GEOLOGINEN TUTKIMUSLAITOS

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STRUCTURAL HISTORY OF THE EASTERN PART OF THE GULLKRONA BASIN, SW-FINLAND

BY

NILS EDELMAN

WITH 16 FIGURES AND 2 TABLES IN TEXT, AND 30 FIGURES ON 8 PLATES

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CONTENTS.

PREFACE.

This paper is the principal result of field studies in the archipelago of SW-Finland during the summers 1944—1948. During the summers 1944—1945 I mapped a limited area for the written examination »pro gradu» (10). This study gave me a basis for further investigations. In the summer of 1948 only small fields in the S. and SE. parts of the map area were surveyed and some excursions were made in the other parts. Mr H. B. Wiik, M. A., mapped in the summer of 1947 the neighbouring part of the island Kimito. His material and the observations from the excursions we made together in this area have given me a better conception of the structure of the W. end of the leptite belt of Kimito. This has been of great importance as regards the problems discussed here.

I have been able to accomplish this investigation partly through several scholarships from Nordenskiöld-samfundet i Finland and from Wilhelm Ramsay Memorial Fund. This study has later through Professor Pentti Eskola's interest become a part of the program of the Geological Survey of Finland.

My teacher, Professor E. H. Kranck, has given me many valuable suggestions during discussions about the problems of this area.

Mr H. B. Wiik has carried out the analyses, Miss Thyra Åberg has drawn the fair copies of the figures and the maps and Mrs Lily Björling has revised the English of the manuscript.

Besides to the above-mentioned persons and institutions I wish to express my sincere thanks to my wife who has helped me in many ways especially in the field work, and to the residents in the area investigated for their hospitality and, last but not least, to my chiefs, Professor Aarne Laitakari, Director, and Dr Ahti Simonen, Chief Geologist of the Geological Survey, for their kindness in affording me possibilities of concluding this investigation and in permitting the publication of this paper in this series.

Geological Survey of Finland, May 1949.

The author.

INTRODUCTION.

The area described in this paper lies in the archipelago of SW-Finland and consists of parts of the parishes of Pargas, Dragsfjärd and Hitis and small corners of the parishes of Nagu, Kimito and Karuna. Fig. 1 shows the location of the area. The length is 40 km. and the breadth varies between 10 and 14 km. The nearest towns are Turku (Åbo) in the N. and Hangö (Hanko) in the E. besides the industrial communities Pargas Malm (Paraisten Malmi) and Dalsbruk (Taalintehdas). The nautical chart Sorpo—Padva and the map of the parish of Pargas, both in the scale 1 : 50 000, were used as basis.

With the exception of the antiquated maps from the last century (4, 40, 41, 42) there exist no geological maps of larger parts of the area.

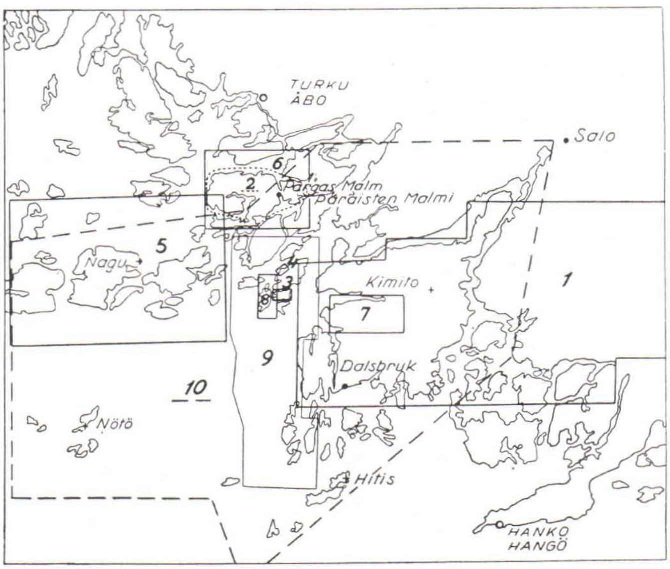

Fig. 1. Sketch-map showing the position of the mapped area and of the geological maps from this area and its immediate vicinity published by: 1 Eskola (15), 2 Laitakari (34), 3 Pehrman (47), 4 Pehrman (48), 5 Hausen (21), 6 Metzger (39), 7 Pehrman (45), 8 Edelman (10), 9 Edelman (Fig. 30 Pl. VIII in the present paper) and 10 Edelman (Fig. 28 Pl. VII in the present paper).

Only limited parts have been closer described by Pehrman (47, 48) and me (10). Eskola's map of the Kisko—Kimito leptite belt reaches to the E. shore of the island of Attu (15). The porphyritic granite of the islands of Dunskär and Små Kalskär has been described in an earlier paper (11). Sederholm (60), Haarmann (18), Hausen (19, 20, 22, 23, 24), Kranck (32) and I (13) have discussed the joint systems and the morphology of the archipelago of SW-Finland.

Some maps and descriptions of the neighbouring areas are published. Besides Eskola's above-mentioned description (15) the N. part of Pargas has been described by Laitakari (34) and recently also structurally by Metzger (39). A preliminary map of the N. parts of the parishes of Nagu and Korpo is published by Hausen (21). Pehrman has published a map of a part of the island of Kimito (45).

The purpose of the present paper is to explain the structural evolution of an area belonging to the Svecofennidic mountain chain. The chronological order of the phenomena is in general followed. I have tried to use photos and drawings as much as possible to elucidate the description, and I hope that the map gives a fairly true idea of the structure, although the contacts in many places are hypothetic partly, because large areas are covered by sea. The distribution of the exposures is fairly well seen on a map of this area, as the islands consist mainly of exposed bedrock, with the exception of only the two islands E. of and a little islet SW. of Helsingholm, these being entirely built up of mantle rock belonging to the third Salpausselkä end moraine. The best exposures occur on the shores, where the rocks, polished by the Glacial ice sheet, are unweathered and free from lichens.

The area belongs to the Archaean Svecofennidic mountain chain, which strikes almost W. through the S. part of Finland and continues in Central Sweden. Several good petrologic descriptions of the Svecofennides occur and therefore it seems unnecessary to describe this part in detail. Only the characteristics of the main rock types will be mentioned. The metamorphism is touched upon only in so far as it is of importance as regards the purpose of this paper and the granitization, being the dominating rock-making process of the area, is discussed only from the structural point of view. It has also been impossible to make a detailed division of the rocks according to the mineral facies, because the number of thin sections is too small and the variations of the mineral parageneses too great even in limited areas (3).

I have in general avoided petrographic terms, which are connected with geographic names, because they do not say anything about the composition or the texture of the rocks. Instead of »trondheimite» (primarily »trondhjemite») and »kinzigite» I have used »gneissose granite» and »gneiss» or »veined garnet gneiss».

OUTLINE OF THE GEOLOGY.

SUMMARY.

The chronological scheme of the evolution of the area described here seems to be as follows (Table 1). Volcanic and sedimentary processes have built up the so called Svionian supracrustal formation consisting

Table 1.

Phase	Rock	Process	Movement	Style
Pre-orogenic	leptites, amphibolites, mica gneisses, limestones	volcanism and sedimentation	anorogenic vertical movements	horizontal or flat layers
Prim-orogenic	alkali-calcic igneous rocks	intrusion, crystallization, folding, metamorphism, brecciation	intrusion of magma along certain horizons, folding movements, flat axes striking E. or W.	mixed style: fluidal, brittle, sinuous folds
Intra-orogenic	amphibolite dikes	jointing, faulting, and intrusion	minute movements along faults	brittle
Ser-orogenic	migmatitic granite, veined gneisses, pegmatites of different kinds	granitization, cross-folding	rising of granites, sinking of other rocks, W-wards movements of the leptite zone, minute movements along faults	mixed style: plastic, shear, brittle
	dikes of migmatitic granite, pegmatites	granitization in joints, intrusion		brittle
Post-orogenic	diabase dikes, orthoclase-bearing granites	intrusion intrusion faulting erosion and peneplanation deformation of the peneplain, faulting, erosion and Glacial erosion, Glacial and Postglacial faulting	tension: W—E. (?) tension: NW—SE. vertical, partly rotatory movements, regional rising, dome-liking rising, sinking of the Gullkrona basin vertical movements	brittle

of leptites, amphibolites, garnet gneisses and limestones. Some subvolcanic sills have been intruded between the beds of the supracrustal rocks. Alkali-calcic infracrustal rocks have later intruded as laccoliths between the almost horizontal layers of the supracrustal formation and locally differentiated during the crystallization. This event seems to have initiated the Svecofennidic orogeny. The movements belonging to the prim-orogenic phase caused a sinuous folding with primarily horizontal or flat axes pitching E. or W. When the alkali-calcic magma crystallized, the supracrustal formation got a harder skeleton, which locally was brecciated before the movements ended. The following phase, the intra-orogenic quiet phase, is characterized by intrusion of amphibolite dikes in joints of the brittle rocks. After that the phase of regional metamorphism and granitization began. The brittle upper parts of the mountain chain were broken, because the foundation became plastic through the granitization. The granites being lighter than the overlying rocks rose upwards like domes, whereas the broken pieces of the ungranitized rocks sank downwards. The older axes got locally almost vertical pitch and the new folds had axes lying in a nearly vertical plane striking N. The largest domes are on the Gullkronafjärd, along the W. shore, and in the N. part of the island Kimito. The leptite belt moved westwards over the underlying plastic migmatite and caused cross-folding and combined to form the cross anticline or dome and the cross syncline or the axial culmination and depression along the W. shore of the island Kimito. After this final plastic phase of the Svecofennidic orogeny the migmatite became brittle. Joints and faults were granitized to migmatitic granite dikes and the last pegmatite generation was intruded.

The intrusion of the diabase dikes and the orthoclase-bearing granites took place during the post-orogenic phase. Faults of different age occur; a great part of them are older than the Sub-Cambrian peneplain. The Gullkrona block and the Pemar block have sunk later than the peneplain was formed and finally the faulting has continued during the Glacial and the Post-Glacial age.

MORPHOLOGY.

The area contains several types of archipelago. In the N. and E. parts the islands are large and close to one another forming a typical inner archipelago, whereas the islands and skerries of the Gullkronafjärd are small and low, a fairly typical outer archipelago. The relief is low; only the channels on the sea bottom have steeper sides. The difference in height between the highest summit and the deepest channel is about 140 m. The height of the summits is seen in Fig. 28 Pl. VII.

