called volcanic conglomerates.

SEDIMENTOGENEOUS ROCKS

In the Koskenkylä area some slight signs have been found recalling normal sedimentogeneous formations, which possibly existed west of the volcanics. Strongest evidence of this kind was noted in the Gisslarböle region, where a small outcrop consists of veined gneiss, including numerous large crystals of almandite garnet. In appearance quite a similar formation is situated on the southwest shore of Forsö. Half way between the aforementioned occurrences the agglomeratic schists grade into mixed beds of tuffites and clayey material. All these observations concern the same zone, which presumably might then represent the lower portion of the sequence of the supracrustal beds met with at Koskenkylä.

In the southern archipelago one distinct bed of quartzite was found on the eastern shore of Kjällöland. The bed is about 20 meters in width and surrounded on all sides by homogeneous potash granites. The contact between these two rocks is gradual. The strike of the formation is N 30°E, *i.e.* conforms to the general strike of chorismitic inclusions in this area. The rock possesses one clearly developed cleavage direction, having the aforementioned strike, and dipping N 30°NW.

Undoubtedly the quartzite from Kjällöland is part of the vast area of Rabbasö quartzite at Pellinge (see the map by Sederholm). In a broader sense these occurrences belong to the same category of relict quartzites that have been investigated in great detail by Eskola and Nieminen (1938) and Hietanen (1938) in the Svecofennidic zone. Consistent with Pettijohn's conception (1943), Simonen has recently (1953) interpreted the rarity of quartzites in the Svecofennidic territory as characterizing the old geosynclinal conditions, in which rapid erosion and incomplete weathering do not favor the sedimentation of pure materials.

The main part of the supracrustal rocks of the Koskenkylä area belong to the amphibolite facies (Eskola 1939, Turner 1948). However, the process of epidotization effectively attacked especially the tuffites, while the mineral composition was changed to epidote-amphibolite facies. In the vicinity of Kudasberg a continuous grading from originally basic tuffites to epidote-plagioclase-quartz rocks can be easily followed. Particularly in this area the epidotization seems to be associated with the zone of migmatic granite. This rock assemblage, the migmatic potash granite followed by highly epidotized schists, suggests that the epidotization in the first place took advantage of the relatively high water content in the respective zones (see later, p. 46). Mr. V. Yletyinen, field assistant during the prospecting work at Koskenkylä, pointed out the limited amount of rocks of greenschists subfacies with the mineral combination, chlorite-epidote-albite-actinolitic hornblende (1952). He suggests as one possibility that the rapakivi was responsible for the aforementioned mineral association, as the rocks seem to occur especially in areas near the rapakivi contact. This remark warrants consideration even though the areas in question are, as a rule, strongly influenced by pegmatites and hydrothermal solutions from younger Archean granites. In his investigation of the region east of Helsinki, Kranck (1931, p. 98) finds epidotization at least of two different ages. The information gained in the course of the present study confirms the statement by Kranck but does not allow a firm correlation as regards the evolution of different infracrustal rocks.

TECTONICS AND STRATIGRAPHY

The structural and tectonical investigations in highly migmatized areas of the Svecofennidic zone commonly encounter interpretative difficulties and sometimes the observations made do not offer much concrete data for further evaluation. This is the situation in the area now under consideration.

The zone of well-preserved supracrustal rocks in the Koskenkylä area curves smoothly from southeast to northwest and west. The schistosity is almost everywhere parallel to the bedding and the dips are in most places steeply falling to the east or northeast. The chorismitic xenoliths and inclusions in the middle of the area investigated clearly show a similar tendency and they display apparently obliterated connections between the supracrustal formations of the northern and southern parts. The wide arc thus formed surrounds the eastern border of the Archean granites. Presumably this behavior reveals the process of diapiric updoming of granitic masses, which consequently explains that the schists in the northern part do not obey the east-westerly strike typical of the Svecofennidic formations.

In the Koskenkylä area the linear structur of the minerals suggests a rather horizontal folding axis. In the Kudasberg area a few observations suggest a small syncline, the axis of which plunges approximately to the west-northwest. Possibly the ramifying zones of schists at Koskenkylä are also in a synclinal position.

The steeply plunging linear structures of dark minerals were observed in many places but they reveal obvious tangential movements of later data than the folding (Wegmann 1931). An example of this kind of lineation may be cited from the neighborhood of the junction of the roads to Baggböle and Koskenkylä: An excellently developed slickenside is exposed, with a lineation plunging 80° southwest and coinciding with the main strike direction N 80°E (Fig. 3). As a rule similar zones are marked by strong pegmatization.

Fig. 3. Road cut in Koskenkylä showing well developed slickensides and steep lineation of the agglomeratic schists.

If the ramifying schist zones in the Koskenkylä area were pushed together, the thickness of the supracrustal formation would be approximately two kilometers. The appended diagram (Fig. 4) shows the stratigraphy from northeast to southwest to be as follows:

— Fine-grained tuffite
— Intercalations of blastoporphyritic lavas, tuffites and agglomerates
— Tuffites and agglomerates
— Garnet-biotite-schists (argillaceous material).

Supposing that the garnet-mica-schists mark the lower portion of the sequence in the Koskenkylä area, the profile demonstrates stratigraphy that seems to be most common in the Svecofennidic zone (Simonen 1953).

The present observations on the extensive schist belt of Pellinki (Pellinge) — Pernaja, partly represented in the southern part of the area investigated, do not suffice for further discussion on tectonics or stratigraphy in this connection.

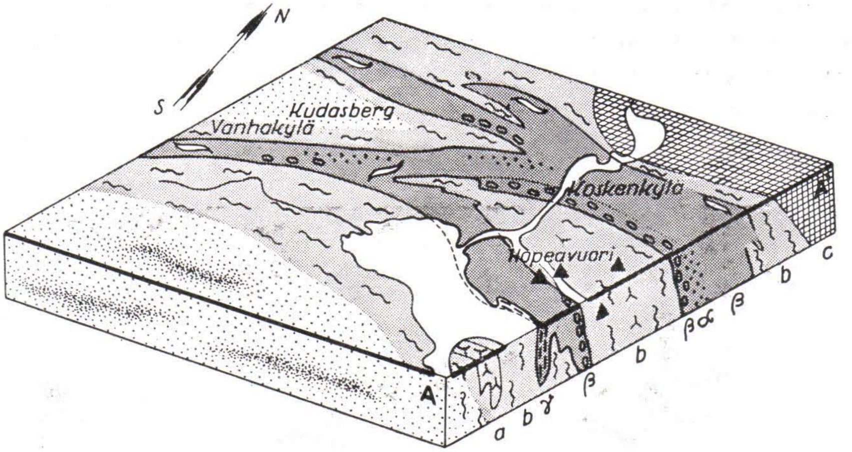

Fig. 4. Isometric block diagram of a part of the Koskenkylä formations. α = blastoporphyritic rocks, β = tuffites and agglomerates, γ = garnet-biotite-schists; a = granodioritic rocks, b = migmatic potash granite, c = rapakivi. Additional information obtainable from the petrological map.

THE INFRACRUSTAL ROCKS

GRANODIORITE

The granodioritic rocks exposed in vast areas of the southern archipelago of Pernaja have been called Våtskär granite by Sederholm. In this region the granodiorites are situated approximately as mapped by him.

The granodiorite under consideration is an almost homogeneous, medium-grained rock, in which the dark components possess a distinct foliation. In his study of the Pellinge region (1923, p. 137) Sederholm has described the rock as follows:

»The rock of Våtskär is a grey, indistinctly porphyritic granite which shows a pronounced gneissose texture, owing to the parallel arrangement of the minerals. This is at least in part due to stress which has acted upon a solid rock. The greater feldspars seldom measure more than 1 cm. in length and possess irregular forms, having been more or less crushed. The main part of the rock has a medium grain and consists of lenses of feldspar with a length of 2—10 mm., together with biotite and hornblende in almost equal parts, arranged in stripes between the feldspar, and granulated, glittering quartz. The gneissose character is so pronounced that the rock may perhaps better be designated as granitic gneiss than a granite.»

Microscopically the rock shows the following characteristics:

The structure is generally granoblastic in some degree and in places the cataclastic phenomena present reveal an effect of strong dynamometamorphic agencies. The composition of plagioclase is An_{27}. Biotite is shattered, α = pale brown, $\beta = \gamma$ = dark green. Hornblende is normally green. Quartz is serrated and mostly shows undulating extinction. As accessories a fair amount of sphene, epidote and oxidic ore grains are present.

In the field numerous, biotite-rich inclusions about 10—20 centimeters long emphasize the gneissose texture of the granodiorite, as the inclusions strictly follow the foliation (Fig. 5). It is equally orientated with the strike of supracrustal rocks south of Våtskär. Porphyroblastic crystals of feldspar very often have been noted in the inclusions.

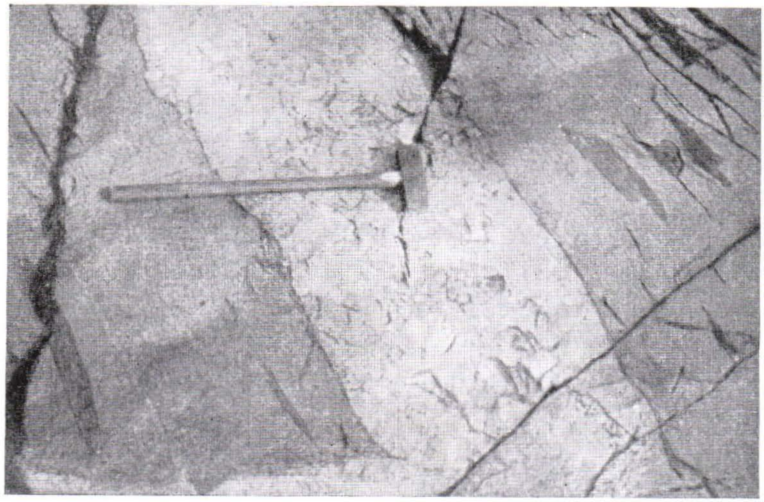

Fig. 5. Granodiorite penetrated by younger pegmatites, eastern shore of Våtskär.

According to Sederholm (1923, map) on the north side of Våtskär between the granodiorite and the potash granite (Hangö granite) there exists a uniform formation of Sundarö schists, although abundantly intersected by potash granites. This conception is hypothetical only, because the zone in question is covered by the sea and therefore the real conditions cannot be controlled. This questionable schist zone has been left out in the present map, for a migmatic zone between the older rocks and the potash granites seems to be more plausible in the area, even if numerous and occasionally large, phlebitic inclusions of schists have been found while mapping the islands. In composition the dark inclusions correspond to amphibole-plagioclase gneisses.

In the northern part of Sundarö a continuation of the granodiorite was found. It appears, however, for a short distance only before disappearing under the sea, and the same zone is found again in Stadsland, which is the last corner to the southwest in the present map. In that locality the potash granites must be in a very close neighborhood, because the granodiorite is repeatedly penetrated by pegmatites inevitably belonging to the potash granite series.

A typical conformity between granodiorite and supracrustal schists is clearly exhibited in several outcrops in the southern part of Våtskär. On Hästholmen, referred to earlier, the contact aureole is rather narrow. The supracrustal beds are intercalations of lavas and tuffs, which, in the immediate vicinity of the granodiorite, within a zone of about 5—10 meters in width, have been metamorphozed into tremolite-actinolite rocks. This strongly schistose, lepidoblastic modification is composed mainly of long crystals of actinolite ($2V\alpha = 80°—88°$; $c \wedge \gamma \cong 15°$; $\alpha \sim 1.637$, $\beta \sim 1.649$, $\gamma \sim 1.659$) and basic plagioclase. As accessories there are fair amounts of apatite and oxidic ore (Pl. I, Fig. 4). A corresponding change of facies has been recognized in the schistose rocks west of Koskenkylä bridge and in a locality about 200 meters to the north of Forsö bridge.

In the northern part of the area investigated the granodiorites are less abundant and only a few outcrops have been met with in the area enclosed by the two branching zones of schists at Koskenkylä and on the island of Ryssö. All these small outcrops fade out diffusely into the surrounding potash granites. In places the granodioritic rocks between Isnäs and Ryssö include modifications, the composition of which approximates that of syenito-diorites (Niggli 1923, p. 125 and 147). Typical of this rock is a relatively high *mg*-number, whereas the *c*/*fm* is low in regard to diorite (Table 2).

Microscopically the structure is hypidiomorphic. The plagioclase is bright and distinctly lamellar. The extinction $\perp$ PM = 13°, α = Canada Balsam. Accordingly the composition of plagioclase is $An_{7\text{-}8}$. Obviously, however, there are two generations of plagioclase, as some few grains, bigger in size and without lamellae have been noted. In addition, these grains are strongly corroded and turbid, although some tendency revealing the original zonal structure is observable. Biotite occurs as beautiful plates: α = light yellow; $\beta = \gamma$ = pure brown. Hornblende is normal, *i.e.* α = almost colorless; β = bluish green and γ = brownish green. $c \wedge \gamma = 12°$ and $2V\alpha = 80°—88°$. Small grains of quartz are accidentally present.

The proportionally low *c*-value is understandable, as the plagioclase is almost pure albite in this rock. On the other hand, the presence of albite implies that the rock is not a well balanced example of a granodioritic series, but probably was originally gabbroic rock, which has been altered metasomatically. It is to be noticed that during the later stages of orogeny there also existed an active material rich in soda. Some additional observations on this matter will be given later, on p. 42. When attacked by this material, the plagioclase of the gabbro gave up the anorthite as happens in the spilite reaction (Eskola, Rankama and Vuoristo 1937). In appropriate PT-conditions, and when the water content was sufficient, the calcium released was enabled to migrate, forming epidote in some other zone, while the femic minerals underwent the following change: hornblende → biotite → chlorite. Thus, the epidote-rich rocks, so abundant in association with the schists in the area investigated, may have some genetical connection with the aforementioned albite-rich rocks, which originally belonged to the granodioritic series. An analogous soda-syenitic rock from Sundarö, which is obviously a modification of granodiorite, has been described also by Sederholm (1923, p. 141).