The shore line represents a natural contour line and a glance at a map, especially at a nautical chart, gives us a good idea of the main structural features (31 p. 10). The bays and capes, many sounds and rows of islands show the direction of the rock layers, for instance the large curves of the Gullkronafjärd and of the area SE. of it, the rectilinear topography of S. Pargas and the curves of Tammo island and of SW. Sorpo. The bays and sounds often continue in the islands as narrow valleys filled with mantle rocks. The veined gneisses generally form valleys, *e. g.* the zones of Sorpo, the zones between Vånå and Tervsund close to the E. shore of Stortervo. Hausen has supposed that the last-mentioned valleys are eroded zones of movements (21 p. 50). This is a possible explanation, but the primary cause is, however, that the veined gneiss is more inhomogeneous than the surrounding granite and therefore yields easier to force, but also is less resistant against erosion. The gabbro of the bays between Attu and Jermo has perhaps weathered more than other basic rocks, depending on the pyroxene and olivine content and the very high Fe percentage (analysis 5 Table 2). Basic and ultrabasic inclusions in more acid rocks are often weathered deeper than the country rocks and this phenomenon is especially characteristic of the diabase dikes. Similar weathering phenomena from Hitis parish are discussed in an earlier paper (13).

The main part of the often long and deep channels, which cut the older structures in many directions, are obviously eroded fault and joint zones. Fig. 28 Pl. VII shows these topographic channels or joints around the area described here. The dominating morphologic feature is the Gullkrona basin and its continuation, the Pemar »Graben» or fault trough, in the old peneplain. These fault troughs form two open sea areas in the archipelago, the Gullkronafjärd and the Pemarfjärd (Paimion selkä).

PETROGRAPHIC DESCRIPTIONS.

SUPRACRUSTAL ROCKS.

The supracrustal formation consists of sediments and acid and basic volcanites. In rather few cases we are able to determine with certainty the origin on the basis of relict textures; metamorphism and granitization have commonly destroyed the primary features; only the bulk composition and the structural behaviour may point to a supracrustal origin. Many transitions between the recognizable sediments and volcanites occur and it is therefore in most cases impossible to determine the origin of these supracrustal rocks. Some of these rocks have been described earlier (10, 45, 48, 49).

The acid volcanites (leptites) are fine-grained and rather thin-bedded. Several occurrences of agglomerate and blastoporphyric rocks were found. Both Na- and K-extreme types occur. The mineral composition of the different types is as follows:

plagioclase, quartz, biotite
quartz, plagioclase, microcline, biotite
microcline, quartz, plagioclase, biotite
microcline, quartz, biotite.

Hornblende, hypersthene, garnet, sillimanite, and epidote have been found predominantly in solitary thin sections. Chlorite, sericite, epidote, and calcite occur as alteration products and apatite, zircon, and ore minerals are accessory constituents.

The hornblende-bearing leptites represent transitional types to the basic volcanites, the porphyrites and amphibolites. Relict textures (basic and intermediary pillow lavas, agglomerates, blastoporphyric, and blasto-ophitic rocks) prove the volcanic origin. Some layers may be subvolcanic intrusive sills. The composition is basaltic and the paragenesis amphibolitic. Plagioclase, rather An-rich, and hornblende are the dominating minerals. The following minerals or mineral associations were found often only in solitary thin sections: augite; hypersthene; diopside and epidote; antophyllite and cordierite; antophyllite and garnet; scapolite. Biotite and quartz occur in many amphibolites. Chlorite, sericite, epidote, and calcite have been found as alteration products and apatite, sphene, and ore minerals as accessories. The phenocrysts of the porphyritic types consist of augite, uralite or plagioclase. The augite porphyrite of SE. Attu is the best preserved type. The augite grains are surrounded by uralite rims in the E. part, whereas the porphyrites close to the NW. contact against the migmatitic granite have entirely uralitized phenocrysts surrounded by biotite rims. It is worth of note that the fine-grained pyroxene of the groundmass is quite clear and unaffected by uralitization and that the intrusion of the granite of the Pemarfjärd, belonging to the Perniö granite (15), has not caused any uralitization. In the island of N. Bergskär, W. of Holma, a porphyrite-like rock occurs, but the phenocrysts have there been entirely altered into biotite.

The primary textures of the sediments are in general transformed past recognition. Only one layer on the shore of the peninsula Korsholm, E. of Pemarfjärd, consists of an arkose-like bottom part and a top part of mica schist. The sediments are in general mica gneisses; some layers are rich in quartz, being nearly quartzitic, but the main part is rich in mica, often also in garnet. The mineral composition is: quartz, plagioclase, biotite, and commonly microcline. Garnet is especially in the granitized types a main constituent and in some cases hornblende is observed. Chlorite, sericite, zircon, apatite, and ore minerals also occur. Graphite is in some layers an essential constituent and occurs commonly together with sulphides, which points to an organic origin.

All the above-mentioned rocks are often granitized into veined gneisses or migmatitic granites. The size of the grains has increased during this process.

The origin of the gneissose granite of S. Sorpo and the islets S. of it is dubious. Narrow concordant layers of fine-grained leptite-like rocks are met with in the granite and in the islet 700 m. S. of the SW. cape of Sorpo four layers of plagioclase porphyrite occur; two of them can be followed about 100 m. (Fig. 2). The phenocrysts are concentrated into the middle part of the layers. The breadth of the layers varies from some dm. to 1 $^{1}/_{2}$ m. and the distance between them is uniformly some metres along their whole length unaffected by the folding. The following facts tell against the possibility of the gneissose granite in question being a

Fig. 2. Two folded plagioclase porphyrite sills in a granitized gneissose granite. SE. shore, rocky islet 700 m. S. of the SW. cape of Sorpo, Pargas parish.

true igneous rock: the distance between the porphyritic layers is uniform, brecciation of the porphyritic, amphibolitic, and leptitic layers is inconsiderable, often entirely lacking and scarcely any rotation of the fragments has been observed. The intrusion of the porphyrite sills has obviously taken place before the folding, but it seems rather improbable that a magma has been able to follow two parallel joints more than 100 m. in length in a brittle granite without intruding along other cutting joints. In supracrustal formations, on the other hand, magmas for the main part follow the well developed bedding planes. Similar concordant porphyrite sills or layers occur also in a supracrustal veined gneiss in a skerry 1 $^{1}/_{2}$ km. NE. of the islet mentioned above. This fact points furthermore to a supracrustal origin of the gneissose granite of S. Sorpo. Sederholm and Hietanen have noted similar alteration processes (57 pp. 27—30, 25 pp. 1070—1071).

The limestones are commonly narrow layers or lenses. They are often intercalated with gneiss and skarn layers but some are fairly pure. An intermediate type between the skarn and the amphibolites is represented by the diopside amphibolites, which probably are metamorphic products of calcareous sediments or tuffs.

A complex consisting of many different rocks *e. g.* quartzite, banded pyroxene-bearing quartzite, plagioclase-hornblende-pyroxene rock, and hornblende skarn occurs entirely enclosed in the migmatite on the SE. shore of the island of Stortervo. Another quartzite has been found on the N. shore of Tammo. Narrow layers of apatite and tremolite give this quartzite a schistose appearance. The origin of these rocks is obscure, but they may be metasomatic products, or »ore quartzites».

ALKALI-CALCIC SUITE.

The alkali-calcic rocks form a complete differentiation suite, which contains all types between hornblendites and plagioclase aplites. They are in general medium-grained, but coarse-grained pegmatites, predominantly gabbro pegmatites (47 pp. 19—24), and fine-grained aplites occur. Fig. 3 gives a good idea of the exceptionally great variations of the garnet-bearing gabbro of Vadviken bay between Attu and Jermo (analysis 5 Table 2). The dominant minerals are: hornblende, biotite, plagioclase, and quartz. Quartz and commonly also biotite are lacking in the basic members, while hornblende does not occur in the most acid ones. Some local variants of the basic and ultrabasic rocks contain furthermore the following minerals or paragenesis: garnet; augite, garnet, and olivine; cummingtonite and biotite; hypersthene. The ore minerals, ilmenite and magnetite, are in some places concentrated to small ore bodies (47). Chlorite, sericite, colourless amphiboles, epidote, microcline, and calcite are secondary minerals and sphene, apatite, and zircon are accessories. The texture is commonly granoblastic but blastohypidiomorphic and blasto-ophitic variants also occur. These rocks have been described earlier (10, 11, 45, 47, 48).

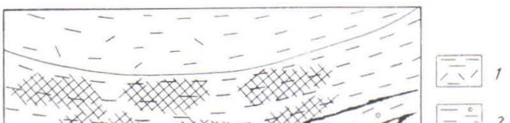

Fig. 3. Sketch-map of a part of a small exposure. W. shore, Vadviken bay between Attu and Jermo, Pargas parish. 1 hornblende gabbro, foliated and massive, 2 the same rock with garnet porphyroblasts, 3 the same rock with plagioclase porphyroblasts (phenocrysts?), 4 hornblendite, 5 garnet rock, 6 hornblende-garnet rock, and 7 pegmatite.

Olivine and pyroxenes occur in the gabbro of Vadviken bay and of Jermo as well as in the basic and ultrabasic rocks of the pluton of NW. Kimito (45). Also the porphyrites of SE. Attu are in great part pyroxene-bearing. The rocks of the zone from N. Jermo and SE. Attu in SE. direction hence belong to the gabbro facies, whereas the rocks in the other parts of the map area generally belong to the amphibolite facies (3). This zone is moreover less granitized and consequently better preserved than the surrounding areas and forms an apophysis of the leptite belt of Kimito as regards the degree of metamorphism.

The alkali-calcic layer of the N. part of Sorpo (Fig. 4) is rather well differentiated. The S. contact against the supracrustal veined gneiss is sharp, whereas the layer along the N. margin is gradually transformed into a migmatitic granite rich in microcline. Several ultrabasic lenses, hornblendites (analysis 1 Table 2), of different size are exposed close to the S. contact between the veined gneiss and the hornblende gabbro (analysis 2 Table 2). This rather fine-grained gabbro with linear foliation forms a zone, 100—200 m. in breadth, and in its N. part more acid layers appear. Going N-wards from there the rock becomes a banded suite containing layers of different acidity from gabbro and diorite (analysis 3 Table 2) to gneissose granite (analysis 4 Table 2) and aplite.

The anticline of Tammo and the monoclines of Sorpo and Attu all show the same direction of the bottom. No signs of any large syncline were found in the area Sorpo—Tammo—Attu—Heisala. Only a minor syncline occurs in the amphibolite of NW. Attu. We are then for the present justified in supposing that the veined gneiss (Fig. 4) stratigraphically lies below the pluton of N. Sorpo. As regards the specific gravity the different members of the layer are consequently arranged with the heaviest ultrabasic ones close to the bottom.