Two analyses from the granodiorite around Våtskär are available (Table 2). According to Simonen's (1948) calculations the Niggli-numbers closely match the curve of the synkinematic rocks of the Svecofennidic orogeny. The dark inclusions characteristic of the granodiorite of Våtskär are also typical of the granodiorites (gneissose granite) elsewhere in Southern Finland; but it seems that the inclusions can be of varying origin in different localities. The ancestry of dark inclusions in the oligoclase-granite of the Orijärvi region has been thoroughly discussed by Eskola (1914, p. 68), who finally gave the following statement on the matter:

»Perhaps the dioritic inclusions in the oligoclase-granite need no other explanation than that which seems natural in this case, *viz.* that fragments from the first consolidated portions have sunk in the still fluid magma.»

A granodiorite (gneissose granite) with small, elongated inclusions found in Gullkrona, Southwestern Finland, has been described by Edelman (1949, p. 21). In harmony with the aforementioned result by Eskola, he explains the dark inclusions as being remnants of the basic members of the alkali-calcic series. However, in the said area on the island of Gubbholm, Edelman has found dark inclusions, which he points out as being of supracrustal origin. An example studied at Småholm in the Enklinge area of granodiorite (gneissose granite) possessing a great similarity to the Våtskär granodiorite has been described by Sederholm (1934, p. 14). The granodiorite borders mica-schists, but obviously in such a manner that the rock modifications within the contact aureole plainly show the micaceous inclusions in the granodiorite as having derived from the adjacent mica-schists. However, there occur, also in Enklinge, granodiorites in which the inclusions are leptites, amphibolites or basic gabbroic rocks.

As for the typical granodiorite in the Pernaja district, the present author has interpreted the dark inclusions to be remnants of supracrustal rocks, which were deformed and strongly affected by resorbing factors animated during the intrusion period of the synkinematic rock series. The homogeneous appearance and the evenly distributed density of inclusions in the granodiorite of Pernaja bolster the opinion that this rock was formed in relatively constant PT-conditions, which account for the general, homogeneous character of synkinematic granodiorites elsewhere in the Svecofennidic zone. As soon as these conditions were disturbed, heterogeneous modifications were produced, as will be shown by many illustrations to follow.

CHORISMITIC GRANODIORITIC AND GRANITIC ROCKS

Among the granodioritic and granitic rocks belonging to the Archean formation in the area investigated considerable structural variations occur, which especially favor a detailed study of potash granites. To illustrate the different structures, descriptive terms proposed by Central European petrographers (Scheumann 1936, Niggli 1949 and Huber 1943) have been used, in order to avoid the ambiguity that necessarily accompanies a genetic terminology.

The terminology referred to includes different migmatic rocks under the term of chorismite. The chorismitic rocks, consequently, are built up of paleosomic and metatectic material, the latter being of ectectic (secretion from the rock itself) or entectic (injection from an external source) origin. Especially the following terms employed for the subdivision of chorismitic rocks, but not familiar in English usage, should be mentioned in this connection:

Merismite: A block-like pattern of paleosome in metatect.

Phlebite: The metatectic material may appear as vein-like formations in the paleosome; or it may form a network of veins, which again, may sometimes swell into lense-like bodies in the paleosome material.

Stromatite: The rock has either a banded or layered appearance, but in such a manner that the relation of paleosomic and metatectic materials is indeterminate.

The potash granites in the area investigated are for the most part chorismites represented by merismites, phlebites and nebulites. The geological map herein included has been drawn as far as possible with an eye on the aforementioned structural patterns visible in the granites. The single occurrences of chorismitic nature, as might be expected, never possess mapable dimensions, but in general they fortunately exist abundantly within certain zones and these have been easily determinable in the scale used on the map.

The m e r i s m i t i c structures prominently imprint the rocks described by Sederholm under the designation of Rysskär granite. The name derives from two islands of Rysskär in the southwest part of the parish of Pernaja. All over this area, Sederholm has emphasized, »the rock is full of inclusions which have undergone resorption in greater or lesser degree, whereby also the composition of the including magma has been changed through the assimilation of basic material.»

In one of the most typical cases Sederholm describes the rock as follows: »The Rysskär granite has a greyish red colour with a more sombre hue than the granites of Hangö type, and is always even-grained. Porphyritic varieties do not occur. It is characterized by the prevalence, in most cases, of plagioclase over microcline, by the euhedral forms of the feldspars, especially the plagioclase, and the anhedral forms of the quartz» (1923, s. 114). In addition to plagioclase and quartz the rock comprises variable amounts of microcline, biotite and hornblende. Some sphene, epidote and magnetite are present as accessories. Pigment is always abundant.

In the stratigraphy of the Pellinge formations Sederholm has determined the Rysskär granite to be between granodiorite and potash granite (Hangö granite). The mineralogical composition of the rock undoubtedly is very close to that of granodiorite. The chemical composition (Table 2) will be discussed in later pages, but also from this point of view the similarity between Rysskär granite and normal granodiorites gains support. Accordingly, it is quite understandable that, in the later investigations undertaken by Sederholm in the Svecofennidic zone, he has found no granite that is stratigraphically correlative to Rysskär granite.

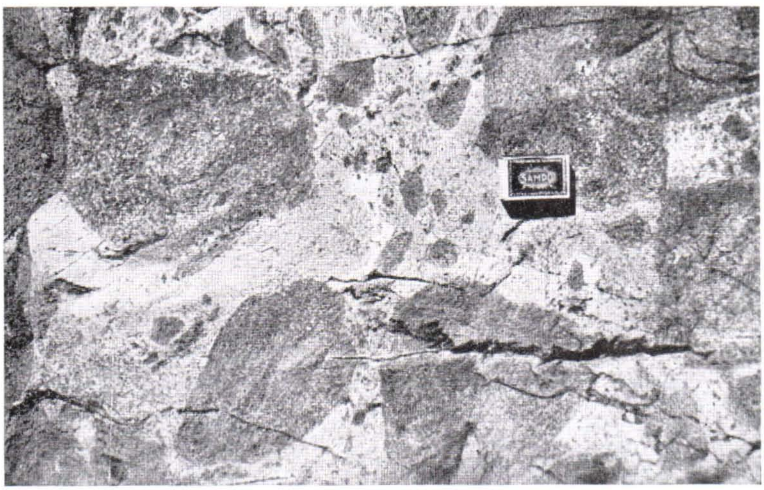

Fig. 6. Merismite of Hopeavuori, Koskenkylä.

The outcrop of Hopeavuori (p. 51) and the near surroundings of Koskenkylä are occupied by merismitic rock, which is best exposed in a large local boulder about 150 meters southwest from Hopeavuori (Fig. 6). The paleosomic fragments are petrologically similar but very variable in size. In the fragments some small grains of blastoporphyritic plagioclase occur here and there. The cementing metatectic material is fine-grained, greyish red granite.

The microscopical texture of the paleosome is strongly granoblastic, and especially the salic components are corroded and obscure. The main constituents are plagioclase, quartz, biotite, and hornblende. The lamellar structure of plagioclase is visible only accidentally. The refractive index is usually about that of Canada Balsam. Hornblende is normally green, biotite brownish. A typical alteration series, hornblende → biotite → chlorite, occurs associated mostly with microcline. This alteration certainly is a consequence of the granitization process, which has attacked the paleosome material. The granitic material of the metatect is identical with that of merismites around Rysskär (the Rysskär granite).

Thus, in its intrinsic features the merismite of Hopeavuori inevitably corresponds to the merismitic rocks of the Rysskär area. In addition, similar merismitic rocks have been met with in several places within the western border of the granitic area that exists between the branching zones of supracrustal rocks at Koskenkylä.

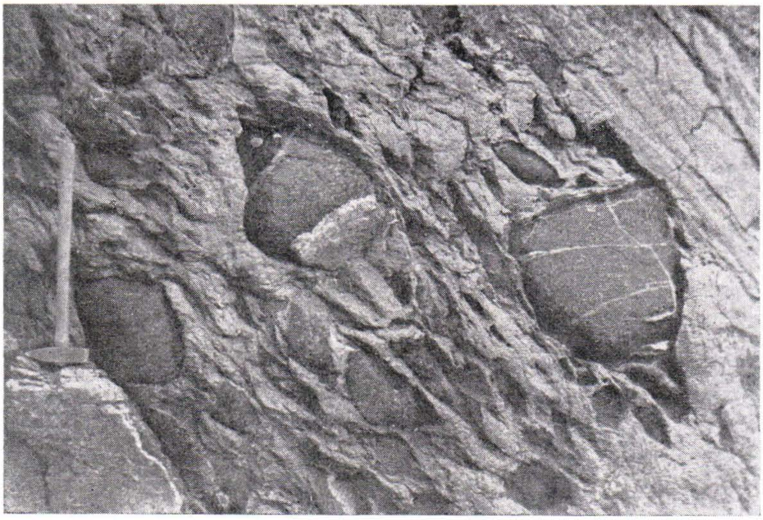

Fig. 7. Merismite with nebulitic potash granite metatect. Hirsalö island.

However, also the potash granites involve rocks with merismitic structures. These usually obscure formations are always small and appear like remnants after older formations of analogous structure. A merismitic rock on the west shore of Hirsalö (Fig. 7) serves preliminarily as an illuminating example of such occurrences.

The p h l e b i t e s and n e b u l i t e s occur most abundantly in association with potash granites occupying the archipelago south of the village of Pernaja, but reminiscent structures have been found in the southern part of the map area as well. In the phlebites a bed of originally supracrustal schists forms the paleosome, which is surrounded usually by a rather homogeneous granite (Fig. 8). The veined metatectic material varies mineralogically from pure quartz to assemblages of potash granite composition.

Phlebitic formations are common everywhere in migmatic areas, and in this connection especially an example identical in appearance to the phlebite in Fig. 8 will be referred to from Southern Greenland (Wegmann 1938, p. 106). Wegmann suggests that the process giving rise to the formation of such a structure can be imposed on the transformations which proceeded along all routes. Apparently the interpretation of phlebitic structures can be attributed to the extensive discussion on »veined gneisses» (Sederholm and Holmquist 1907) in which Seitsaari recently (1951) participated,

Fig. 8. Phlebite on small island south of Hirsalö

meritoriously reviewing the literature concerned. Seitsaari's approach suggests that the formation of phlebitic structures has taken considerable advantage of planes of schistosity in the supracrustal beds, either in such a way that the planes of schistosity have served as channels of escape for entectic material, or that ectectic metatect has been generated within these planes in connection with shearing movements. It is plausible to conclude that both agencies have been in operation and, especially in completely migmatized areas, it is likely that a phlebitic structure is the result of multifold processes caused by various factors during different orogenic epochs.

Nebulitic formations with indistinct remnants of the earlier chorismitic structures have been met with frequently. It should be noted at this point that the homogeneous metatectic material may have a mean composition of granodiorites or potash granites, depending upon the stage of orogeny in which the nebulitic rock finally had been modified. In other words, there certainly exist chorismites originating during different orogenic phases, *i.e.* connected with potash granitic or granodioritic stage, and, consequently, polychorismites comprising both the aforementioned Archean rocks have been met with (polymigmatites, Sederholm).

POTASH GRANITES

The potash granites of the Pernaja district belong to the group of granites which, in relation to the Svecofennidic folding, are called serorogenic by Wahl (1936) and late-kinematic by Eskola (1931). Here Eskola's terms have been applied.

The chemical character of late-kinematic potash granites is rather consistent (Table 2) but in texture they involve several variations, which regionally may be confusingly superimposed. In the Pellinge area Sederholm treated all the granitic rocks north of the archipelago under the designation of Hangö granite and developed no further classification among these rocks. This amounts to a shortcoming in method, whereby data on relevant incidents pertaining to the total processes within the migmatite-forming front might not have been obtained. In the course of the present study attention, therefore, has been called to the evident textural discrepancies in the late-kinematic granite group. Three different modifications of potash granites, occurring as uniform masses beside chorismitic formations, have then been established. A brief description on each of them will be offered in the following pages.

MIGMATIC POTASH GRANITE

The rock chiefly occurs along the borders or inside the two main branches of supracrustal rocks of Koskenkylä. The group includes more or less foliated granites, which also may embrace conforming, chorismitic xenoliths of micaceous or amphibolitic schists. Taken generally, the migmatic potash granite makes the transition from older rocks, including schists or granodiorites, to garnet-bearing, homogeneous potash granites. The transition from the migmatic granite to schists occurs by means of veined gneisses (see explanation on phlebites, p. 23), shifting the compositional variation from biotite-microcline-quartz rocks to amphibole-plagioclase (An_{25})-quartz rocks, respectively. An instance of this tendency on a small scale was studied in the Kudasberg area between ramifying zones of schists, north-northwest from Koskenkylä. The outcrops closer to the schistose beds are composed of migmatic potash granite, while the garnet-bearing granite showing nebulitic structures occupies the central parts of this area (Fig. 9).

Fig. 9. Nebulitic potash granite from Kudasberg, Vanhakylä.

Between the ramifying schist zones in Koskenkylä and its surroundings, there is evidence that the older rocks were changed to migmatic granite by granitizing agencies, but probably an intrusive-like material was in operation, too. Thus, in the aforementioned locality, the migmatic granite sometimes forms sharp contacts against the schists, while the granite may show aplitic features and sends apophyses along available cracks of the schists. About 400 meters to east-northeast from Hopeavuori a small, inclusion-like outcrop of grey granodiorite rich in plagioclase was found. Rocks similar in character occur in the area under consideration also near the farmhouses of Hovi and Stockholm. All the said occurrences of granodiorite are situated in approximately the same zone, orientated along the prevailing strike in the area. It therefore seems plausible that the granodioritic rocks here are only remnants of an earlier uniform zone, which later during the late-kinematic stage of orogeny became granitized. Especially in the Vanhakylä area, west-northwest from Koskenkylä, the rock is very similar in texture to granodiorite, but with microcline, quartz, and biotite as predominant minerals. Compared to the homogeneous potash granites, the rock at hand is essentially distinguished by its high content of hydrous minerals; the typomorphic mineral combinations are biotite — (epidote) — chlorite, or biotite — chlorite. In addition alteration products such as zoisite, sericite and iron pigment are abundant. The computed *fm* and *c/fm*- numbers (Table 2) clearly show the special mineralogical character of migmatic granite as related to other potash granites of the area investigated.