The differentiation of this alkali-calcic layer may be either metamorphic or magmatic; a sedimentary differentiation is not probable in this case, because there are no signs of a sedimentary origin of the rocks. The schistosity of many members of the suite points to an influence of the metamorphism, which may have been able to separate the

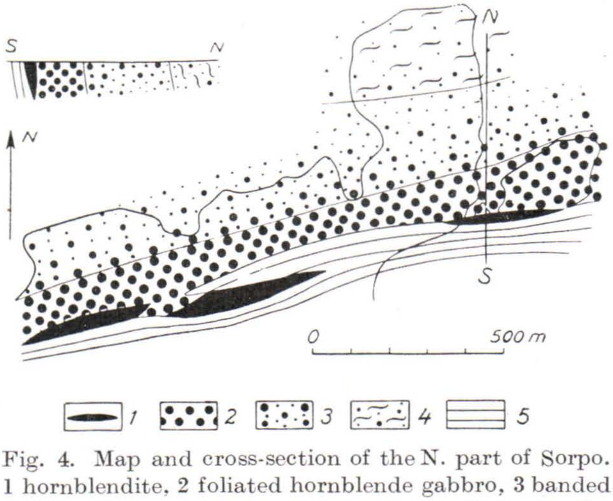

Fig. 4. Map and cross-section of the N. part of Sorpo. 1 hornblendite, 2 foliated hornblende gabbro, 3 banded gabbro — diorite — gneissose granite — aplite suite; the size of the dots gives a conception of the basicity, 4 the banded suite granitized and 5 supracrustal veined garnet gneiss.

acid and basic constituents from each other, thus causing the banded structure. The N. part may then have become more acid through granitization. This hypothesis, however, does not explain why the S. contact against the granitized veined gneiss is quite sharp in contrast to the gradual transition in the N. part. Furthermore, the main rocks of the layer, also the acid ones (Table 2), have a remarkably low K_2O percentage and do not show any signs of a Na-metasomatism (plagioclase porphyroblasts), which could be a result of a granitization (11). Another fact telling against the metamorphic differentiation is the rather low degree of metamorphism in the neighbouring area E. of N. Sorpo, the zone of N. Jermo—Kimito.

The distribution of the different rocks corresponds on the other hand fairly well to a gravitative differentiation. The acidity increases in N-ly direction *i.e.* from the bottom towards the top of the layer. Also the banding is a phenomenon frequently observed in basic igneous rocks and it

Table 2.

	1	2	3	4	5
SiO_2	50.61	50.82	57.98	66.79	41.39
TiO_2	0.57	1.66	0.66	0.52	2.27
Al_2O_3	6.92	16.19	16.49	14.40	10.06
Fe_2O_3	1.28	1.56	1.16	1.28	4.61
FeO	8.57	8.82	5.80	4.03	23.00
MnO	0.23	0.18	0.13	0.07	0.47
MgO	16.49	5.94	4.57	2.41	4.32
CaO	11.79	8.92	7.57	4.57	8.52
Na_2O	0.74	3.02	2.56	3.18	1.34
K_2O	0.76	0.81	1.36	1.18	0.45
P_2O_5	0.07	0.51	0.40	0.12	1.23
H_2O+	1.67	1.51	1.67	1.39	2.22
H_2O-	0.16	0.14	0.08	0.13	0.15
	99.86	100.08	100.43	100.07	100.03
si	99.6	123.4	171.0	263.0	87.3
ti	0.8	3.1	1.6	1.4	3.8
al	8.0	23.7	28.6	33.5	12.9
fm	64.7	44.0	37.7	31.6	64.2
c	24.9	23.7	23.8	19.2	19.5
alk	2.4	8.5	9.9	15.7	3.4
qz	—10.0	—11.6	31.4	100.9	—26.3
k	0.40	0.16	0.27	0.21	0.19
mg	0.82	0.51	0.54	0.45	0.22
c/fm	0.38	0.54	0.61	0.61	0.30

1. Hornblendite, 2. hornblende gabbro, 3. diorite, 4. gneissose granite, NE. shore, Sorpo island, 5. garnet-bearing gabbro, Vadviken bay, between Attu and Jermo. Analyst H. B. Wiik.

has been explained as a primary feature due to a gravitative crystallization differentiation (9). Gaseous transfer, thermal diffusion and assimilation of fragments of the country rocks may have modified the course of the differentiation, and metamorphism has later transformed the rocks, but gravitative differentiation seems, however, to have been the dominating rock-making process in the alkali-calcic layer of N. Sorpo.

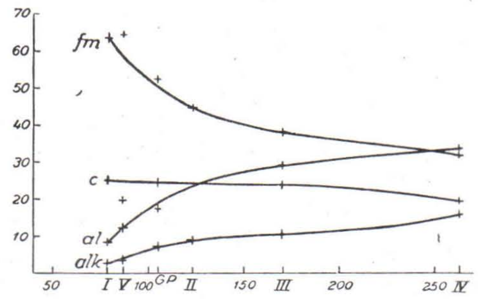

Fig. 5. Diagram of the Niggli-values for the analyses in Table 2. GP = the hornblende gabbro of Runholm peninsula, Jermo (47 Table II). The lines are drawn according to the analyses 1—4 showing the differentiation of NE. Sorpo.

The Niggli-values (Table 2) form fairly regular curves (Fig. 5), from which the values of the garnet-bearing gabbro and the hornblende gabbro of Jermo (47 Table II) differ to some extent. The alkali-calc index of this differentiation suite is very high, about 67 %, compared with the average of the Svecofennidic igneous rocks, 61 % (61 p. 6). It is 3 % higher even than the index of the Katmai suite (3 p. 63).

AMPHIBOLITE DIKES.

The amphibolite dikes are in general fine-grained and schistose. The texture is commonly granoblastic but blastoporphyric types were also found. The principal minerals are hornblende, biotite, and plagioclase. Chlorite, sericite, quartz, apatite, zircon, and ore minerals also occur. Some other minerals are found in granitized amphibolite dikes.

MIGMATITIC GRANITE.

The granite dominating in large parts of the area under discussion is a migmatitic granite. Its appearance is consequently very varied; coarse- and medium-grained, porphyritic and even-grained, homogeneous and nebulitic types often occur promiscuously. The content and the shape of the more or less granitized remnants of the older rocks vary very much and all transitions between homogeneous granite and untransformed rocks may be found. The granitization of the Dunskär—Små Kalskär zone has been described in an earlier paper and also the syenite-like rocks belonging to the same granitization process (11).

Owing to the migmatitic origin and the great variation of the primary material and of the granitization process these granites show quite a number of constituents. The dominating minerals are: microcline, quartz, plagioclase, and biotite. Myrmekite is common and its origin has been explained in an earlier paper (11). Hornblende, garnet, chlorite, muscovite (sericite), epidote, calcite, apatite, zircon, sphene, graphite, and ore minerals are found in different types. The texture is granoblastic, often also porphyroblastic. The microcline porphyroblasts commonly show a subparallel arrangement.

Dikes of migmatitic granite were found in several places. They are in general straight and cut the older rocks, also the migmatitic granite. The dikes show a foliation or a banded structure parallel with the blended or diffuse contacts (Fig. 20 Pl. IV). Some dikes contain fragments, often more or less elongated, of the wall rock. The mineral composition resembles that of the migmatitic granite with the exception of the content of zircon, which is remarkably higher.

ORTHOCLASE-BEARING GRANITE.

A small rounded massif in the SW. part of the island Tammo consists of coarse-grained and easily weathering granite. It forms a nearly cylindrical top of a hill. The height over the surrounding surface is about 10 m. and the diameter is about 100 m. There is in the N., W. and SW. a steep scarp, whereas the E. and SE. sides slope more gently. The granite cuts sharply the older gneissose granite. The S. contact is almost vertical, but at least the W. contact is nearly horizontal. Only one large fragment of the country rock has been found in the massif, but apophyses and dikes of the granite occur in the neighbourhood. These facts may point to the granite being a remnant of the bottom part of a laccolith with the feeding channel.

The mineral composition is: microcline, quartz, plagioclase, hornblende, biotite, and apatite. The quadrille structure of the microcline becomes finer towards the centre of the grains and some areas have parallel extinction on the (010)-section and seem therefore to be remnants of untransformed orthoclase within the microcline grains. The potash feldspar, which forms big crystals, contains quartz inclusions with hexagonal cross-sections. This quartz generation has no undulating extinction, as is sometimes the case with the xenomorphic quartz.

A granite which petrographically resembles the granite of Tammo forms a dike on the NW. shore of Falkö island. The breadth of this dike is at least 5 m. The strike is 60° and the dip is 85°SE.

These granites greatly resemble the post-orogenic granites in the Svecofennidic territory. The contacts are sharply cutting; orthoclase nuclei are surrounded by microcline, idiomorphic quartz grains are enclosed in the grains of potash feldspar, whereas another quartz generation is xenomorphic.

Furthermore many types of the rapakivi granites are easily weathering.

DIABASE (TRAP) DIKES.

Five narrow dikes of diabase were found within the area. They are very fine-grained; only the plagioclase forms megascopic crystals. The mafic constituents have only in the broadest dikes crystallized to determinable pyroxene; they appear in general as opaque pigment. Chlorite, muscovite, epidote, calcite, and quartz occur as secondary minerals, especially in miarolitic cavities and mineralized joints. Similar diabase dikes have been described from different areas of S. Finland (21, 25, 26, 28, 34, 39, 44, 46, 57, 58).

STRUCTURAL HISTORY.

PRE-OROGENIC PHASE.

The oldest rocks of the area described here are of supracrustal origin. Well preserved parts are rather rare, forming only limited fragments in the highly metamorphic surroundings. It is therefore impossible to establish with certainty the history of this phase. Only in the N. part of the island of Attu may a kind of stratigraphic succession be found. A veined garnet gneiss lies N. of or over an amphibolite. The direction of the bottom is earlier mentioned (p. 15). Small lenses and layers of limestone form a horizon between the gneiss and the amphibolite and another limestone horizon lies in the gneiss 100—200 m. N. of the first mentioned one. This formation resembles the better preserved northern part of the parish of Pargas, where the limestone occurs between the garnet gneiss (kinzigite) and the amphibolite (39 p. 79). The distribution of garnet is another regular stratigraphic feature. Garnet is rather rare in the Gullkrona dome, whereas it is a main constituent of the rocks of Pargas. It depends probably on the fact, that the primary rocks of the Gullkrona dome seem to be predominantly acid volcanites and arenaceous sediments, in Pargas on the contrary basic volcanites and argillaceous sediments.

To what extent these supracrustal rocks are of sedimentary or volcanic origin is impossible to determine. The volcanic textures are perhaps easier to recognize and more able to resist the influence of the metamorphism and therefore better preserved than the sedimentary ones. For the present it is, however, best to leave open the questions about the conditions and the events during the pre-orogenic phase.

PRIM-OROGENIC PHASE.

INTRUSION.

The intrusion of the alkali-calcic magma seems to be the event which, in the region here described, initiated the orogenic evolution of the Svecofennides. I have not been able to trace with certainty older movements which, however, may have taken place. As the maps show (Fig. 25 Pl. V, Fig. 30 Pl. VIII), the intrusion has in some degree followed a certain horizon in the older bedrock. In the N. part of the area the magma has formed a broad zone of igneous rocks split up by supracrustal layers into narrow laccoliths. In the NE. part the alkali-calcic plutonic rocks form on the Pemarfjärd and in the island of Kimito a large body, probably syncline-shaped. From there a zone branches out and runs S-wards across the islands of Hamnholm and Norrö, turning to SW. in the island of Högsåra and continuing in the islets around Dunskär. This zone possibly represents a stratigraphic horizon of the supracrustal formation, as is also suggested by the strikes and dips. Also in the N. part of Pargas parish the prim-orogenic intrusives follow a certain horizon (39 p. 56). Kranck (oral communication) suggested, that the horizon may be an older thrust along which the magma had intruded. This is a possible explanation, but I have not observed any signs of thrust movements in this area. We may perhaps never be able to prove thrust structures of Alpine type in the Svecofennides of S. Finland owing to the strong metamorphism. Further, the Alpine thrust are rather exceptions than typical features of the structure of mountain ranges. It seems therefore better to leave the hypothetic thrust out of account for the present. Wegmann introduced the thrust folds in the geological science of Finland, but his proofs of the occurrence of such structures in the archipelago E. of Helsingfors do not seem quite conclusive (72).

Some conclusions about the relations between the crystallization and the movements may be drawn from the structures of the differentiation products. The gravitative differentiation in the N. part of Sorpo (p. 16) points to a primarily flat or horizontal attitude of the now vertical pluton. This intrusive layer is at least along the S. contact concordant with the underlying gneiss; it was consequently before the folding a laccolith or a concordant sheet. The alkali-calcic plutons of the area described here are in general lens- or sheet-shaped. The large body SE. of Jermo and Tammo is possibly syncline-shaped owing to the dip of the leptites N. and S. of it. It is, however, difficult to determine to what extent the shape of the alkali-calcic plutons is primary and to what extent it is caused by movements during the different folding phases of the orogeny. Also many »urgranites» of Central Sweden form concordant lenses and layers (17 pp. 44—45). The almost ophitic texture of the gabbro of Hundholm, 750 m. W. of Norrö, points to hypabyssic conditions during the crystallization. Metzger has also thought that the prim-orogenic igneous rocks of N. Pargas have intruded at a rather high level of the earth crust (39 p. 65). Also the gabbro of Haverö seems to be laccolith-shaped (21 Fig. 3). Hence it seems probable, that at least some prim-orogenic plutons have primarily been flat-lying laccoliths in the upper part of the earth crust.

The orogenic movements began, as the hornblendites of the laccolith of N. Sorpo had crystallized, and caused the lineation and foliation of the acid members. The laccolith of the middle part of Sorpo was sheltered against cooling by the laccoliths above it — N. of it — and crystallized as the movements already had begun. These prevented the magma from differentiation and gave the rock a marked lineation. Later movements have of course further developed this texture, especially in the more acid types, whereas the hornblendites have only been brecciated to some extent.

The garnet-bearing gabbro of Vadviken bay almost 1 km. E. of the place described above points to similar conditions during the crystallization. The foliated gabbro contains fragments of a massive gabbro showing little or no signs of deformation (Fig. 3).

A similar evolution is seen in the beautiful breccias on the shore of the islands of Flisholm and Hummelholm (Figs. 1 Pl. I and 11 Pl. II). The first mentioned figure shows a breccia containing fragments of a medium-grained gabbro, a nearly fine-grained foliated gabbro and a gneissose granite. Aplitic dikes are cutting and enclosing these fragments. The evolution of this breccia may in the simplest way be explained as follows. The medium-grained gabbro had first crystallized during a period without differential movements. Later on, as the orogenic movements began, the cooling became more rapid and the foliated fine-grained gabbro crystallized. Another possible explanation is that the coarse type represents the inner part of the pluton, whereas the fine-grained foliated type has crystallized close to the contact, where the temperature was lower and the differential movements stronger. The more acid rest-magma and the orogenic movements have repeatedly brecciated the rocks which had solidified earlier and hence this complex breccia has originated.

The evolution is similar in all the above-mentioned cases. The oldest and most basic members do not show any remarkable signs of deformation, whereas the younger members are more or less foliated. The facts presented above are most easily understood, if we assume the intrusion to have taken place before the folding started. The intrusion and the folding were neither instantaneous nor necessarily simultaneous in the whole Svecofennidic area and we should therefore not expect the chronology to be quite identical even in adjacent areas.

In many places the breccias have been deformed by movements during and after the crystallization. The basic fragments then became more or less flattened in a more acid rock and the end member of this evolution series is represented by the gneissose granite with dark amphibolitic inclusions. This structure is beautifully developed in the gneissose granite of the islands of Trollö and Lökholm (Fig. 2 Pl. I). Because the series from the breccias to the gneissose granite with basic clots is fairly contihous, there is no doubt that the dark inclusions really are remnants of the basic members of the alkali-calcic suite, as Eskola assumes (15 pp. 64—68). They have of course recrystallized under the influence of the granite.

A foliated breccia, which to some extent resembles the above-mentioned gneissose granites, occurs on the SW. shore of Gubbholm island 600 m. NE. of Flisholm. However, in this case the inclusions probably are fragments of the supracrustal country rock, as some fragments have a better preserved nucleus surrounded by a reaction rim.

The aplite dikes represent the youngest rock belonging to the alkali-calcic suite. A fact worthy of notice is that in contrast to the dikes belonging to the migmatitic granite alkali-calcic pegmatites are very rare. Many of them are furthermore basic, gabbro pegmatites. One gneissose granite pegmatite has been found on an islet E. of Holma. This pegmatite is cut by an aplite belonging to the same suite. A probable explanation of this lack of coarse-grained dikes is, that the alkali-calcic magma has intruded at a rather high level of the mountain chain. The pressure has there been so low that a boiling has taken place at an early stage of the crystallization of the differentiation suite, giving rise to the gabbro pegmatites. In the final stage the rocks were so brittle that the volatiles had a possibility to escape rather quickly along the joints of the breccias or the shear surfaces of the banded rocks. The acid dikes therefore became fine-grained aplites (12 p. 55).

FOLDING.

The orogenic movements, which have caused principally foliation and brecciation in the igneous rocks, have in the supracrustal rocks moreover brought about folding. We must assume that these rocks became foliated during the prim-orogenic phase, although this process of course continued later.

The folds from this phase have axes with an almost east-westerly strike, consequently parallel with the general strike of the Svecofennides. The pitch of the axes is commonly gentle, either westerly as in the N. parts or easterly as on the Gullkronafjärd. The westerly pitch in the N. part may perhaps be connected with the axial depression of Åland (74). Folds with gently pitching or nearly horizontal axes dominate the structural style of many regions of S. Finland (25, 26, 39, 43, 44). The variations of the axial pitch depend on alternating axial depressions and culminations, where later movements have not turned the axes. In a small rocky islet between the SW. cape of Jermo peninsula and Sorpo this phenomenon appears very strikingly. The axes of two small folds lying only some metres from each other pitch in opposite directions. It is, however, rather difficult to get a correct idea of this old folding on a great scale, especially of the primary directions of the axes, because later movements in connection with the granitization have deformed and turned the folds dating from the prim-orogenic phase.

The well preserved parts of the supracrustal formation, which occur as fragments in the migmatite, give us, however, to a certain extent a conception of the folding style. The folds are commonly sinuous or semicircular, for instance on the SW. shore of the island of Hirsalö NE. of Mielisholm. An amphibolite layer in the E. part of Jermo has been so brittle, that radial tension cracks have been opened during the folding and filled with quartz (Fig. 3 Pl. I). Similar semicircular folds of larger dimensions occur *e. g.* in the cape Ölmoss udde SE. of Storö, in the islet Västerharu W. of Helsingholm and in the island Tammo. In the layers of NW. and SW. Sorpo and of the central part of Attu the folding has stopped half-way, forming only monoclines. It is worthy of notice that in the four last-mentioned cases, where the radius of the folds is many hundreds of metres, the folded rocks are rigid infracrustal rocks, whereas the folds in the relatively thin-bedded supracrustal rocks are of smaller dimensions. In spite of its probably supracrustal origin (p. 12) the gneissose granite of SW. Sorpo was nevertheless during the folding recrystallized and as rigid as an igneous rock.

By the folding the different layers are sliding over each other, causing a rotation. A beautiful example of this phenomenon is seen in the islet of Rundharu, 3 km. S. of Högland, where quartz- and quartz-garnet-hornblende clods have rotated in the leptite (Fig. 4 Pl. I). This fact proves that these clods are older than the folding and probably are metamorphic quartz- and calcite-filled cavities, possibly of volcanic origin. These clods show that there may occur quartz-filled veins and lenses of very different age and that we must examine everyone of them individually.

The folds are in some places V-shaped, in contrast to those of semicircular form. Fig. 5 Pl. I shows such folds in the NW. shore of Attu. This folding seems to be merely due to shear rather than to bending, and may be a result of later deformation of the older folds. This V-shaped, nearly isoclinal type is probably common in the supracrustal formation, of which more or less parallel layers often are characteristic.

This old folding is in many places rather well preserved, even in the migmatitic granite and the veined gneisses. Some anticlines and synclines in the island of Stortervo may date from this phase, as perhaps also the folds in the central part of the island of Mielisholm. It is of course impossible to determine with certainty the age of every separate fold, but the different characteristics of the folds such as the style, the plasticity of the rocks, the direction of the axis give us some idea of their age.

INTRA-OROGENIC PHASE.