HOMOGENEOUS BIOTITE AND/OR GARNET-BEARING POTASH GRANITE

Starting from the immediate vicinity of the village of Pernaja, the homogeneous potash granite for the most part occupies the rock ground in the archipelago spreading towards the south in the Gulf of Pernaja. The nebulitic and phlebitic structures for the most part likewise occur in the same area and it seems that the homogeneous granite actually can be interpreted as a special, extreme modification of the aforementioned chorismitic rocks. Typical medium-grained, greyish red massifs of this rock occur between Pernaja village and the island of Påsalö.

The rock always contains much microcline and quartz. The other important components are plagioclase (An_{10-15}), biotite, and garnet. Muscovite may occur accidentally. Sphene, apatite, and grains of oxidic ore are insignificant accessories. Special attention has to be paid to the existence of garnet, a very characteristic component of the rock at hand; but sometimes this mineral may also be lacking and biotite occur instead. Between these two cases is an intermediate stage, in which the dark, indeterminate spots visible in the rock appear to have a core of garnet surrounded by pseudomorphic material, composed of biotite and chlorite (Pl. I, Fig. 5).

The garnet in granites and accompanying pegmatites of the Pernaja district is almandite in main composition. The refractive index is $n = 1.821 \pm 0.002$. After removing most of the impurities from hand-picked and powdered material with a Frank-type isodynamic separator, a powder diffraction pattern was made, using the Norelco x-ray spectrometer ($CuK_{\alpha_1+\alpha_2}$ radation). The calculation for the unit cell dimension ($d_{004} = 2.90$ Å, $d_{224} = 2.36$ Å, $d_{240} = 2.59$ Å) yielded the result $a_0 = 11.60 \pm .02$ Å. The value obtained is, however, clearly higher than that for almandite ($a_0 = 11.495$ Å) reported by Fleischer (1937). The low content of manganese in the analysis of pegmatite rich in garnet (Table 2, Anal. 13) reveals that the spessartite component in the present case must be quite insignificant. On the other hand, the relatively high content of calcium (see especially Fig. 19) suggests that this element might, at least partly be due to a grossularite component present in the garnet, which assumption is in accord also with the observed fact that the unit cell dimension of Ca-garnets is larger than those of pure Fe-Mg-Al-garnets.

Coarsely micropegmatitic material occurs as irregular patches in the homogeneous potash granite or the same material conforms to a banded structure in granite. The bands are rich in garnet and/or biotite, the latter being always of very fine flake. The pegmatite is chiefly composed of crystals of microcline 3—5 centimeters long graphically intergrown with quartz. The big crystals in turn are cemented by a finer-grained micropegmatitic mass of microcline and quartz, accompanied by some biotite. A similar kind of pegmatite often occurs as conformable veins between chorismitic schist beds and homogeneous granite, as will be described in connection with the pegmatites (Fig. 20).

COARSE-GRAINED POTASH GRANITE

The rocks belonging to this group have been found in relatively small areas south of Garpgård, on the eastern side of the main road between Porvoo and Loviisa. Incidentally, it should be noticed that the rock, wherever existing in the area, always appears as the outermost granitic rock near or against the rapakivi massif. This situation has been well established by many observations near the rapakivi contacts all the way from Strömsland to the outcrops east-northeast of the village of Pernaja.

Seen from a distance, the coarse-grained granite very closely resembles the typical ovoidal rapakivi. However, more detailed inspection in the field soon reveals the intrinsic differences between the said rocks. The big microcline crystals, measuring about 1—3 centimeters in length have a pink color caused by abundant iron pigment. Quartz, some plagioclase (An_{5-10}) and biotite build up the finer material. Myrmekitic structures between quartz and microcline are commonly seen. Also in this granite fair-sized xenoliths of schistose material rich in mica and chlorite occur.

Around the northern end of the island of Hirsalö the coarse granite grades into micropegmatitic rock or the alteration results garnet bearing homogeneous potash granite. The transitions between these rocks are always gradual. The coarse-grained granite is evidently very closely related to migmatic potash granite, which equally well may possess a porphyritic appearance in certain cases. On the other hand, both of these granites have many features in common with the microcline granites widely distributed in Central Finland.

CONTACT RELATIONS AND GRANITIZATION PHENOMENA AS SEEN ESPECIALLY IN CHORISMITIC STRUCTURES

In the archipelago of Pernaja the sea has so thoroughly accomplished the washing and polishing of outcrops on the rocky islands that a geologist is irresistibly urged to get to work, *i.e.* to engage in a detailed study of the chorismitic formations in this fascinating environment. So far as reliable conclusions can be drawn, a knowledge of the history of the destruction of the older basement and ensuing processes is especially necessary for this study, aiming at a genetical evaluation of the ore mineralizations partly associated with the chorismitic rocks at Koskenkylä.

GRANODIORITE — OLDER FORMATIONS

In the area between Stadsland and the islands of Rysskär the chorismitic formations are most abundant. The present author had an opportunity of carrying out a detailed study in Stadsland, whereas in the complicated areas around Rysskär, such instances only were considered that might be most informative on the basis of Sederholm's description. From the excessive quantity of chorismites looked over in the field, only the few most adequate to characterize the development of granodioritic rock series are reproduced by figures. The respective localities have been marked by the letters a-e in the appended map in Fig. 10.

The outcrop shown in Fig. 11 is a typical example of the merismites in Rysskär (Fig. 10, a). Two kinds of paleosome material occur in it;

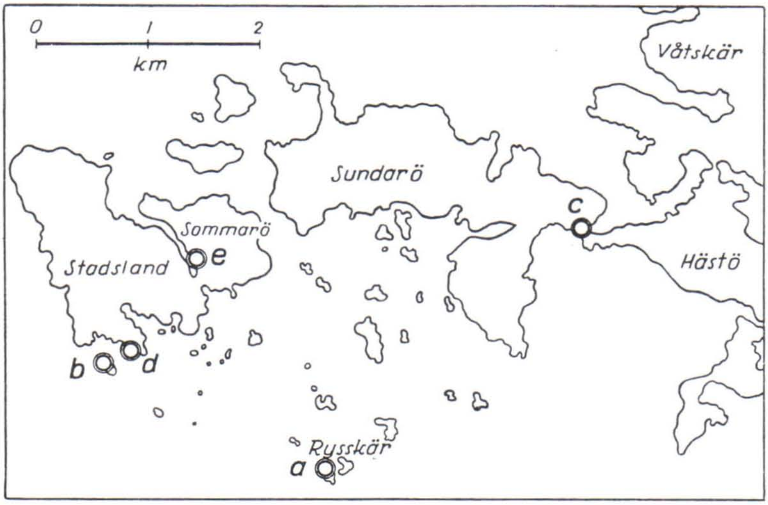

Fig. 10. Locations of the chorismites between granodiorites and older rocks used as examples from the area Hästö—Stadsland—Rysskär.

the one is dark and dense, basic rock, while the other is a distinct representative of coarse plagioclase porphyrites (p. 9). The dark fragments originally may have been basaltic veins intersecting the plagioclase porphyrites, but both belong to the same period of volcanic activity. Such basic veins at Träskholm in southeast Pernaja have been described by Sederholm (1923, p. 37).

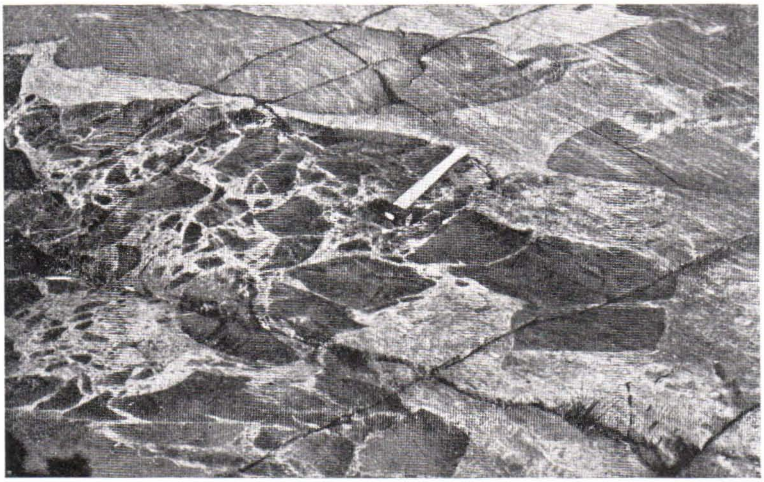

Fig. 11. Merismite from Öster Rysskär. Two kinds of paleosome present: Dark = amphibolite (basalt), grey = plagioclase porphyrite (Fig. 10, a).

Because the dark fragments have very clean-cut outlines and the plagioclase porphyrite has retained its characteristic primary mode of appearance, it seems that the merismite originated in a zone where only a mechanical brecciation but no significant process of assimilation or resorption had taken place. The dark fragments especially seem to have reacted as entirely solid material.

As has been pointed out, a typical metatect in the merismites of Rysskär is a reddish grey granite (p. 21). Beside it, a lighter metatectic material is noted as foggy accumulations or as diffuse, vein-like formations following especially the cracks and joint directions in the reddish metatect material. Already in this connection it is advisable to call attention to the mode of appearance of the light metatect, although the matter principally belongs to the items dealt with in the next subchapter of this paper. The light metatect, obviously younger in age, may in some cases have promoted to a degree the granitization of plagioclase porphyrite fragments. However, the dark fragments resisted also this effect, except that the young material sometimes has been poured into cracks, already earlier filled by the older metatect. The cracks thus were widened but without any change of the outlines of the original crack borders (Fig. 11). This behavior shows that, while the younger metatect was wandering, the older was plastic to the extent that slight movement of solid fragments was possible. In these conditions the younger metatect presumably advanced as a kind of fluid of a character the more precise attributes of which will be described in the following.

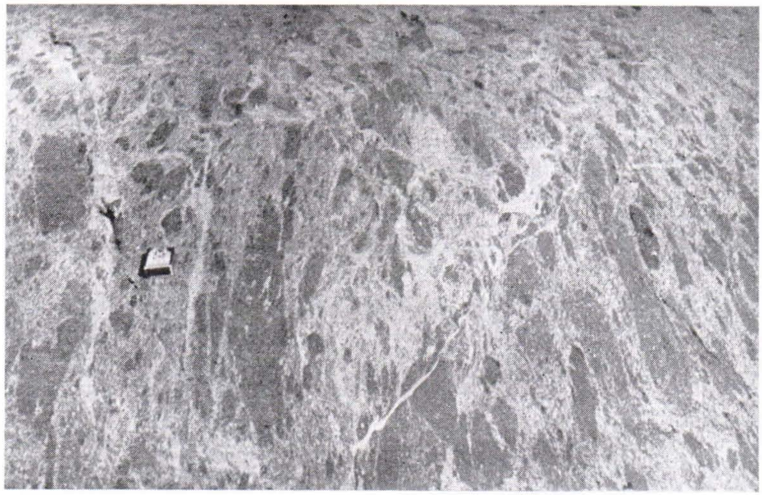

Fig. 12. Nebulized merismite from small island in the immediate vicinity of the southern shore of Stadsland (Fig. 10, b).

It must be pointed out that the said merismite is situated within the area of merismitic rocks around Rysskär. Close to the southern shore of Stadsland, in the vicinity of granodiorites and in the immediate periphery of potash granites, the fragments in merismitic formations (Fig. 10, b) possess more plastic forms, are usually more abundant, but smaller in size, and the light metatectic material occurs in greater amounts (Fig. 12). The well developed flow structure indicating the earlier mobility of the whole mass and strongly marked phenomena of resorption lead to the assumption that these rocks have been formed in zones of higher PT-conditions than the merismite previously described from Rysskär. The homogeneous matrix composed of reddish metatect is in places very strongly dissipated by collections of the light one. Considering the close vicinity of potash granites in this locality, the opinion is justified that the younger metatect definitely belongs to the intergranular effects caused by the invasion of the migmatite front in the potash granitic stage. In this connection an incidental remark must be made regarding the merismite of Hopeavuori (Fig. 6, p. 22) in which the light metatect has acted on the older as well, but not on the paleosomic fragments. In the »bleached» portions of older metatect an interesting phenomenon appears accidentally in all the instances mentioned — entirely recrystallized hornblende having gathered in worm-like collections. Analogous formations have often been found in the area investigated and also Sederholm (1923, p. 119) has presented one example from the Rysskär region. In this case the small veins, composed of recrystallized hornblende, exist in an outcrop comprising plagioclase porphyrite penetrated by granitic veins.

Fig. 13. Highly nebulized merismite from Hästö, southwest from Våtskär (Fig. 10, c).

On the isthmus between Hästö and Sundarö in the neighborhood of the granodiorite contact of Våtskär a merismitic formation (Fig. 10, c) exists in which, however, only few and small fragments of paleosomic material are visible here and there (Fig. 13). Apparently the occurrence is an extreme case in the series of merismites previously described and it probably has been modified by still higher PT-conditions than those prevailing when the merismite, previously mentioned, from the vicinity of Stadsland, was formed (Fig. 12). As a whole the rock closely resembles the Våtskär granodiorite, and, actually, the metatectic material is quite analogous in both cases. It is to be observed, however, that the characteristic inclusions of mica-schist in the granodiorite of Våtskär, always lie practically parallel in a direction consistent to the general strike of other rock formations within the area in question. The paleosomic fragments in the rock of Hästö have directions greatly differing from each other, and consequently, from the general strike in that particular zone.