A phase poor in movements began after the above described phase of intrusion and folding. This may partly be due to the fact that the magma had crystallized. The alkali-calcic igneous rocks formed a rigid skeleton in the mountain chain. The supracrustal rocks had in addition become harder through the metamorphism during the prim-orogenic phase. This explains why a phase of fracture followed a phase of folding. The intra-orogenic phase is as to age equivalent to the hiatus between the Svionian and the Bothnian formation according to Sederholm (55, 56, 57, 59). This quiet phase seems, however, to be an interruption of the orogeny, not a geologic period between two orogenies. Owing to the absence of movements it is very difficult to arrive at a conception of its length. But on the basis of its extension in the Svecofennides it cannot have been quite an unimportant interval in the orogeny (17, 28, 29, 35, 36, 39, 55, 56, 57, 58, 59, 71, 72). There may exist a certain level of fracture in the mountain chain and it does not need to be simultaneous in all areas; at the same time folding may have taken place both above and below this level.

The amphibolite dikes are the obvious proofs of this brittle phase between the two main deformation phases. They cut the alkali-calcic rocks rectilinearly or angularly and sometimes contain fragments of the country rock. The migmatitic granite has, on the other hand, granitized and folded the dikes (Fig. 6 Pl. I). These dikes occur more frequently in the brittle igneous rocks than in the supracrustal rocks, in which open joints or faults do not appear quite so easily as in the first-mentioned ones.

Sederholm assumed that these dikes are genetically connected with a volcanic formation, the Bothnian supracrustal formation (55, 56, 57, 58, 59), but Eskola's opinion that these dikes are hypabyssal (15 p. 15) seems more probable.

SER-OROGENIC PHASE.

GRANITIZATION STRUCTURES.

The following phase of the orogeny is characterized by different kinds of migmatites and more homogeneous migmatitic granites, and by structures indicating a high plasticity of the rocks. If we want to understand the evolution of the geologic structures during this phase, we must in some degree examine the origin of the migmatitic granites. The most important question from the structural point of view is the mechanism of the »intrusion» and the space problem.

Although the migmatitic granite is the dominating rock in the greatest part of the mapped area, it is rather rarely quite homogeneous and free from more or less granitized inclusions of other rocks. Fig. 7 Pl. II shows a supracrustal gneiss in which the microcline granite or migmatitic granite occurs as veins and irregular patches. The layers of the gneiss continue behind the granite or pegmatite veins without any deflection. Obviously no remarkable increase of volume has taken place as the granite originated and we must assume in this case a granitization in place. The mafic constituents have recrystallized as garnet aggregates. A final product of this granitization is seen in Fig. 8 Pl. II. The granite is homogeneous, with the exception of the garnet content. This mineral occurs in layers parallel with the general strike of the gneiss inclusions in the vicinity. Because all transitions between the granite and the veined gneiss occur in the neighbourhood, it appears to be impossible to explain this granite otherwise than as a completely granitized gneiss, in which a primary or secondary difference in chemical composition remains in alternation of the garnet-bearing and garnet-free layers. The distribution of garnet may of course be due to a metamorphic differentiation during the earlier stages of the regional metamorphism, when the primary supracrustal rock was transformed into a schist and later into a veined gneiss, or it may be due to a primary layering of the sediment.

A still more beautiful case of granitization in place is seen in Fig. 9 Pl. II. This example is from the island of Nämanland, about 15 km. S. of the map area, but it is worth mentioning here. A dike of gneissose granite cuts a gneissose granite, an amphibolite, and penetrates almost 30 cm. into a pegmatitic migmatitic granite, which again granitizes the dike. It seems quite obvious that the younger pegmatitic granite has not been able to intrude as a magma without breaking the dike along the contact against the amphibolite. A similar phenomenon is seen on the W. shore of Sopisklobb 100 m. SE. of the SE. cape of Kasnäs.

Another example of granitization in place occurs *i. a.* in the island of Lamskär, about 3 km. W. of Söderö, where microcline porphyroblasts have formed in the migmatitic granite and grown together into irregular pegmatite lenses or patches. The origin of the microcline porphyroblasts in gneissose granites and diorites of the S. part of the area has been described in an earlier paper (11). It is there closely connected with crushing and movements. A similar explanation is perhaps true in many other cases where porphyritic granites have originated.

In the well preserved zone Attu—Sorpo—Trollö the granitization or its cause, the regional metamorphism, has found an expression in a metamorphic differentiation. The first stage of this phenomenon consists in a recrystallization. The grains grow in size and the felsic and mafic minerals separate from each other. The rather brittle infracrustal rocks have yielded with feather fractures to the movements and the recrystallizing felsic constituents have filled the opened joints. These pegmatites have sometimes amphibole nuclei, as they occur in basic rocks, for instance in the gabbro of the central part of Attu (Fig. 10 Pl. II), and in the amphibolite of the island of Norrland W. of Högland. This fact as well as the ilmenite content of some pegmatite clods and dikes in the gabbros, which are rich in Ti, proves furthermore that at least a part of the material has been derived from the country rock.

The above-mentioned examples are fairly conclusive proofs of a metasomatic granitization in place (2, 10, 11, 28, 29, 30, 76). Many other features point to this mode of origin, such as the well preserved older structures of the more or less granitized fragments of the primary rocks. The greatest problem is in what degree a melting process has taken place in connection with the granitization. Many pegmatite dikes in the brittle country rocks seem to be products of such a melting, for instance the dikes in the breccias of the islands of Flisholm and Hummelholm, where pegmatites belonging to the migmatitic granite cut rectilinearly through the fragments of the older breccia (Fig. 11 Pl. II), a fact showing obviously that the older breccia has been quite healed and brittle during this phase of the orogeny. Sederholm has described a similar phenomenon from the Pellinge region, where an amphibolite dike cuts through fragments of a breccia (56 Fig. 55).

The difference in the appearance of the pegmatites in different country rocks is conspicuous. They are straight and of uniform breadth in the brittle alkali-calcic igneous rocks, but of an irregular shape in the soft supracrustal rocks (Figs. 11 and 12 Pl. II). We are often on the basis of the shape of the pegmatites able to determine, whether the country rock is supracrustal or infracrustal. Properly speaking, the pegmatites have no structure of their own, they adapt themselves to the structure and the plasticity of the country rocks.

During the process of granitization the rocks in general were more plastic than before or after. The structures of the granitized areas are often very complicated, because the plasticity of the different rocks has been unequal. This depends to a great extent on the variable degree of granitization. Acid rocks, for instance, are commonly more easily granitized than basic ones. Fig. 15 Pl. III shows a broken porphyrite layer, into which the somewhat granitized leptite has intruded forming a boudinage. The porphyrite s megascopically quite unaffected by granitization. The intrusion has in this case certainly taken place in crystalline state, because the thin layers of leptite are continuing in the »intrusive apophyse or dike». Some pegmatitic material has crystallized in the pressure minima, which have arisen in the most sheltered places between the fragments. This instance affords an evident proof that an »intrusion» is the result of a difference in plasticity and not an immediate result of different states of aggregation, and that we are not justified in putting a sign of equality between the words »intrusive» and »magmatic». Especially if the leptite were not banded but homogeneous its appearance would be quite »magmatic». A still more extreme instance of this phenomenon is conceivable. It is very plausible that a crystalline limestone under high pressure could intrude in the joints of a glassy lava, or in other words that a solid rock can be intrusive in a liquid rock. Hence a typical intrusive contact is no proof of a magmatic origin of the intersecting rock. Wegmann has expressed similar thoughts (72 p. 58) and Metzger has described a phenomenon in some degree similar (39 Fig. 1 Pl. XII and p. 82).

Fig. 15 Pl. III shows also a typical plastic folding and the influence of a brittle fragment on the structure of a plastic rock. A brittle fragment causes during the movements local folds in the surrounding plastic material and the folding axes may there have almost any direction.

The basic and ultrabasic inclusions in the granitized rocks have not, however, in every case been brittle. Fig. 13 Pl. III shows a very plastic ultrabasic inclusion in a veined gneiss. There arises of course the question, whether all basic fragments are true inclusions of igneous rocks. They may, as perhaps in this case, be skarn rocks, which have obtained the present mineral composition only after the folding. But we must take into consideration the possibility that ultrabasic rocks under certain conditions may be as plastic as granites.

I have here used the terms »plastic deformation or folding» instead of »flowage or flow (Fliessfaltung)», because »flow» is too closely connected with the liquid state of aggregation. There will scarcely arise any misunderstanding, if we speak of the »flow» of a limestone, but if we speak about granites, the reader may very easily get the conception, that the granite has been a liquid magma. The plastic structures, however, are rather a proof of the solid state of aggregation than of the liquid one and they depend on the plasticity in the same way as the intrusive contacts. We must in other words distinguish between the structural phenomenon, the plasticity, and the physico-chemical one, the state of aggregation.

There are furthermore some differences between the »flow» of a liquid and of a plastic solid. In contrast to the flow of a common liquid the movements of a plastic solid are so slow, that neither do turbulence motions occur nor does the law of inertia have any influence. The solids are furthermore built with a great number of anisotropic grains which have their own crystallographic sliding planes or surfaces orientated in different directions. All transitions between these two types of movements occur of course, but the pure types differ from each other qualitatively.

The rocks have sometimes been neither plastic enough to yield with plastic deformation nor brittle enough to brecciate. In these cases shearing often has taken place. Fig. 14 Pl. III shows an amphibolite layer in an almost entirely granitized veined gneiss. There are in the basic layer numerous subparallel shear planes, along which minute movements have taken place, causing small repeated folds and an indistinct foliation nearly perpendicular to the layer. Another beautiful example of shear folding occurs on the W. shore of Holma. Its style resembles that of the plastic folding, but the straightness and the parallelism of the axes of the small folds point to shearing.

Another structure connected with difference in plasticity is the boudin-

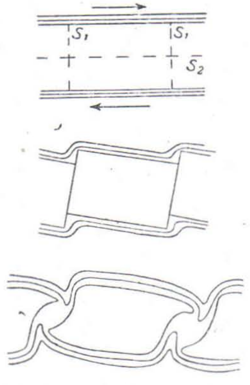

Fig. 6. Three sketches showing the origin of a boudinage by a couple. The arrows show the direction of the forces. The shear surface S_1 at right angles to the strike forms in the brittle layer, whereas the shear surface S_2 parallel with the strike and the forces forms in the plastic layer.

age or the sausage structure. The observations in the area described here give a conception of the origin of this structure. The porphyrite layer in Fig. 15 Pl. III has been so brittle that the shape of the fragments is quite unaffected by the movements of the surrounding leptite. Fig. 16 Pl. III shows a boudinage, where the fragments have the typical form and where the small boudin has rotated. Fig. 17 Pl. III shows again an initial stage of the evolution of this structure. Joints have formed almost at right angles to the strike of the layers and the fragments of the brittle layer have rotated (Fig. 6). The surrounding ductile layers have intruded in the opened joints and dragged the corners of the more brittle fragments with it, causing the sausage form. The greater part of the boudinages within the mapped area show signs of a rotational strain; only in narrow layers no proofs of rotation are seen, probably depending on the fact that short and broad fragments rotate much more easily than long and narrow ones. A couple causes two sets of shear surfaces in the rock (Fig. 6). One of them is parallel with the couple, the other one is perpendicular to this but it rotates during the deformation process (77 Fig. 4). The first mentioned set forms more easily in ductile rocks causing schistosity, but if the layer is brittle enough the later one forms, because the shear joints across the layer in general are shorter than the joints parallel with the layer.