The ultimate series of changes in structural pattern in the merismites represented in this chapter yields the clue that the rock in Hästö represents an intrusive breccia, whereas it is more probable that the structural pattern dominant in the granodiorite of Våtskär is a product of large-scale injections poured into the supracrustal rocks. Both processes, of course, were accompanied by resorptions and differentiation of molten material in deep-seated zones, where rocks of almost equal composition then generated, in spite of a different mechanism at the beginning of the process. At first Sederholm interpreted the gneissose texture of Våtskär granite as having been caused by dynamometamorphism, which had acted on the rock after its solidification. Later, however, he regarded magmatic assimilation of older schistose rocks as a more probable mechanism in generating the parallel texture of the »oldest granite» also of the Pellinge area (1927, p. 145). In his study of granodiorites of Elsinore Quadrangle, Southern California, Larsen has arrived at an analogous estimation regarding the generation of dark inclusions (1948). He also points out that the lense-like shape of the inclusions is in part due to subparallel fracturing of the rocks (*op. cit.*, p. 63).

If on the basis of the foregoing, our hypothetical situation now presumes that the so-called Rysskär granite, including the merismites from the Hopeavuori region, is in close relationship to the granodiorites of Våtskär, there is no real reason for believing that these two rocks had originated during different orogenic cycles, as asserted by Sederholm (1923). The operation of several kinds of intrusion mechanism even within one orogenic cycle is more than likely. Detailed reasoning on the matter, however, involves too many viewpoints mainly of a speculative nature, and is therefore not warranted in this connection.

POTASH GRANITE — OLDER FORMATIONS

Besides the uniform areas, granodiorite has also been found in merismitic formations. Simplest of all is a merismite in which pegmatite veins belonging to a potash granitic series intersect the granodiorites (Fig. 5, p. 18). Similar formations are rather common in the exposures along the eastern shore of Våtskär, on the islands of Salöcktholm and Kallholm in the northern part of the area investigated. An analogous occurrence has been found on a crag west-northwest from Kjällöland, but here the veins are light rather than reddish in color, as in the former case. In the neighborhood of Kjällöland on the island of Granö a merismite occurs in which granodioritic paleosome fragments contain additional basic inclusions. The homogeneous potash granite (p. 26) builds up the metatect. Exactly similar formations have been found on the island of Åkersholm, southeast of Kjällöland, and on a rocky islet to south of Åkersholm. The latter occurrence is still penetrated by the reddish pegmatites. In the granodioritic paleosome of this merismite the plagioclase (An_{15-20}) is predominant among the salic constituents, even though microcline sometimes occurs in considerable amounts. Quartz is abundant while fair amounts of biotite, accompanied by hornblende and chlorite, some sericite and apatite comprise the rest of the rock. A corresponding formation has been found on the shore curving to the northeast from the harbor of Pernaja. In this occurrence there is an abundance of young pegmatite material (Fig. 14).

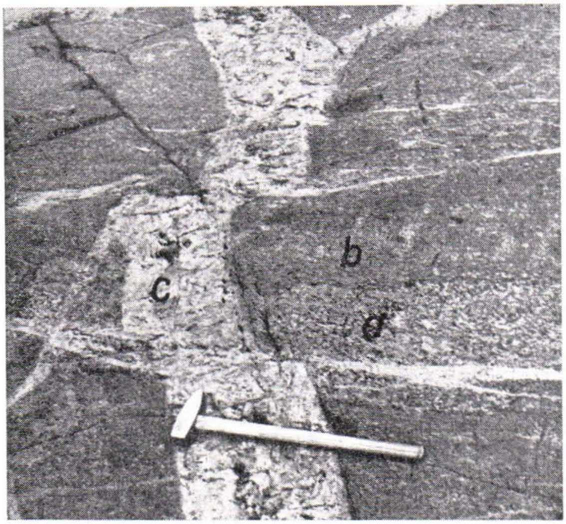

Fig. 14. Polychorismite in the vicinity of Pernaja harbor. a = granodiorite, b = potash granite, c = potash pegmatites.

The potash granites or concomitant pegmatites form the youngest metatect material in all the aforementioned formations of polymerismitic character. Because in the paleosome material the relationship between fragments of different ages are still distinguishable and some primary features in the fragments are fortuitously visible as well, it might be premised that the merismites of this kind have survived only insofar as they generated in or were brought into the periphery of the migmatite-forming front. If the polymerismite has been in a zone of material with relatively high mobility, the primary structures accordingly have become confused. An example plainly illustrating this phenomenon was discovered in the vicinity of Segerstråhle's summer house at Stadsland (Fig. 10, d) and another on the island of Hirsalö.

In Stadsland the main mass of the occurrence is almost nebulitic chorismite, in which a few but rather large, dark fragments with sharp borders are also visible. From a distance the occurrence (Fig. 15) is therefore like a simple merismite the effect being caused by a great contrast between the dark fragments and the main rock. As an intrinsic feature the older structure clearly appears to have been attacked by younger injections; in the nebulitic portion an entectic metatect composed of potash granite

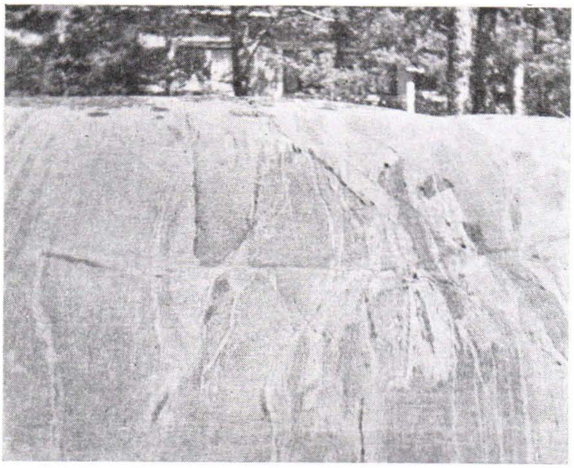

Fig. 15. Polychorismite. Southern shore of Stadsland (Fig. 10, d). Only a couple of the darkest fragments are visible in this picture.

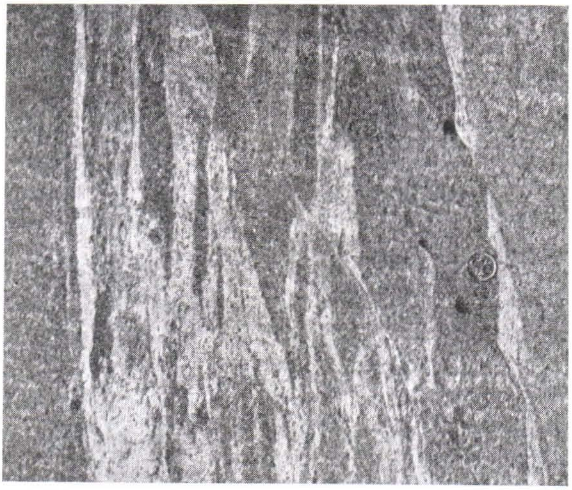

Fig. 16. A detail from Fig. 15. Veins of potash granite injecting the older granodioritic metatect of the chorismitic host.

exists mostly as narrow injection veins between the strongly elongated fragments of slightly granitized granodioritic rock, which obviously formed the older metatect (Fig. 16). A much farther developed instance of similar character was found on the western shore of the island of Hirsalö (Fig. 7). In this occurrence the old metatect was nebulized almost completely into a rock of potash granitic composition, but the dark fragments of old paleosome were highly resistant also in this case.

Previously reference has been made to a strongly nebulized merismitic rock among the formations of Rysskär, near the southern shore of Stadsland (Fig. 12, p. 30). As pointed out, the brecciation and nebulization visible in that occurrence were accomplished by the processes of the granodioritic stage of orogeny. In the extreme case this nebulization produced subtly merismitic rocks with a metatect of almost granodioritic composition, as seen on the isthmus between Hästö and Sundarö (Fig. 13, p. 31). On the other hand, the nebulization connected with the potash granitic stage produced a metatect of potash granitic composition. For these processes the terms granodioritization and granitization have been used respectively.

Alterations analogous to those noted in merismitic rocks can be followed also by means of stromatitic formations *i.e.* by rocks derived from sedimentary and pyroclastic beds by injections during both orogenic stages. In the successive processes different kinds of stromatites have presumably transmitted the structural transformations, some evidence of this having been found in the periphery of the areas occupied by granodioritic rocks, *e.g.* on the west-southwest shore of Sommarö near Stadsland (Fig. 10, e). In conditions prevailing near the proximal zone of the synkinematic stage, the tuffs and sediments were homogenized into granodiorites of the Våtskär type by a continuous process involving injections, anatexis, differentiation, *etc.*, according to the lines laid down by Eskola (1932, 1933).

In the aforementioned stromatite of Sommarö a slight effect of later granitization is present as lighter-colored metatect material. In an advanced stage an almost perfect granitization of some layers has been accomplished, whereas the basic layers have largely withstood the pervasive influence even of the prolonged process. As an example the phlebite will be referred to in Fig. 20, p. 43; the metatect material is now composed of nebulitic (homogeneous) potash granite marked by a banded structure concomitant with conformable, light pegmatites. In other words, in the homogeneous potash granites the said bands, rich in garnet and/or biotite (Fig. 17), thus reflect the original structure of the stromatite and may be reasonably called pseudostratification. This was initiated during the synkinematic stage of orogeny and modified further by the granitization process belonging to the late-kinematic stage. Instances of similar development are abundant in the Svecofennidic zone and have been investigated especially in the Kalanti area by Hietanen (1943).

Fig. 17. Pseudostratified nebulitic granite. Eastern shore of Hirsalö.

STADSLAND GABBRO AND METABASALTIC VEINS?

The existence of real gabbros in the Stadsland area at first will be questioned and secondly the stratigraphical position of metabasaltic veins, as determined by Sederholm, seems not to be quite unambiguous. Especially the last-mentioned aspect, while possessing wider than local interest only, warrants some criticism in the light of current observations. However, as the interrogative form of above heading supposes, the following remarks in criticism of the earlier conceptions fostered by Sederholm will merely serve as a guide how matters might be, and not how they precisely are, in this area of most complicated geology. Still, it should be remembered that a correct survey of the region around Stadsland and Sundarö involves many difficulties because a considerable part of the interesting areas has been covered by the sea.

According to Sederholm most of the Stadsland area is composed of gabbro, of which the following description will be quoted (1923, p. 146):

»The prevalent rock is of medium grain and has on the surface a brownish red colour, which is determined mainly by that of the feldspar constituents and not so dark as could be expected in such a basic rock. It shows an indistinct parallel texture, which is probably secondary. It often contains inclusions of rock varieties with identical composition but very varying texture, most of them porphyritic, showing phenocrysts of plagioclase or uralite in a groundmass of varying grain.» And further on in another place in the same chapter:» . . . . the delimitation of the gabbro area is very peculiar. It forms a narrow zone following all the sinuosities of a line which seems to indicate the original boundary between the oldest schists and the volcanic rocks of the Pernå (Pernaja)[1] formation. This suggests the idea that the gabbro originally formed a thin sheet which did not solidify very far from the earth's surface.»

During the present investigation in Stadsland three relatively uniform zones of different formations have been distinguished when crossing the island from north to south. The potash granites border the northern part of the island as a narrow, approximately east-westerly striking band. This is followed by supracrustal beds with a strike N 70°E and intermingled by several pegmatites derived from the potash granites. Usually the primary structure of the schists is not recognizable with the exception of the outcrops on the western shore, near the summer houses of Söderström and Nikander, where agglomeratic structures have been noted; the rock is obviously similar to that near Ahlers at Koskenkylä. Some distance to the south, the third zone starts with a transmitting contact area, built up of a subtly merismitic rock, in places rather dark in color. In the field this rock resembles gabbros, but is clearly granodioritic or quartz-dioritic when studied under the microscope.

The texture is gneissose, almost mylonitic. The main constituents are plagioclase (An_{20-25}), quartz, biotite and hornblende, in the order of abundance. Some potash feldspar and sphene are present in addition. The interspaces between the typically elongated collections of dark constituents have been filled by the light components, showing strong cataclastic features.

More to the south the merismitic appearance of the rock merges into a distinctly foliated texture, which is visible especially in the exposures near the Anderson summer house. The observations made in the last-mentioned locality actually caused all the gneissose rocks of granodioritic or quartz-dioritic composition, listed in Stadsland, to be included in the group of granodiorites previously defined in this paper. This is even more probable because the zone in Stadsland may thus indicate one of the granodioritic occurrences that according to Sederholm's map, should exist as connecting links between the granodiorite of the Våtskär area and those around Småholmarna within the same zone in the archipelago of Pellinge. However, it must be noticed, that the granodiorite area in Stadsland is very heterogeneous in character and along the southern shore intermingles to a large extent with the merismites of Rysskär. In places within the same area also a homogeneous, reddish grey rock occurs which is characterized by evenly distributed crystals of hornblende, ½ to 1 centimeter long, which give to the rock an appearance of basic, typically blastoporphyritic volcanics. Under the microscope the texture is distinctly granoblastic. The main components are green hornblende and strongly saussuritized plagioclase (An_{30-35}), while quartz, biotite, epidote and grains of oxidic ore are pres-

[1]) The parenthetic remark by the present author.

ent in minor amounts. The attributes of this basic rock suggest that it is primarily an uralite porphyrite or gabbro, which has been largely metamorphozed. As regards the predominating geological features of the surrounding area, however, it is more probable that the rock must be identified as uralite porphyrite. In this case chemical analysis of the rock might not provide much coordinative aid and the result might well correspond to the available analysis of Stadsland gabbro (Table 2).

Thus the central area of Stadsland gabbro, as described by Sederholm, appears, in fact, to be very complicated in character. The dominant rocks are of supracrustal origin or granodiorites, even though the primary structures in most occurrences have been obscured by the multifold effects of metamorphism and granitization (p. 35). In the outcrops along the southern shore line and neighboring islets, the rocks are to be interpreted mainly as chorismites between supracrustal schists and granodiorites or granites, which conception is ultimately in good accord with the observations recently made in the Rysskär area.

According to Sederholm, the supracrustal rocks in the area now under consideration belong either to the older eruptives of Sundarö or the younger eruptives of Pernaja. Some of the principal arguments which Sederholm has provided for his conception may be summed up as follows: In Stadsland the eruptions of younger volcanics has been marked by metabasaltic dykes. These intersect migmatic rocks, which resulted when the »Våtskär granite» was intruded into the complex of Sundarö schists and Stadsland gabbro. On the other hand, the basaltic dykes have been intersected by veins belonging to »Rysskär granite». Thus the age of the metabasaltic dykes is timed between the intrusions of »Våtskär granite» and »Rysskär granite» and on the strength of this observation, Sederholm considered that all the volcanic rocks in the archipelago of Rysskär belong to the same period of volcanic activity (the Pernå formation).

Now, unfortunately, in spite of every effort, the metabasaltic dykes at Stadsland depicted by Sederholm could not be found during this investigation. The basic dyke noted is situated on both sides of a deep gulf in the middle of the southern shore of Stadsland. The dyke, about ½—1 ½ meters in width, strikes N 60°E and has been found also on the southeast end of the island. In the last-mentioned locality a pegmatite, presumably belonging to a potash granitic rock suite, is in the close vicinity; but an intersection between the pegmatite and the basic dyke has not been established. Microscopically the dyke material consists mainly of plagioclase (An_{30-35}) and hornblende associated with secondary biotite. Small grains of oxidic ore and sphene are usual accessories. All the minerals are relatively finegrained and have irregular outlines. The dyke obviously is relatively young and possibly corresponds to the »trap» dykes common in Southern Finland (Sederholm 1926, p. 117). The occurrence including the metabasaltic dykes from Stadsland, pictured in great detail by Sederholm (1923, Pl. VI and VII), must apparently be designated as polymerismitic formations analogous to those demonstrated earlier from the Rysskär area. Moreover, the existence of any metabasaltic dyke of such character as suggested by Sederholm is in conflict with the ideas advanced in this paper, *i.e.* the granodiorites of Våtskär and the chorismites of Rysskär, both represent products of one orogenic cycle, and subsequently, no evident discontinuity in formation of these two structurally different rocks has existed.

After contemplation of the stratigraphical scheme in the Barösund region, west of Helsinki, Sederholm stated (1926, p. 34): »Further the writer has endeavoured to prove that in the Pellinge area even two volcanic formations occur, separated by the intrusion of a granite (Rysskär granite)[1], but as neither this granite, nor more than one group of metabasalts, seems to occur in the present area, it is not necessary here to recapitulate the reasons for that further subdivision.» This reservation for a subdivision in the Pernaja—Pellinge area is unnecessary, and the volcanic formations of »Sundarö» and »Pernaja» actually belong to one period of eruptive activity, including also the volcanic formations met with in the Koskenkylä area. In a broader sense, the »Pernaja» formation actually represents the second cycle of Archean volcanism, according to Sederholm (1926). In the Pernaja area both are penetrated by synkinematic rocks, a result consistent with the stratigraphy proposed by Simonen (1953).

SUPPLEMENTARY EXAMINATION OF GRANITE ANALYSES

In the previous text some references have already been made to the Table 2. Here some special aspects still need to be considered.

The term granite has been used in a rather broad sense by Finnish geologists, and, certainly, expressions like gneissose granite and gneissose oligoclase-granite do not fit the subjects these terms cover. Probably the misleading usage has arisen partly from the fact that the said rocks mostly appear as last acidic members of the synkinematic rock suite of the Svecofennidic zone. Hence, in wide areas they are the only rocks with granite-like habit and this circumstance might have caused these plainly granodioritic rocks to be erroneously called granites.

The term gneissose granite apparently has caused much vain confusion, as probably often applied to distinct potash granites whenever possessing a pronounced gneissose texture. Similarly in the Koskenkylä area the migmatic potash granite may often texturally resemble the »gneissose granite» at Våtskär. The mineralogical and chemical composition, however, are different enough to justify the separation.

[1]) The parenthetic remarks by the present author.

Table 2. Analyses of the Infracrustal

	5		6		7		8	
	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.
SiO_2	48.08	8 005	55.40	9 224	67.36	11 260	75.64	12 594
TiO_2	1.46	183	.80	100	.61	76	.30	38
Al_2O_3	18.00	1 766	15.80	1 550	15.20	1 491	12.34	1 211
Fe_2O_3	2.38	149	.32	20	.85	53	1.78	111
FeO	8.94	1 240	7.78	1 083	2.80	389	1.19	166
MnO	—		.16	23	.06	8	.03	4
MgO	6.93	1 719	6.55	1 625	1.30	322	.57	141
CaO	8.70	1 551	7.03	1 254	3.40	606	2.27	405
Na_2O	2.00	323	2.84	458	3.93	634	3.06	494
K_2O	1.01	107	1.97	209	3.12	331	2.92	310
P_2O_5	.26	18	.17	12				
H_2O+	2.02		1.66		.84		.38	
H_2O-	.29		.10					
	100.07		100.58		99.47		100.48	

Niggli numbers

	5	6	7	8
si	114	148	290	427
al	25.2	24.9	38.4	41.0
fm	46.5	44.4	21.2	18.1
c	22.1	20.1	15.6	13.7
alk	6.1	10.7	24.8	27.2
k	.25	.31	.34	.39
mg	.53	.59	.39	.26
c/fm	.48	.45	.73	.76
Or : Ab : An			28 : 50 : 22	32 : 47 : 21

5. Gabbro from the NE-shore of Stadsland, Pernaja (Sederholm 1923, p. 148).
6. Syenito-diorite, Ryssö, Pernaja. Analyst H. B. Wiik.
7. Gneissose granite from the eastern shore of Våtskär, Pernaja (Sederholm 1923, p. 139).
8. Granite from Öster-Rysskär, Pernaja (Sederholm 1923, p. 116).
9. » » Väster » » » » p. 117).

In Fig. 18 the granites and granodiorites (Våtskär granite) analyzed are represented by the accompanying Or-Ab-An diagram. The dots indicating oligoclase-granite (Eskola 1914, p. 41) and those indicating typical microcline granite (*op. cit.*, p. 17) have been added to serve as »seamarks» for correlation. To illustrate the differences in calcium content the diagram in Fig. 19 has been plotted according to Niggli numbers.

Regarding the content of Or Analysis 9 is closer to potash granites than 8. On the other hand, in the Niggli diagram, 8 and 9 show *c*-values high enough for granodioritic composition. Both analyses are of Rysskär granite, and thus the said diagrammatical properties conform to the tentative ideas suggested on the genesis of the rock mentioned earlier in this paper. For instance, Analysis 8 probably refers to the composition of a merismite, distinctly contaminated by younger metatect, caused by invasion of potash granite material (p. 30).

Rocks in the Pernaja District.

9		10		11		12		13	
%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.	%	Mol. prop.
70.31	11 707	72.09	12 003	73.50	12 238	75.40	12 445	75.72	12 774
.38	48	.43	54	.30	38	.09	11	tr.	—
15.45	1 516	13.04	1 279	14.36	1 409	13.51	1 325	11.90	1 167
.25	16	.77	48	.33	21	.36	23	.04	3
2.30	320	2.80	390	1.58	219	.83	116	.54	75
—	—	.04	6	.02	3	.01	1	.01	1
1.15	285	1.06	263	.74	184	.36	89	.58	144
2.40	428	.84	150	1.38	246	1.00	178	2.83	505
3.33	537	3.02	487	3.84	620	2.85	460	2.93	473
3.91	415	4.29	456	3.24	349	5.56	590	5.35	568
.08	6	.05	4	.07	5	.04	3	.04	3
.62		1.03		.70		.42		.43	
		.13		.10		.02		.02	
100.18		99.59		100.16		100.45		100.39	

331	384	424	448	430
42.9	40.9	45.9	47.3	39.7
18.0	24.1	14.6	8.9	7.7
12.1	4.8	8.0	6.4	17.2
27.0	30.2	35.5	37.4	35.4
.44	.49	.36	.56	.55
.45	.35	.45	.43	.65
.67	.20	.55	.71	2.23
43 : 42 : 15	46 : 47 : 7	34 : 55 : 11	53 : 39 : 8	53 : 41 : 6

10. Reddish migmatic granite, east of Hopeavuori, Pernaja. Analyst H. B. Wiik.
11. Grey » » , Nykulla, Pernaja. Analyst H. B. Wiik.
12. Homogeneous garnetiferous granite, Pernaja. Analyst H. B. Wiik.
13. Garnetiferous light pegmatite, Pernaja. Analyst H. B. Wiik.

c-numbers for Analyses 10 and 11 are typically those of potash granites. As pointed out earlier, these undoubtedly late-kinematic granites, essentially deviate from each other by *fm*-numbers but also the soda content is appreciably higher in the latter case. These differences plainly appear mineralogically, as shown by the volymetric analyses:

	No 10	No 11
Quartz	32.5	32.0
Plagioclase	29.8 (An_{10-20})	46.6 (An_{10-20})
Microcline	27.1	17.7
Biotite	10.2	3.7
Accessories	0.4	—

Especially when estimating the results shown by Analyses 10, 12 and 13, it should be borne in mind that, according to field data, the corresponding rocks appear to be in close relationship to each other and, in a broader sense, behave like special modifications of one and the same material. As pointed out on page 11, the conspicuous amount of lime in Analysis 13 presumably in part accounts for the grossularite component included in the garnet. This possibility, however, was not considered when computing the normative composition of the said analysis and the lime in excess was used to form the pyroxene molecules. The slightly trondhjemitic rock rich in soda (Anal. 11) occurs in very limited areas, which are intimately connected with those of garnet-bearing homogeneous granites. The boundary varieties of granodiorites rich in soda of the Svecofennidic zone have been often noted and their existence has stimulated much discussion (Seitsaari 1951, p. 67). In the present case it seems plausible that this rock was generated in connection with the later process of granitization, which also best explains such alterations of older rocks as manifested by the syenito-dioritic modification at Ryssö (Anal. 6).

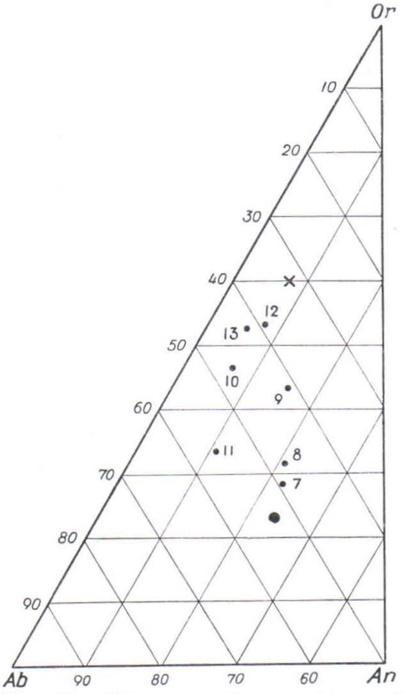

Fig. 18. The normative relations of Or : Ab : An in the acidic infracrustal rocks of the Pernaja district. The numbers correspond to those in table 2. The cross denotes the microcline granite and the larger dot denotes the gneissose oligoclase-granite according to Eskola.

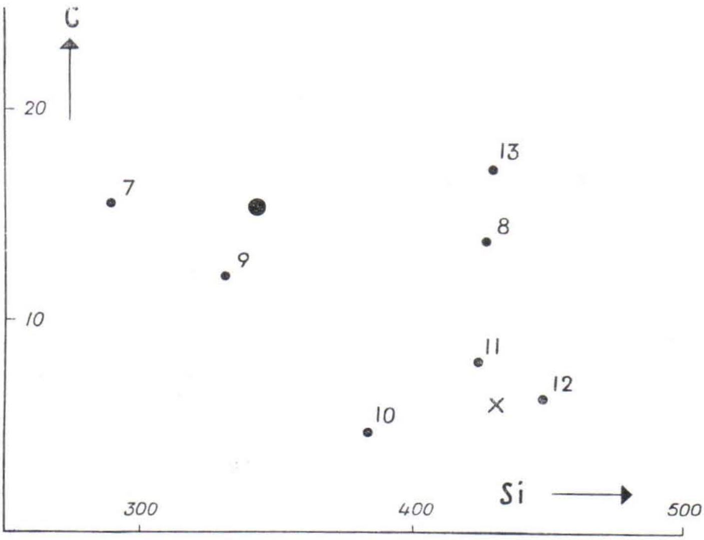

Fig. 19. The *c*-diagram of the rocks plotted in Fig. 18.

PEGMATITES

Numerous pegmatitic bodies associated with the group of late-kinematic granites occur in the area investigated. No complex pegmatites, however, have been met with — a feature commonly indicating the metasomatic or palingenic character of the granites in the reference area. At the outset, based on the existing differences in color and mineralogical composition, the pegmatites of the Pernaja area are separated into two groups: Light-colored microcline-garnet-biotite pegmatites and reddish microcline-biotite pegmatites.

The light-colored pegmatites are usually associated with medium-grained, homogeneous potash granites (p. 26) and occur as irregular bosses, occasionally containing almandite garnet, or as veins always containing garnet and variable amounts of biotite. The veins are in general dilatation veins conforming to the flow structure visible in the aforementioned granites (Fig. 20). However, the relationship between pegmatites and chorismitic inclusions of granites in certain cases may be discordant as well and sometimes the light-colored pegmatites even intersect each other. This variable behavior does not signify any great differences in age, but merely refers to a rhythmic deposition belonging as a whole to one period of pegmatitic activity which displaced the material at first dilatationally and later along the fracture joints.

The reddish pegmatites are usually concordant to the schistosity of supracrustal rocks, as is plainly exhibited near the road junction of Baggböle

Fig. 20. Light dilatation pegmatites embedding the schists and the homogeneous potash granite grading into pseudostratified granite. Storholm, east of Hirsalö.

at Koskenkylä; a crowd of parallel, reddish pegmatites runs strictly following the schistosity of a highly metamorphic agglomeratic rock. The same crowd has been observed in several outcrops to the east, and at a distance of ½ km to the west.