The older explanation of the boudinage structure is as follows: a stress at right angles to the brittle layer causes a nonrotational strain (51 p. 656). The layers are then in general drawn out, but the brittle rocks cannot yield otherwise than by fracture (6, 73). We may, however, in this case expect that shear joints at an angle of 45° with the strike of the layer and the direction of the lateral stress should form, as in Fig. 18 Pl. III. This structure is not identical with the true boudinage and it must be distinguished from this. The explanation of the origin of the boudinage suggested above is of course not the only possible one; boudinages and boudinage-like structures may originate in different ways and the connection between the rotational strain and the boudinages may be only a coincidence. Many boudinages reproduced in the literature show, however, signs of a rotational strain (2 Fig. 2, 3 Fig. 39 p. 309, 6 Fig. 1 Pl. III, 10 Figs. 31 and 32, 15 Fig. 51, 27 Figs. 2, 3, 9 and 14, 51 Figs. 3 and 4, 73 Figs. 1 and 2 Pl. XXVIII). Also Quirke speaks about »boudin-like» structures due to drag-folding» (51 Fig. 7).

MOVEMENTS IN S.PARGAS.

The pitch of the axes in the basic zone Attu—Sorpo—Heisala varies greatly. On the E. shore of Attu the pitch is as much as 50°W., being about 20°W. in the middle part of Attu. On a line from the NW. cape of Attu in SE-ly direction to the S. shore the pitch changes suddenly to 20°E. and W. of this line the axis has a pitch between 10°E. and 30°E. in an area, which partly extends to the border of the map. At the SW. end of this area the axial pitch gradually changes and becomes W-ly. There seems to be a close connection between the migmatitic granite and the pitch of the axes. This granite is exposed in two small islets between Lökholm and Kuggö in the SW. culmination as well as in the depression of central Attu and in the Pemarfjärd under the W-ly dipping layers on the E. shore of Attu.

The simplest explanation is shown in Fig. 7. The axis has primarily been horizontal or gently sloping. The surrounding areas have become plastic through granitization, whereas this zone of basic igneous rocks remained rather brittle. The migmatitic granite was rising and the broken parts of this igneous zone were sinking depending on the difference in specific gravity. Both these movements took place simultaneously and in causal connection with each other. The granite turned upwards the E. end and the W. part of the Attu—Sorpo—Heisala zone, causing the axial culminations of the E. shore of Attu and of Lökholm—Kuggö. The zone of igneous rocks was then bent until it broke along the line, which crosses Attu in a NW—SE-ly direction, and the granite got possibilities to intrude in this fracture and between the layers in the central part of Attu. The pegmatite-filled feather joints in the igneous rocks of Attu, Sorpo and Trollö show that the older folds, especially the monocline of the central part of Attu, were further developed during this phase (Fig. 10 Pl. II). The northern and western sides were moving towards the west or south respectively. The movements have used older structures as much as possible, instead of producing quite new structures. The fault along lake Österviken in

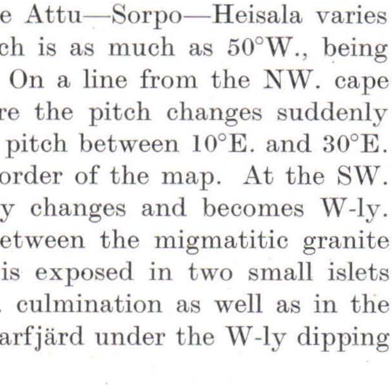

Fig. 7. Three sections striking almost ENE. showing the evolution of the zone of alkali-calcic igneous rocks through the islands of Attu, Sorpo, Trollö, and Lökholm. The lines represent the axial pitch in the well preserved parts. The sinuous dashes show the granitization and the migmatitic granite. The arrows show the movements. The granite outcrops in the undermost section from E. to W.: the Pemarfjärd, Central Attu and the islets between Kuggö and Lökholm. The length of the section is 17 km.

the E. part of Attu has probably originated during this phase. The N. side seems to be the upthrow side, as the axial pitch is steeper there. This most likely depends on the fact that the migmatitic granite has risen more N. than S. of the fault, where the contact of the granite seems to turn to SE. The low degree of metamorphism in the porphyrite on the E. shore of Attu also points in this direction.

Some small folds, which are connected with pegmatites, have primary steep or vertical axes; they are produced by a couple. In these cases the N. side has moved towards the E. They are seemingly not simultaneous with the events mentioned above, although they belong to the same phase.

GULLKRONA DOME.

On the Gullkronafjärd the layers form a large dome. The axes of a great part of the minor folds are subparallel with the axis of the dome. The pitch is generally rather gentle eastwards but there occur, however, vertical axes as well as horizontal ones. A closer examination of the folds gives a clue to the puzzling structure of this dome.

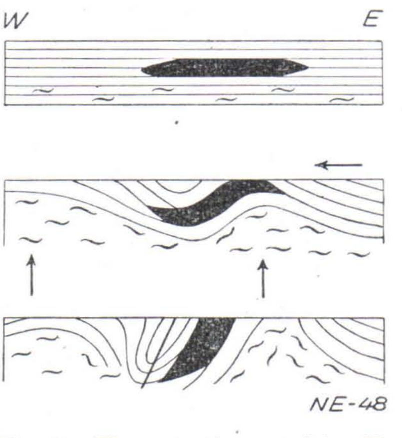

Fig. 8. Three sections striking E. showing the evolution of the axial depression and culmination along the W. shore of Kimito island between the Gullkrona dome in the W. and the leptite zone in the E. The lines represent the axial pitch of the supracrustal rocks, the black area the alkali-calcic rocks and the sinuous dashes the migmatitic granite. The arrows show the direction of the movements. The length of the sections is 14 km.

The E. boundary of the dome follows an almost N—S-ly line, which begins E. of Högland and ends SE. of Hamnholm (Fig. 25 Pl. V and Fig. 30 Pl. VIII). This line represents an isoclinal axial depression. E. of this line the layers dip W. The folds of the islands of Högland and Furuskär 1 km. E. of Högland prove, that there really exists a depression, as the almost parallel layers of these islands in the N. parts turn in opposite directions away from each other. This depression ends in the sound between Hamnholm and Norrö, as the layers S. of this point are dipping E.

The W. shore of Kimito island from Ölmoss S. of Storö to Purunpää represents a corresponding axial culmination. This consists of migmatitic granite, whereas leptites and alkali-calcic igneous rocks dominate in the depressions W. and E. of it. Minor folds with almost horizontal axes striking N. and consequently subparallel with the abovementioned depression and culmination

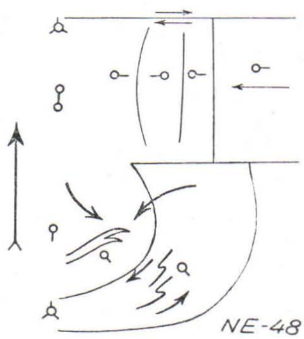

Fig. 9. Sketch-map showing the movements around the Gullkronafjärd. The leptite zone in the upper right-hand corner has moved W-wards, causing the axial culmination and depression and minor cross-folds in front of itself. The Gullkrona dome on the left-hand side has bulged out in SE-ly direction, causing the large curve in the SE. The granitized inner part of this curved zone contains folds due to lateral compression, the middle part contains drag-folds, whereas the folds of the outer part are smoothed out, due to stretching. The N. limit of the Gullkrona dome is represented by a probable shear zone as well as the continuation of the S. limit of the leptite zone. The axial signs along the W. side of the figure show the pseudo-culmination of the cross-axes. Scale 1 : 400 000.

occur in many islands of the Gullkronafjärd W. of the depression. This cross-folding is very well developed in the islands E. Dömarskär 2.5 km. W. and Västerharu 0.7 km. W. of Helsingholm. The dips of the layers are there oscillating between vertical and gentle E-wards sloping, sometimes horizontal directions. On the NW. shore of the small island of Ljusskär, 700 m. N. of Skogsskär, a minute upthrust directed against W. has been observed in causal connection with a cross-fold.

The culmination and the depression, or rather the cross-anticline and the cross-syncline, along the W. shore of Kimito seem to be results of two movements (Figs. 8 and 10). The migmatite has risen upwards and the leptite zone of Kimito has moved W-wards. The last-mentioned movement has caused the cross-folding with the almost vertical axial plane striking N. Because the axis necessarily lies in the axial plane as well as in the foliation or bedding plane, the cross-axes form a pseudo-culmination on the Gullkronafjärd as a consequence of the dome-shape of the layers (Figs. 9 and 10). The cross-axes are steep or vertical in the

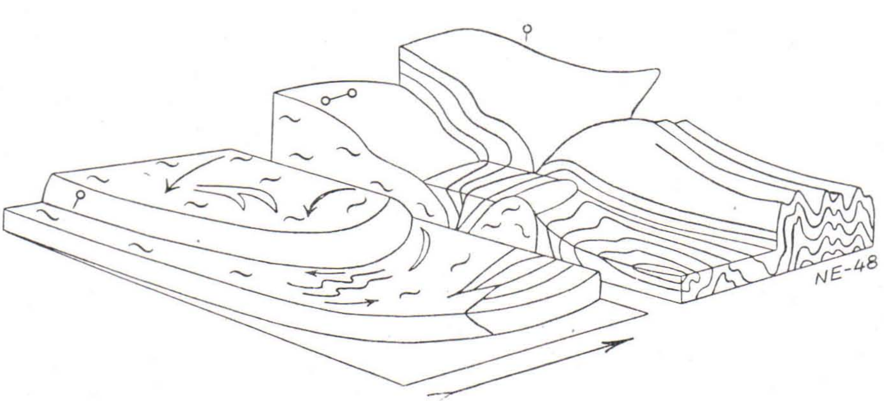

Fig. 10. Block-stereogram of the same area as in Fig. 9.