Obviously the pegmatitic material has at first been intruded into the schist as a lit-par-lit injection along the s_1-planes and the interstices were gradually opened wider by the invading material. Thus, at present,

Fig. 21. Folded red pegmatite causing slight feldspatization in the agglomeratic host. Koskenkylä.

most pegmatites of this kind look more or less like conformable fissure veins. However, in places they show more plastic features and have caused a slight feldspatization in their near surroundings (Fig. 21). This phenomenon clearly indicates that the country rock has been rather flexible, owing to a considerable heat flow from the direction of the invading material on the one hand and to a strong tectonic pressure on the other. The minor folds in the pegmatites, otherwise concordant to the foliation of the host, are probably caused by local distortions in the relation between injection pressure and tectonic agents. A secondary foliation induced by the aggression of pegmatites is a common phenomenon in the host, as also pointed out by Flawn (1951).

Mainly following the strike of supracrustal formations (N 60°W), several reddish pegmatites occur in the area of Vanhakylä, Koskenkylä. But exceptions do often occur, and approximately 300 meters northwest from Mosabacka some apophyses, almost perpendicular to the schistosity, form tributaries from one larger pegmatitic vein. These are undoubtedly fissure veins, developed in the rigid country rock by cross jointing. The latter mechanism is illustrated by several other occurrences in the area. In all cases the cross joints with infilling of red pegmatites are approximately perpendicular to the foliation of the schist or the flow structure of adjoining infracrustal rocks.

Consequently, some of the reddish pegmatites in the Koskenkylä area were formed by lit-par-lit injection, whereas others must be classified as fissure veins. However, there is no doubt that the differences in behavior of the reddish pegmatites, resulting from changes in the flexibility of the country rock reflect alterations in the country rock during successive stages in the outposts of the cooling migmatite front. The injection appropriately was a very slow, one-pulsed process. On the other hand, the material for fissure veins sometimes was forced ahead in a relatively short time. The considerable temperature gradient, between the wall and vein infilling, then produced chilled margins as manifested in the fair-sized pegmatite near Hammerfors.

Here it must be mentioned that the idea of dividing the pegmatites into injections and fissure veins is not a new one in regard to the zone of migmatites east of Helsinki. In particular Kranck and Wegmann (1931, p. 59) distinguished between »ältere Gänge» (injections) and »Quergänge» (fissure veins). Wegmann has further based many of his tectonical interpretations according to this classification of pegmatites.

In the middle and southern parts of the area investigated reddish pegmatites, somewhat lighter in color than those at Koskenkylä, are associated with the areas of homogeneous potash granites or granodiorites, and sometimes the pegmatites form merismites with older rocks (p. 18). In all instances they are considered as having been intruded in cross joints or fissures. On the island of Vikholm, west of Påsalö, two pegmatitic veins about 1 ½—2 m. wide, associated with several narrower veins, were met with as parallel swarms. In these pegmatites the crystals of potash feldspar usually are gigantic, often being more than 10 cm. in diameter. In addition they contain thick lumps of black biotite and rather coarse quartz. The swarm of veins striking in the direction N 10°W was followed up to the small islands on the eastern side of Påsalö. The strike of the veins possibly marks a fault direction which is of some significance for the emplacement of rapakivi, as will be pointed out further on. In general the reddish pegmatites are very abundant in the archipelago south of Påsalö and especially within the border of the granodioritic area in Våtskär. They occur in the most conspicuous amounts in the vicinity of the contact at Hästholmen referred to earlier (p. 19).

The abundance of garnet in some of the potash granites and associated pegmatites inspired a thorough discussion already by Sederholm in his memoir on migmatites in the Barösund region (1927). The present author's interest in the same phenomenon gave rise to the following observations:

Garnet-bearing pegmatites are typical in the more central parts of the granitic stock in Pernaja, *i.e.* in areas mostly occupied by homogeneous potash granites. In association with the Koskenkylä schists or within the corresponding but smaller schist zones, the pegmatites never contain garnet but biotite as the characteristic component. The dominating granite concomitant with those areas accounts for what has been called migmatic potash granite (p. 25), which is likewise rich in biotite but practically without megascopic garnet. Between these extreme instances intermediate modifications of pegmatites as well as granites occur, in which garnet is mainly altered into biotite and chlorite (Pl. I, Fig. 5). Even if it is true that the existence of almandite garnet in granites signifies an excess of alumina (or the mineral is a relict of older rocks, Kranck 1931), the behavior as herein propounded suggests also the change of »dryness» in the material. Accordingly the garnet-bearing pegmatites and granites might have crystallized from relatively dry material, while the rocks with altered garnet might have formed under the conditions of an increased content of water in the operating material. Actually this is what Sederholm also thought in speaking about »geological hygrometers» (1927, p. 127) and in venturing to consider not only temperature and pressure but also the presence of solvents as essential to the formation of certain minerals. On the basis of his experimental study of stability relations of grossularite, Yoder (1950) prefers temperature *vs.* pressure for the formation of garnets and arrives at the following, tentative conclusion: »Grossularite probably has a field of stability at atmospheric pressure; that is, the garnet does not require pressure for its formation. Theoretically, however, pressure should favor its formation.»

The micrographic texture present especially in the random bodies of garnet-bearing light pegmatites represents an eutectic system and has not resulted by partial replacement. Evidently, an analogous material, present in the latter pegmatitic formations and in the dilatation veins (Fig. 20), was active during the granitization leading to complete nebulization of the older chorismitic structures. This possibility is strikingly illustrated by the pseudostratified potash granites accompanied by the light pegmatites (Fig. 17, p. 36). This standpoint prefers to regard the active material causing the granitization clearly reminiscent of extremely mobile, approximately supercritical fluids or gases capable of migrating along minute interstices. As asserted by Bowen and Tuttle (1950, p. 54),» . . . . . . it is such vapors and the vapors boiling off at earlier stages that introduce material into surrounding rocks with resultant 'granitization' of these rocks.» This statement concerns the ternary system $NaAlSi_3O_8$—$KAlSi_3O_8$—H_2O, which is fairly appropriate also in the present case. At the stage when those phases were not more capable of escaping but were concentrated in the granitic body, they probably produced pegmatitic liquids.

The random pegmatitic bodies provably represent the material that generated and solidified in an implicitly granitic environment. As soon as a material of similar character invaded, *e.g.*, the schists, iron was digested from the wall rock minerals in excessive amounts (Wegmann and Kranck 1931). The intense red color of pegmatites supposedly marks a highly dissolving and aggressive stage of pegmatitic activity in intimate connection with the migmatization in the respective zones.

SUMMARY REVIEW OF THE ARCHEAN INFRACRUSTAL GEOLOGY IN THE PERNAJA DISTRICT

The review will be offered under the designation of chorismites as related to infracrustal rocks:

THE CHORISMITES ASSOCIATED WITH GRANODIORITES:

— The structure of the Våtskär granodiorite and the stromatite formations found in the immediate periphery of the granodiorite suggest that the rock was generated by a process combined of magmatic exudations from below and resorption of pre-existing strata (see Niggli 1946, p. 68 and Larsen 1948, pp. 161—170). In other words: During the generation of rocks of the Våtskär type, the circumstances changed smoothly and the homogenization of entectic and ectectic materials was accomplished in accordance with the thermodynamic equilibria conditions prevailing at any given moment. In these conditions the process of differentiation of cumulative molten material was possible, as indicated by the series of differentiated rocks in the areas characterized by synkinematic granodiorites in the Svecofennidic zone.

— On the other hand, brecciation also took place during the period under consideration: The brecciation rendered the splitting within a wide range in the overlying beds. The paleosome fragments of the merismites, formed in the deep-seated zone, have been much displaced and strongly resorbed. In these merismites primary features are no longer recognizable and the metatect has a composition approximately that of granodiorites. In marginal zones produced by brecciation, the resorption caused by invading metatect from below was weak, with the composition of metatectic material apparently being richer in potash (Table 2). This increase of potash in the metatect may either be a result of differentiation, or the metatect originally had been of its present composition not having changed towards that of granodiorites, apparently owing to the weak effects of resorption. In the merismites of marginal zones, the primary texture of plagioclase porphyrites is recognizable in the paleosome.

— The light metatectic material in association with the chorismitic rocks probably accounts for the later material incorporated during the potash granitic stage.

THE CHORISMITES ASSOCIATED WITH POTASH GRANITES:

The predominantly polychorismitic rock patterns, which occur within the periphery of the areas occupied by potash granites, are represented in Table 3.

Table 3

	PALEOSOME	YOUNGEST METATECT
1	Amphibolite (basalt) » »	Nebulite (Hirsalö) » (Segerstråhle)
2	Supracrustal schists + granodiorite Granodiorite	Homogeneous potash granite » » »
3	Amphibolite (basalt) + granodiorite + homogeneous potash granite Granodiorite + homogeneous potash granite Granodiorite	Pegmatites of potash granite » » » » » » » »

In the patterns belonging to the first group of the table the metatectic material is heterogeneous, whereas in the second and third group the metatect is homogeneous. The occurrences in the vicinity of Segerstråhle's summer house and at Hirsalö (Figs. 15 and 7) illustrate the nebulization of older merismitic structures, when influenced by an effective process of granitization in the potash granitic stage. Consolidation had already affected the marginal portions of the late-kinematic granite stock, which were then attacked by cross jointing and fracturing, before the chorismites belonging to the third group, except the last example, were generated.

As seen in the Rysskär and Hopeavuori areas, the initial influence of the late-kinematic stage of orogeny appears as light, foggy collections of younger metatect. The increasing influx of the said stage finally led to a complete nebulization of the older rock patterns. Only the dark amphibolitic fragments, probably of basaltic or diabasic origin, have maintained their forms, even though the material itself has been strongly metamorphosed (Pl. I, Fig. 6). The corresponding succession established by merismitic rocks is traced also by means of stromatites; the accomplished granitization (nebulization) of the structures, derived from the granodioritic stage, finally introduced the banded homogeneous granites. The sufficiently basic layers of the original stromatite survived as narrow, biotite-rich bands in phlebites (Fig. 8) or only as »Schlieren» so typical of migmatite areas (Fig. 9).

The examination especially of merismitic rocks in the areas of homogeneous potash granites suggests that no real brecciation, except as caused by later fracturing and followed by pegmatitic activity, was exerted on the older formations during the late-kinematic stage of orogeny. On one hand, the granitization of older rocks seems to have proceeded metasomatically in such a manner that the »old design» was preserved, as first suggested by Wegmann (1931 and 1938) and recently reaffirmed by Eskola (1952). For the entire stock of potash granites, spreading to the west from the arcing band of the schistose and chorismitic formations of the map area, quiet granitization is a feature in common, and as a whole, the process is obviously connected with the doming of the stock.

On the other hand, as pointed out by Eskola (1952), in certain cases the old design may be disturbed altogether. In the present area this is true with regard to the migmatic potash granite, without discernible normal chorismitic structures, but forming veined gneisses or, if more granitic, including numerous scattered, micaceous xenoliths (p. 25). This matter is scrutinized further in the concluding chapters of this paper.

Recapitulating the examination of chorismitic rocks in the Pernaja district bolsters the opinion that these rocks were modified by each of the magmatectonic stages of the Svecofennidic orogeny. The conclusion has been drawn that the formation of the Rysskär merismites accounts for the synkinematic intrusions. Subsequently, a discontinuity marked by Bothnian volcanism between the generation of normal granodiorites (Våtskär) and the merismites of the Rysskär type appears as an improbable interpretation.

RAPAKIVI

The occurrences within the approximately 35 kilometers long contact of rapakivi, as drawn in the map, have offered many interesting aspects, a further study of which, however, is not consistent with the scope of the present investigation dealing with Archean formations. Yet some intrinsic field data will be considered here, as more or less preliminary notes.

A fairly well exposed occurrence in the neighborhood of Buckholm on the southeastern shore of Våtskär served as the first example to show that the contact between the rapakivi and adjacent granodiorite dips approximately 75° to the southeast and has a strike N 10°W. On the island of Åkersholm, 3 ½ kilometers north of Buckholm, the contact between the rapakivi and the adjoining potash granite is sinuously shaped, including a fine-grained variety of rapakivi without ovoidal structure. However, at approximately a distance of one meter the rock is again typical rapakivi crowded with mantled ovoides, the bed showing a dip 70°—75° to the southeast and a strike N10°W (Fig. 22). A third instance, although different in character, was found in the Koskenkylä area; behind the old mill of Hammerfors a fine, even-grained, reddish modification of rapakivi is in direct contact with mica – amphibole schist. The latter also occurs as xenoliths in the rapakivi right in the contact zone. These xenoliths, having a strike N 70°W and a dip 75° W, conform to the general trend of the supracrustal beds of the same area.

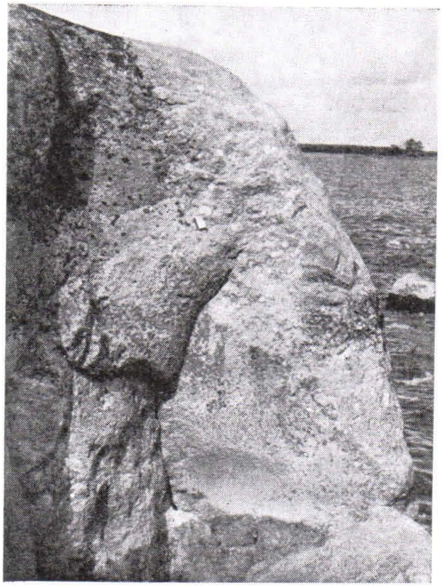

Fig. 22. Contact between rapakivi and Archean granite. The ovoidal texture changes rather abruptly into fine-grained rapakivi texture. This contact variety grades diffusely into older granite. However, the main trend of this contact is still consistent with the line showing the termination of the ovoidal texture.

The aforementioned observations prove that the contact between the rapakivi and the adjacent rocks merely has a steep dip to the east, instead of having a rather flat-lying »inclination» to the southwest or to the west, as Sederholm briefly points out from Buckholm in southern Pernaja (1923, p. 82).