N. and S. parts, where the layers are steep or vertical, but horizontal in the middle part, where the layers dip E-wards. The cross-folds occur generally in migmatites or in connection with pegmatites. Similar cross-folds connected with the granitization have been described by Hietanen (25 p. 1066, 26 p. 70). Neuvonen and Matisto have also described small folds with steep axes almost at right angles to the larger folds, but the relation between these folds and the granitization is unexplained (43 p. 80). The lineation of better preserved schists in the Svecofennidic area seems often to be steep (43, 62 p. 11).

The N. margin of the Gullkrona dome is straight as far as to the sharp NE. corner in the island of Högland, whereas the S. part forms a large curve. The axes are there striking SE. and especially the rocks of Holma and Söderö islands are strongly folded. Fig. 19 Pl. IV shows the typical folding of the area around these islands. The folds are S-formed; the NW. sides have moved towards SW. Very few exceptions to this rule have been found. These folds seem to be primary folds transformed into drag-folds (33 Fig. 139) or »Gleitbretterfalten» (52 Fig. 23) by a couple.

In the outer part of this curve, *e. g.* in the islands of Långholm and Stor Ängskär S. and SE. of Holma and in the E. part of Kasnäs, the layers are in general straight, because this outer part is stretched by the bending and the small folds are then smoothed out. The compression in the inner parts of the curve has caused a folding with axes striking SE. for instance in the area around Benskär (Figs. 9 and 10). The above-mentioned drag-folds occur in the central zone of the curve, where neither elongation nor shortening has taken place.

The NW. strike of the layers in the area S. and SW. of the sound between Hamnholm and Norrö seems to depend on a drag, as the N. part has moved W-wards. The depression and the culmination N. of this sound represent a remarkable shortening in E—W-ly direction. The drag in the area S. of this sound proves movements along a line which is a continuation of the S. boundary of the leptite zone of Kimito (Figs. 9 and 10 and Fig. 25 Pl. V).

The cross-folds (Fig. 11 and Fig. 19 Pl. IV) as well as the boudinages (Fig. 16 Pl. III) show that the movements of the N. and the S. parts of the area are reflections of each other. This fact points to the central part having slid W-wards (Fig. 9).

The second movement of crucial importance to the development of the domes is the rising of the migmatitic granite. Properly speaking, this movement may be the primary one. It is probably a result of the difference in the specific gravity of the rocks, although the main components of the migmatitic granite and the leptite are the same: quartz and feldspar. But there have perhaps been heavier rocks, such as gabbros, overlying the leptites (45 p. 9). Another cause is the probable increase of the volume by the granitization (2 p. 343, 11). Although this increase may be rather small in percentage, its absolute rate may, however, be noteworthy.

The dome of the Gullkronafjärd has thus formed in the following way (Figs. 8, 9 and 10). The granitization made the lower parts of the mountain chain plastic and specifically lighter than the rocks above. The mobile migmatitic granite rose and expanded to a large dome in the Gullkronafjärd and a smaller one along the W. shore of Kimito island. The hard zone of alkali-calcic igneous rocks of Attu—Sorpo—Trollö prevented the granite from expanding in a N-ly direction and produced then the sharp fold of Högland overturned in E-ly direction. In contrast hereto the more plastic rocks in the S. part of the area yielded forming the large curve. The leptite zone slid W-wards over the plastic granite and caused the cross-folding. Straight in the front of the moving leptite zone along the W. shore of Kimito an anticline and a syncline were formed. Fig. 9 shows the movements in the area as the leptite belt was sliding W-wards, and it resembles very much a figure »of stresses produced by a punch pressed against an elastic mass» (77 Fig. 7). Two shear planes represent the continuation of the N. and S. boundaries of the leptite zone. The N. one between Högland and Tammo, being almost parallel with the strike is not as evident as the S. one between Hamnholm and Norrö, which has turned the strikes about 45° from N. to NW.

DIKES OF MIGMATITIC GRANITE.

The plasticity of the granite descreased in the final stage of the migmatite or ser-orogenic phase. A veined gneiss on the E. shore of Sorpo had during the folding gradually become so brittle that the crest part of the fold was faulted along a surface almost parallel with the general strike (Fig. 11). The migmatitic granite dikes are another instance of this hardening (Fig. 20 Pl. IV). They are in general straight and vertical or steep, but two nearly horizontal dikes were found. Dark bands, parallel with the contacts, give them a schistose or gneissose appearance. The contacts are in some degree blended. Fig. 21 Pl. IV gives a clue to the origin of these dikes. A banded gneiss is cut by shear joints, which are filled by pegmatitic material. A thin plate of gneiss in the middle pegmatite dike is in the E. end granitized into a nebulitic band. The pegmatite has in this way got a foliated structure parallel with the walls. This explanation of the origin of the banded structure of these dikes seems to be correct, because nebulitic rotated or elongated fragments of the country rocks have been observed in other cases too. The migmatitic dikes are hence granitized joint or mylonite zones. The dikes cut the migmatitic granite, but they are often cut by pegmatites (Fig. 20 Pl. IV). Hence they lie as to the age between the migmatitic granite and the latest pegmatite generation. Sederholm has described a dike, which greatly resembles these dikes, but he thinks that it belongs to the gneissose granite (57 Fig. 8 and p. 25).

PEGMATITES.

The pegmatites of the Gullkrona area are of several kinds. The oldest generation belongs to the alkali-calcic suite. The second generation appears partly as veins in the gneisses, partly as clods, lenses, or dikes of very different shapes. They are connected with the migmatitic granite and have formed during the whole of the ser-orogenic phase, being not only the forerunners but also an afterbirth of the granitization.

On the W. shore of the island of Dirgerholm between Heisala and Attu two pegmatites cut an older pegmatite. At least two generations of red pigmented bands, which represent healed joints, occur, but their age relations to the pegmatites are not quite clear. Some of the red bands are possibly older than the younger pegmatite generation, but in some cases the pigment may have formed only in the gneissose granite, because the pegmatites are poor in bivalent iron, which can be oxidated. Stigzelius has described similar bands in the Viljakkala area (63 p. 29).

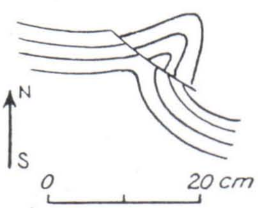

Fig. 11.

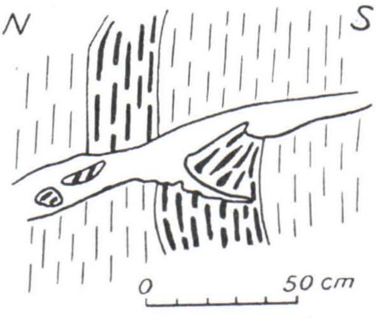

Fig. 12.

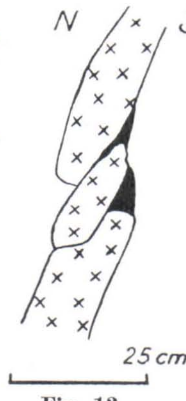

Fig. 13.

Fig. 11. Faulted crest part of a small fold with axis pitching 50°NE. The N. part has moved some cm. towards E. Veined gneiss, E. shore, Sorpo island, Pargas parish. Sketch after photo.

Fig. 12. Pegmatite filling a minute thrust fault in a gneissose granite (thin dashes). The broken amphibolite band (thick dashes) shows that the hanging block first moved towards S. and later slipped towards N., probably using the pegmatite material (white) as a lubricant. W. shore, Sorpo island, Pargas parish. Sketch after photo.

Fig. 13. Broken pegmatite (crosses) in a hornblende gabbro. The pressure minima, which originated when the pegmatite fragments moved downwards, have been filled with biotite (black). About 100 m. S. of Yxäng landing-stage, W. shore, Attu island, Pargas parish. Sketch after photo.

Movements have probably often taken place in connection with the intrusion of the pegmatites, but it is generally difficult to trace them. Some instances may, however, be mentioned. A pegmatite on the W. shore of Sorpo has intruded along a low angle thrust fault (Fig. 12). The upper block has first moved upwards and later slid down N-wards, most likely using the pegmatite as a lubricant. An instance of a faulting somewhat younger than a pegmatite is seen on the W. shore of Attu about 100 m. S. of the landing-stage at Yxäng (Fig. 13). The fault in this case is of a high angle and the pegmatite is broken in sausage-shaped parts, which have to some extent slid over each other. The pegmatite in Fig. 22 Pl. IV is broken into sharp-edged fragments, whereas the surrounding leptite is entirely healed. The primarily unbroken pegmatite is in this manner elongated to a string of pearls. The age of this pegmatite has, however, not been determined.

The youngest pegmatites represent to some extent the end of the plastic phase as well as the end of the granitization. The structures of the pegmatites are therefore miscellaneous and point to conditions varying from entirely plastic to quite brittle.

POST-OROGENIC PHASE.

INTRUSION OF THE DIABASE (TRAP) DIKES.

Only five Pre-Jotnian diabase dikes have been found in the mapped area. Three of them have a nearly N-ly strike and a breadth between 50 and 75 cm. The dike in the central part of Stortervo striking 60° can be followed about 120 m. and its maximal breadth is 12 cm. The small dike of Högland dips about 10°N. in contrast to the first mentioned steep or vertical dikes. It is only a few cm. in breadth and about 5 m. in length. In spite of the deficiency of diabase dikes the above-mentioned observations seem to point to an E—W-ly tension, which has opened joints striking N. during the intrusion of these dikes. This does not mean that the joints have originated at this time. Farther NW. of this area the diabase dikes strike generally NE. or NNE. (20 pp. 62—64, 23 p. 30, 46). The tension has there had a NW—SE-ly direction. Our knowledge of the diabase dikes is, however, too imperfect to justify a comparison with the diabase dikes of SE. Sweden, striking N. and NE. (1 Fig. 12).

Some faults cutting these dikes have been observed. The dike of Heisala is faulted along a surface subparallel with the foliation of the country rock; the S. part has moved E-wards. The dike of Högland is cut by vertical faults striking E. The S. part has in this case sunk a few cm. The only conclusion we can draw from these facts is that the movements are younger than the diabase dikes.