Sederholm was one of the first to emphasize the intrusive character of rapakivi. This opinion arose mainly from the observations he made in the areas around Våtskär. During the present investigation several new merismites, sometimes analogous to those on a small island southwest of Buckholm described by Sederholm (*op.cit.*, p. 88; see also Read 1948, p. 76 and Eskola 1948, p. 7) were found elsewhere along the rapakivi contact in the Pernaja district. Obviously some of the merismites near the rapakivi contact connect closely with the emplacement of the rapakivi, while some are to be considered of older origin. A final scrutiny still requires revision in the field, accompanied by careful analytical studies, which was not possible to carry out as yet.

Some relevant observations made on dykes of rapakivi aplite in Våtskär should be pointed out in this connection (Sederholm 1923, p. 90). The existence of some scattered orthoclase crystals, grains of idiomorphic quartz and microscopically visible fluorite, indicate the distinct rapakivi properties of the material. The dyke cuts all the structural patterns of the wall rock, which is granodiorite in places penetrated by pegmatites belonging to the late-kinematic group. One of the smaller tributaries of the major aplitic dyke is almost perpendicular and shows dense and almost glassy margins, ½ to 1 centimeter wide, against the granodioritic wall.

Recent scattered observations, as pointed out reveal that the rapakivi, when associated with a fine-grained (aplitic) marginal modification, may also have steeply dipping contacts against the adjacent rocks. Around the Våtskär area it seems that the emplacement of the rapakivi material has, at least partly, followed the earlier fault or joint direction, which runs approximately N 10°W. Some merismites, the fine-grained marginal modifications and, especially, the aplite with glassy margins strongly suggest that a mobile magma-like material has been in operation, whatsoever its origin.

ORE MINERALIZATIONS

THE LOCATION OF MINERALIZATIONS AND PARAGENIC PROPERTIES OF THE ORES

The first instance of ore mineralizations occurs at Hopeavuori as veins in the merismitic wall rock, generated during the synkinematic stage of orogeny (p. 30). The quartz veins containing sulphides have been marked by a and b (Fig. 23). The intensity of the mineralizations varies in different parts of the veins; in places there only are a few sulphidic grains but in other places most of the gangue material is replaced by compact ore, and these places have also been quarried during earlier days (Q). Another system of fractures (c) filled by quartz, but not containing sulphides, runs in an E—W direction and probably is of considerably later origin than the shear fractures including mineralizations.

The occurrences at Hopeavuori in particular have been called galena quartz veins, even though the paragenesis may occasionally be variable and contain the greatest number of different ore minerals met with in the area investigated. Besides galena, arsenopyrite, loellingite, pyrite, sphalerite, pyrrhotite and some tetrahedrite associated with galena are found. Most abundant among these additional components are arsenopyrite and loellingite, the former being predominant. Pyrrhotite occurs here and there as small,

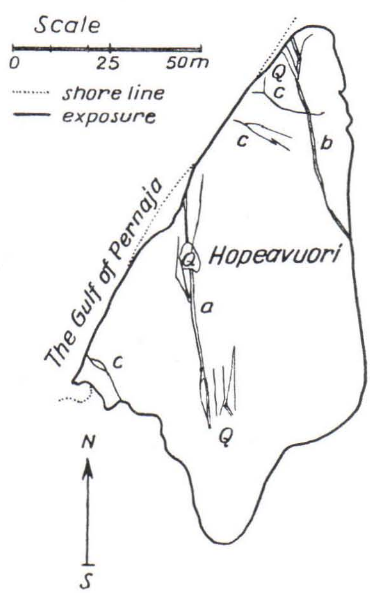

Fig. 23. Joint and fracture system in the outcrop of Hopeavuori, Koskenkylä.

strongly resorbed grains. The pyrite is mostly strange in appearance because of alteration phenomena to be demonstrated later on.

About 300 meters east from Hopeavuori previously quarried, dense impregnation of arsenopyrite has been met with. This, let us say, second type of mineralization follows the silicified parts of the merismitic wall rock. In the same way there occurs a rather weak impregnation in the merismitic granite just behind the farmhouse of Hovi. In these occurrences the mineralization is mainly composed of arsenopyrite and loellingite, while some pyrite, sphalerite and minute amounts of pyrrhotite are present as additional compounds. Galena is entirely lacking in both examples of impregnation.

The occurrence on the island of Forsö is considered as a third type of mineralization in the area investigated. The mineralization occupies a limited area, and it follows quartz veins injected along the planes of schistosity of biotite-chlorite schists. From the former occurrences the mineralization of Forsö deviates mineralogically, so that loellingite and altered pyrite have not been met with and even arsenopyrite is a wholly accidental component.

The pyrite, sphalerite, chalcopyrite and very subordinate pyrrhotite occur always as strongly resorbed grains replaced by loellingite, arsenopyrite and galena. No idiomorphic forms are noticeable in the pyrite. All the minerals — pyrite, sphalerite, chalcopyrite and pyrrhotite — have a sort of old imprint that encourages the opinion that these minerals represent inevitably the oldest generation. Apparently some of arsenopyrite also belongs to this oldest generation of ore minerals in the Koskenkylä area.

In addition to the aforementioned behavior, the arsenopyrite shows peculiarities suggesting that this mineral has been formed in two different ways: a. directly, as a primary phase, and b. by replacement from loellingite and from pyrite. Subsequently, loellingite can be found in arsenopyrite only as residuals of varying size (Fig. 24). This phenomenon is well known and needs no further comment (Edwards 1947). The arsenopyrite has a strong tendency to replace pyrite, but the process was not accomplished in the degree reported, *e.g.* recently by Creasey (1952, p. 53). The partly altered, xenomorph pyrite still has a dimly yellowish general color, but more detailed inspection reveals it to be very heterogeneous, while containing numerous whitish, indeterminate flecks which are obviously arsenopyrite in composition. Under the crossed nicols the remaining pyrite is still isotropic, whereas the altered mass shows approximately the same change of colors as arsenopyrite. Evidently the aforementioned sequence does not belong to the category of alterations which involve the generation of anisotropic pyrites as demonstrated from upper Silesia by Schneiderhöhn (1930) and from Malånäs district in Sweden by Gavelin (1939). In both of these cases the authors assume that the anisotropy had been caused by an unusual high content of arsenic in the pyrite. Presumably the mineral represents a kind of substitutional solid solution produced in a high temperature under sufficient partial pressure of arsenic. In the Koskenkylä area anisotropic pyrite was not found, but the alteration has been an

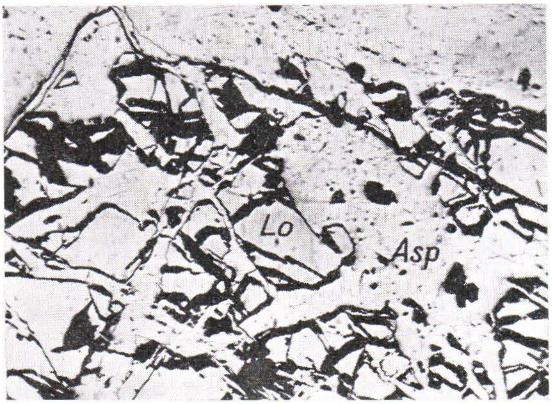

Fig. 24. Replacement of loellingite by arsenopyrite.

ordered replacement of pyrite under dominant partial pressure of arsenic.

Considering the mutual phenomena of resorption between the ore minerals, the following order of crystallization for the species has been established:

1. *Pyrite, sphalerite, chalcopyrite, pyrrhotite, arsenopyrite I*
2. *Loellingite, arsenopyrite II*
3. *Galena, tetrahedrite*

The first generation is very slight in relation to the second and third generations. The strongly resorbed sphalerite usually contains numerous irregularly shaped spots of chalcopyrite and pyrrhotite, obviously incorporated by replacing solutions advanced from the borders to the interior of a grain.

The three different phases overlap in the veins of Hopeavuori. The impregnations in the merismitic wall rock around Hopeavuori involve the first and second generations, whereas in Forsö the first and third generations only are present. The variable overlapping in different localities might depend on the differing potentialities of ore-bearing solutions for propagation in the wall rock environment, and some directions in the wall rock are also particularly favored. Because the ore minerals belonging to the first generation show some evidence of deformation, it is plausible that there has been a marked time interval between the mineralizations of the first and second phases, whereas the second and third phases have been more or less concomitant. The resorption phenomena tentatively suggest that at the beginning of the second phase the partial pressure of arsenic has been at a maximum, causing the formation of loellingite as the first species.

DISCUSSION ON THE ORIGIN OF THE ORE MINERALIZATIONS AS RELATED TO THE MIGMATITE FRONT

So far the generation of ores showing paragenic properties similar to those in Koskenkylä has taken place in conjunction with some granite present in the reference area. Since the origin of granites has been a controversial subject (in the sense of Read 1948), there has taken place discussion about »Granite and Ore» (Locke 1941, critically reviewed by McKinstry 1941) as well as »Ore and Granitization» (in an extreme manner by Sullivan 1948), and the nature of the ore-forming fluids has ceased to be pertinent in the strict sense supposed by the hydrothermal theory (Niggli, Schneiderhöhn, Lindgren, *etc.*). The economic geologists are thus facing the problem as recently expressed by Goodspeed (1952): »Can granitization be a source of mineralizing emanations in some areas, and the crystallization of magmas in others?» This viewpoint has to be considered also in the present case. Apparently in the Koskenkylä area the rocks of two magmatectonically different phases overlap a great deal. Based on the field evidence described in the foregoing chapters, the mineralizations presumably were emplaced in their present localities by the same agencies, which drove the granitization and migmatization in the late-kinematic stage. This idea obviously requires additional proofs and scrutiny of details. Having already the main formational and tectonical background in this particular area, the present author wishes to engage in further discussion under the following headlines: 1. The initial character and source of ore-bearing fluids, 2. The final emplacement of ore mineralizations. For the first aspect mentioned a special reference has to be made to the general principle of granitic pore-magma as represented by Eskola (1948).

1. The assumption is plausible that a relatively open system obtained in the plastically doming stock when the quiet granitization progressed. In the present author's opinion the process took advantage of the areas earlier occupied by granodiorites associated with normal chorismitic rocks, as shown by many examples in the previous text. When forced against a massive zone of uneffected schists (»genügend resistente Rahmen» according to Wegmann, 1931, p. 58), the concentration of mobile phases was induced in some degree. This event expectedly marked a change of quietly transgressive incidents in favor of »destructive» migmatization (p. 25) which obviously operated within the zones, now characterized by the migmatic potash granites associated with different kinds of gneissose rocks. Speaking

in terms of movements Wegmann depicts the same situation as follows: »Die Bewegung konsentriert sich auf gewisse Gebiete zwischen festeren Bergmassen. Solches Aufstiegen leitet zu einem Bewegungstyp über, welcher als Intrusion bezeichnet wird» (*op. cit.*, p. 62). In the Koskenkylä area the red injection pegmatites, concomitant to tangential movements, presumably marked a highly dissolving and aggressive stage in migmatic activity, which adequately might have induced a generation of greater amounts of intrusive-like material as well. This material, when consolidated, acceptably leads to a composition of »ideal granites» as proposed by Eskola in several connections (1948). Based on the field observations on the veined gneisses and associated ores of the Kantorp district, Central Sweden, Magnusson (1936) established the age relations within the period of invasion of granitic material as follows: The pneumatolytic and hydrothermal solutions have preceded the pegmatites and granites, while the homogeneous granites have finished the process of alterations. This seems to be an appropriate assumption even when tracing the probable sequence of the destructive process, by which the migmatic potash granites and veined gneisses originated in the Koskenkylä area. In addition, however, one has to consider that the highly transgressive period was followed by continuous cooling, producing effects that are still of interest from the ore-geological point of view.

So far as the cumulative material is concerned, it is important, though it is difficult to determine what thermodynamic attributes would best characterize it during the time of concentration against the wall. In the areas south and west of Pernaja village, the process during the quiet granitization was supposed to be »dry» in character, the granitizing effect having been transmitted by vapors of approximately the supercritical stage. According to Bowen and Tuttle (1950), considering that in the late-magmatic process »the principal function of water is a fluxing one, in which capacity it is indeed very powerful,» and further, that in the ternary system $NaAlSi_3O_8$—$KAlSi_3O_8$—H_2O (in appropriate temperature and pressure of deep-seated zone) »containing water up to 10 per cent, crystallization equilibria are nearly the same as in the dry melts.» And still according to the authors cited (*op. cit.*) »this vapor phase, filling minute interstices, will also induce recrystallization even after exhaustion of all liquid.» Now, all the remarks made amount to a conclusion that obviously the mobile phase during the doming might have been of relatively small quantity. On the other hand, however, the concentration of the mobile phases must have been considerable in the zones where the process of destructive granitization commenced.

Supposedly one is dealing somewhere in the PT-interval between those of the pegmatitic phase and those of hydrothermal solutions, *i.e.* the temperature being lower than in the pegmatitic stage, but the pressure relatively high. Holding this point of view the »supercritical» phases still continued their existence as dense gases or fluids, as maintained by Verhoogen (1949,

p. 133). A later change of thermodynamic equilibria below the conditions of the three-phase boundary caused the releasing of aqueous substances as hydrothermal solutions and gases of lower temperature. That supposedly characterizes the termination of transgressive granitization.

The conception has been generally adopted by geologists that the aqueous constituents, in a similar process and in a geological milieu similar to those now under discussion, have been derived from the hydrous minerals of the wall. In the present case, moreover, it might be assumed that the arching roofs displayed the »cold wall» in which the residual liquids were concentrated under synkinematic folding movements. The content of water, so fixed, might well be responsible for increasing the content of aqueous substances in certain zones attacked by the granitization of the late-kinematic stage.

2. Against the background given the red injection pegmatites, accompanied by feldspathized and silicified zones (p. 44), might properly indicate the most far-reaching effect of injections, but at the same time they indicate the termination of the migmatizing activity in this particular zone. Possibly the material involved also some metallic elements, presumably originating from the pre-existing formations. The metallic elements were separated during the successive stages of emplacement, in which process the change of phase equilibria (see Smith 1948 and Kennedy 1950), the geochemical factors and the permeability of the wall (*e.g.* Ohle 1951) were of special significance. As regards the last aspect, in the Koskenkylä area the favored rocks for later subcapillary propagation of solutions (Webb 1946) seems to be the synkinematic merismitic rock, which expectedly contains huge amounts of invisible micro-fissures and cracks. The ore impregnations connected with irregularly distributed light metatect behind the Hovi farmhouse definitely belong to this category of formations and represent the first generation in the paragenic succession of Koskenkylä ores. Especially metalliferous solutions may escape within long distances in the wall rock environment, as shown by preliminary calculations carried out *e.g.* by Smith (1948).

By advanced cooling of the migmatite front, some portions of the overlying masses began to consolidate while the interior remained in a partly plastic state, partly involving also mobile phases. During this period the circumstances of the mobile phases approximated those of a closed system and an accumulation of liquid material may have occurred in some degree, until cross-jointing (Querklüftung) and shear fracturing of the frozen cover took place. Because of the relatively low temperature conditions obtaining during the whole process under consideration, the forming of a retrograde vapor phase was not probable at any time. Instead, unsaturated vapor phases presumably accompanied the pegmatitic-hydrothermal material, which then erupted along the opened channelways and gave rise to pegmatites rich in quartz, sometimes with chilled margins (p. 45). The quartz sulphide veins corresponding to the mineralizations of the second and third generations obviously account for this period of pegmatitic activity.

Accordingly, the accumulation of aqueous substances embracing the ore materials occurred partly at the early pegmatitic stage (red injection pegmatites), but the maximum as suggested by the vapor pressure curve (Niggli 1925) was never attained, owing to the conditions of a relatively open system. Accordingly, the formation of typically pneumatolytic ores is not evident in this process. The resulting hydrothermal solutions finally produced ore impregnations in the wall. Usually ores of economic value are not formed this way because of the many dispersive factors affecting the process. The density of the impregnations as observed in the field presumably offers a direct controll on the economic possibilities in deeply eroded parts of the Svecofennidic territory.

In a manner the initiating mechanism, responsible for the ore filling in the shear fractures, recalled that giving rise to hydrothermal solutions at the late-magmatic stage. Even in this case, however, the maximum as presupposed by the vapor pressure curve is not likely. Contrary to magmatic development, the accumulation of ore-bearing mobile phases evidently took place in several small nests within the cooling migmatite front. This development subsequently very largely eliminates the possibility that any ore occurrence of economic magnitude originated in this way. The mineralogical composition may be extraordinarily good, as evidenced by many examples scattered around the migmatite granitic zone in Southern Finland.

The assumption that the emplacement of re-mobilized older ore material took place in transgressive and regressive periods of the migmatizing activity also explains the obvious time interval between the first and second generations of ore minerals, as suggested earlier (p. 53). Moreover, the existence of ore mineralizations *in situ*, as arising from the synkinematic stage or being of still older origin, is not probable in the Koskenkylä area, where only the roots of highly metamorphozed supracrustal formations are exposed, after the deep-reaching erosion. This, however, is a local result and does not eliminate, *e.g.*, the existence of synkinematic ore formations *in situ*, in better preserved areas, especially in the vicinity of anticlinal folds of the Svecofennidic mountain chain.

CONCLUDING REMARKS ON THE EVOLUTION OF THE ROCK CRUST IN PERNAJA

Excluding the amphibolitic dyke in Stadsland, the supracrustal rocks in Pernaja are all older than any of the infracrustal rocks in the area investigated. The material studied does not suffice, however, to clear up the age relation between quartzite and other supracrustal rocks. The former probably accounts for the rocks generated of argillaceous and arenaceous material, which usually seem to underlie the volcanics of the Svecofennidic supracrustal formations.

The synkinematic granodiorites and late-kinematic granites are determined consistently according to the earlier usage of these terms in the Southern Finland. Apparently the rocks of the synkinematic series previously had a much wider distribution than today; especially the granodiorites have altered metasomatically to a great extent by later granitization. Two kinds of granitization mechanism have been distinguished as having been active during the late-kinematic stage: quiet granitization and destructive migmatization. An increasing quantity of aqueous substances in the operating material has been suggested as one significant factor giving rise to granite intrusions, pegmatization and migmatization in appropriate marginal zones.

In the course of the present study the so-called Rysskär granite appeared to be a special modification of the synkinematic granodiorites. In the Barösund (1927) and Ahvenanmaa (Åland) regions Sederholm similarly designated the merismitic rocks, analogous to those of Rysskär, as gneissose granites (*i.e.* corresponding to the synkinematic stage). That has been the case even when the metatect of the merismites shows striking amounts of potash, as in a rock called »Skeppvik granite» from Ahvenanmaa (Sederholm 1934, p. 24). The rock apparently corresponds to those merismites of Rysskär in which the metatect was strongly contaminated by later granitization (p. 30). The elimination of the Rysskär granite as a separate intrusion contributes a principal correction to the stratigraphical scheme proposed by Sederholm in the Pellinge area, and the leading features of the evolution of different formations in the Pernaja district may be listed as follows:

	Rapakivi
	Amphibolitic dykes
Faulting	Discontinuity
Updoming and tangential movements	Late-kinematic granites and associated pegmatites
Folding	Synkinematic rock series
	Blastoporphyritic rocks and pyroclastic sediments
	Argillaceous material (garnet-biotite-schists) and quartzite
	Unknown basement

The initial purpose of this study was to illuminate the origin of the ore mineralizations in the Koskenkylä area. Accordingly, an attempt was made to trace the principal development, which involved the generation and escape of ore-bearing phases. The conclusion was reached that the metallic elements of older derivation have been mobilized and emplaced in obedience of the total process of migmatization during the late-kinematic stage of orogeny.

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EXPLANATION OF PLATE I.

Fig. 1. Coarse-grained, strongly metamorphozed plagioclase porphyrite. 200 hundred meters west of Koskenkylä bridge. Nic. + , 6 ×, (p. 10).

Fig. 2. Basic tuff from Koskenkylä schists. Main components are plagioclase, hornblende, biotite and grains of oxidic ore. Nic. //, 20 ×, (p. 11).

Fig. 3. Fine-grained, distinctly schistose tuffite in easternmost part of the Koskenkylä formation. Coarser grained quartz layers visible. Nic. //, 5 ×, (p. 12).

Fig. 4. Actinolite bearing amphibolite from the contact area in Hästö to south of Våtskär. Nic. +, 30 ×, (p. 19).

Fig. 5. Homogeneous potash granite showing the alteration of garnet into biotite and chlorite. Small islet southeast of Hirsalö. Nic. //, 50 ×, (p. 26).

Fig. 6. Basic inclusion in the merismite of Hirsalö. Main components are hornblende, biotite and chlorite. Nic. //, 20 ×, (p. 48).

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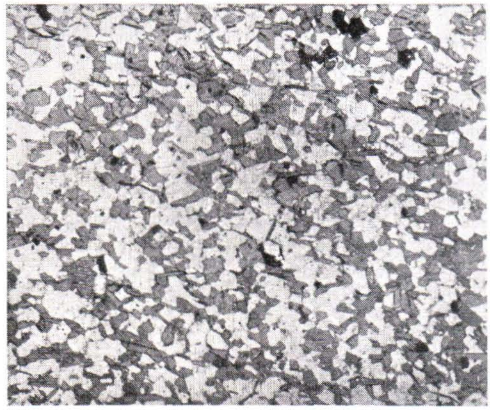

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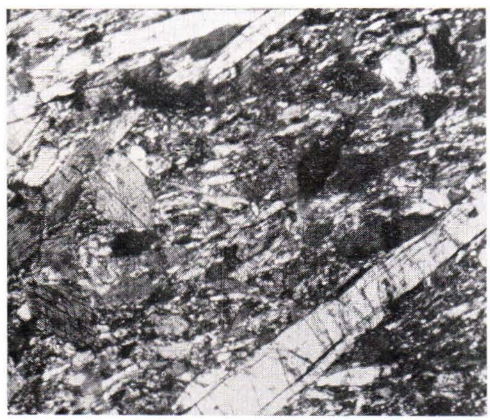

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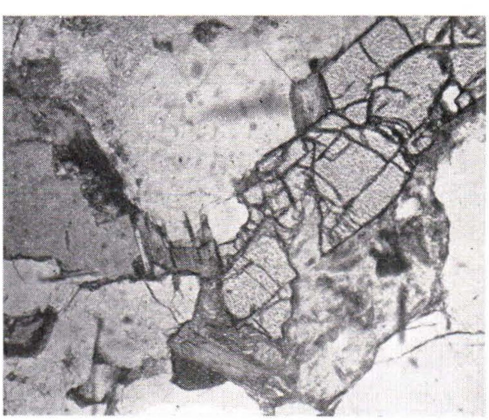

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*) Loppuunmyyty.
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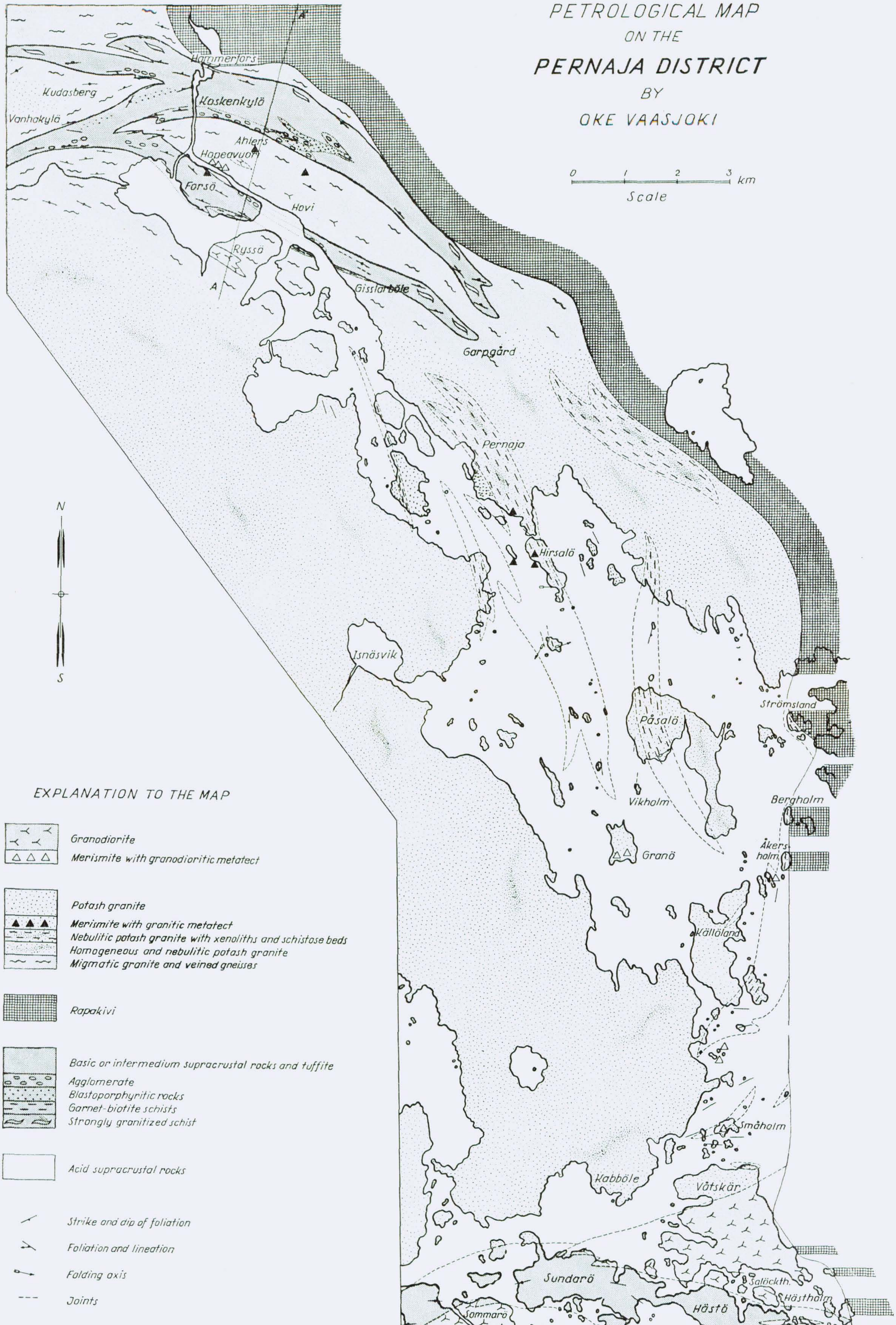

PETROLOGICAL MAP
ON THE
PERNAJA DISTRICT
BY
OKE VAASJOKI
0 1 2 3 km
Scale
N
S
Hammerfors
Kudasberg
Koskenkylä
Vanhakylä
Ahlens
Hopeavuori
Forsö
Hovi
Ryssä
A
Gisslarböle
Garpgård
Pernaja
Hirsalö
Isnäsvik
Strömsland
Påsalö
Vikholm
Bergholm
Granö
Åkers-
holm
Källöland
Småholm
Kabböle
Våtskär
Sundarö
Salöckth.
Hästholm
Hästö
Sommarö
Stadsland
EXPLANATION TO THE MAP
Granodiorite
Merismite with granodioritic metatect
Potash granite
Merismite with granitic metatect
Nebulitic potash granite with xenoliths and schistose beds
Homogeneous and nebulitic potash granite
Migmatic granite and veined gneisses
Rapakivi
Basic or intermedium supracrustal rocks and tuffite
Agglomerate
Blastoporphyritic rocks
Garnet-biotite schists
Strongly granitized schist
Acid supracrustal rocks
Strike and dip of foliation
Foliation and lineation
Folding axis
Joints