The faults which cut the diabase dike in the central part of Stortervo

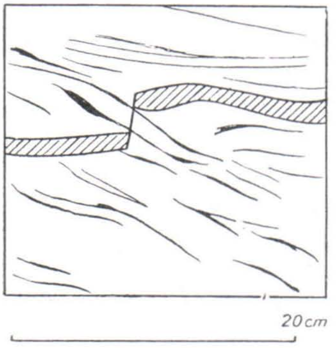

Fig. 14. Faulted diabase dike (shaded) in a highly granitized veined gneiss. Only a fine joint shows the fault in the veined gneiss; the biotite streaks of the gneiss continue over the fault and are moreover in some cases deflected around the ends of the younger diabase. Central part of Stortervo island, Pargas parish. Sketch after photo.

are much more problematic. The dike cuts the veined gneiss in general at an angle of 10—20°. Many small faults striking 170° cut the dike again. The W. side of every fault has moved S-wards. Fig. 14 shows one of these faults. A scarcely observable joint is the only sign of the fault in the veined gneiss, but on the contrary streaks of biotite continue over the joint unaffected by the fault. Other streaks seem again to be deflected around the one end of the diabase dike, suggesting an influence of the dike on the structure of the country rock. The dike is younger than the country rock; it has chilled contacts in the broad middle part. The veined gneiss seems on the other hand to have crystallized or recrystallized after the intrusion of the dike. The dike shows, however, no signs of a recrystallization. The possibility that the diabase has intruded in an opened angular joint does not explain the lack of a fault in the gneiss. The slip would in this case equal the breadth of the dike but such a fault could not even be observed in the gneiss. It seems for the present more likely that a recrystallization has taken place in the veined gneiss after the intrusion of the dike, but the problem must be considered unsolved.

Sederholm has published sketch maps of folded and faulted diabase dikes too (58 Figs. 38 and 40). The structure of the country rocks is not seen on his figures, but probably it is quite healed. The earlier mentioned phenomenon described by Metzger, where an older diorite seems younger than a younger pegmatite, is to some extent similar to the example described here (39 Fig. 1 Pl. XII and p. 82).

INTRUSION OF THE ORTHOCLASE-BEARING GRANITES.

The orthoclase-bearing granites are younger than the country rocks, which are gneissose granites. Their appearance and their petrographic characteristics point to a connection with the post-orogenic granites of the Svecofennidic territory, the granites of Sederholm's third and fourth group. The relation between the granites described here and the diabase dikes is not clear in the Gullkrona area.

Also the age relations between the granites belonging to the third and the fourth group seems obscure. Sederholm remarked in 1924 (54) that the granites of the third group in the archipelago of SW. Finland (the granites of Sottunga, Lemland and Åva) geologically belong to the fourth group (the rapakivi group) and Wahl has recently expressed similar thoughts (70). Sederholm, however, later retained his older division into four groups principally on the basis of petrographic differences and of the relations to the diabase dikes (58, 59).

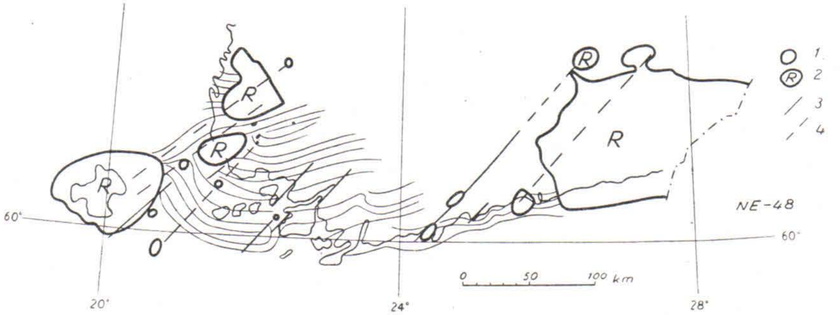

Fig. 15. Post-orogenic granites and some morphologic joints striking NE. in S. Finland. 1 granites belonging to Sederholm's third group, 2 the large rapakivi granites (Sederholm's fourth group), 3 some remarkable morphologic joints, and 4 lines connecting the young granites together. The curved lines show the strike of the layers. The map is compiled from the newer published and some unpublished maps of the area in question, excluding entirely the old maps of the Geological Survey, and from Sederholm's papers 53 and 54. The joints are predominantly from (60).

If we examine the positions of the post-orogenic granites of S. Finland, we find that they lie on lines striking almost NE. (Fig. 15). They are moreover often connected with joints striking NE., *e. g.* the granites of Bodom and Obbnäs (31 p. 12, 66 p. 189). The dike of Falkö strikes 60° and the granite of Tammo lies close to the joints of Pemarfjärd striking NE. (Fig. 28 Pl. VII). The diabase dike of Föglö, which is connected with the rapakivi granite of Åland also strikes NE. (58). Also Hausen has assumed, that the rapakivi granites are connected with deep joints (22 pp. 9—11). The line Åland—Åva—Vehmaa coincides also with a sharp fold or an angle of the rock layers (Fig. 15). All these facts point to a causal relation between the intrusion of the post-orogenic granites and the opening of the joints striking NE. or in other words with a NW-SE-ly tension. Hence the tension seems to have turned about 45° from the W—E-ly direction to the NW—SE-ly direction during the interval between the intrusion of the diabase (trap) dikes and the intrusion of the post-orogenic granites, perhaps already during the diabase intrusion.

FAULTS.

The origin of the faults is in general obscure, because they form in brittle rocks, wherefore the movements take place along certain surfaces contrary to the folding, which affects the whole rocks. The faults, whose age is determinable through the relation to certain rocks, were described earlier. I wish here to discuss the faults only as regards their relation to the two main erosion surfaces, the peneplain and the Glacial erosion surface. The peneplain seems to be of Sub-Cambrian age (14, 50, 66, 67), but it was probably rather well developed early in the Sub-Jotnian time (22, 24, 66, 67).

The faults, older than the peneplain, form the greatest group. Many faults of this group strike almost N. *e. g.* the long Pargas Port fault between Attu and Sorpo. This fault is older than the peneplain, the summits being nearly on the same level on both sides of the fault. By examining the N. and S. end of the Pargas Port fault we find that the folds are much broader on the W. side. The fold of Tammo is an anticline and consequently the block on the E. side has sunk at the S. end of the fault. A movement in the opposite direction must have taken place at the N. end, because the fold of SE. Stortervo is a syncline. These facts point to a rotatory movement, but faulting may also have taken place along the contact planes of the rock layers, which cross the fault. Many other similar faults occur, *e.g.* in the islands of Trollö, Kuggö and Hirsalö and on the W. and E. side of Stortervo. There are in all these cases no remarkable differences in height of the hill summits on the opposite sides of the faults. They seem consequently to be older than the peneplain.

The faults bordering the Gullkronafjärd and the Pemarfjärd are on the contrary younger than the peneplain (Fig. 28 Pl. VII). The Gullkronafjärd forms a basin or a »Graben», which ramifies in its E. end into two branches. This is a common feature of »Grabens» (8 Fig. 20). The N. branch, the Pemarfjärd, seems to be longer than the S. one. The Gullkrona basin has earlier been mentioned by Hausen (20, 22, 23, 24) and Brenner (5).

Some faults and mylonite breccias striking N. and probably connected with the origin of the Gullkrona basin are filled with calcite (SE. cape of Bockholm island SE. of Tammo) or quartz (the small skerries E. of the NE. cape of Attu).

The Gullkrona block seems to have sunk about 40 m. This value has been calculated on the basis of the summit levels of the Gullkronafjärd and of Kimito and of the percentage of the area over the contour line —40 m. on the nautical chart.

Around the Gullkronafjärd the morphologic joints form a system (Fig. 28 Pl. VII), which is nearly identical with a joint system produced by an experimental upwarping (Fig. 26 Pl. VI, drawing according to Fig. 18 in H. Cloos' paper 8). This striking resemblance points to a similar origin. In Fig. 27 Pl. VI three sections of the summit level along the dashed lines I—III in Fig. 28 Pl. VII are seen. The curves II and III show a remarkable upwarping compared with the curve I from the area E. of Kimito (15 p. 14). Farther E-wards the summit level rises again according to Tanner (66 Fig. 95). If these curves of the summit level represent the deformed peneplain, then this has formed a ridge in a nearly E—W-ly direction some km. N. of the S. shore of Kimito island. The crest of this ridge coincides with the continuation of the long axis of the Gullkrona basin. This fact is an additional proof of the theory that the basin is produced by a primary upwarping and a secondary sinking of the crest part.

The W. part of Kimito contains several long faults, in the field represented by narrows bays and channels. These faults are subparallel with the E. limit of the Gullkrona basin. The topographic section at almost right angles to these faults shows that the blocks between the faults have steep escarpments on their W. sides whereas the flat upper surfaces slope gently E-wards (Fig. 29 Pl. VII). These back slopes seem primarily to have formed a horizontal peneplain, which in connection with the origin of the Gullkrona basin broke into long ribs. These have sunk W-wards and simultaneously tilted in some degree. The step faults or »antitetische Schollentreppe» (7 Figs. 219 and 220) have formed in this way. Brenner has also thought a causal connection to exist between these faults and the origin of the Gullkrona basin (5 pp. 21—22) and De Geer has described a similar step faulting in Central Sweden (16 Figs. 3a and 5).

It is also interesting to compare the faults on the different sides of the Gullkrona basin with each other. The S. margin is nearly rectilinear, being at least in part parallel with the layers. The E. fault is also rectilinear and quite unaffected by the strike of the layers. The N. marginal fault seems on the other hand to be composed of several small faults along cross-joints and layer planes. The Pemarfjärd faults seem to be similar composite faults. Some blocks close to the N. marginal fault have obtained an inclined position, probably in connection with the origin of the Gullkrona basin. Högland is obviously the super-elevated corner of such a tilted block, as its top 39 m. above sea level is higher than the summits N. of the fault (Fig. 28 Pl. VII). The block Sorpo—Trollö—Lökholm is possibly also inclined against SW., as the islands become smaller in this direction and the highest summits of this block are close to the E. shore of Sorpo. The older fault line Pargas Port seems consequently to have been used anew in connection with the origin of the Gullkrona basin.

The Gullkrona basin is younger than the peneplain but older than the Pleistocene Ice Age. But the movements of the earth crust have continued during and after the Ice Age. The Glacial fault of Lambholm island E. of Stor Ängskär and the Postglacial faults of Linjen island E. of Storö are proof of these movements. They have been closer described in an earlier paper (13). Also De Geer thinks that the faulting in the Mälar valley of Central Sweden continues nowadays (16 p. 418).

JOINTS.

The joints have not been methodically studied, but some observations may be mentioned. Especially the age of the joints is very obscure. The minimum age of many joints is fixed by the material, which has filled them such as: pegmatite, granite, diabase, quartz, epidote, and zeolites. The age of the joints without filling material is commonly impossible to determine but some of them seem to be of recent time.

The sheet jointing has recently been studied by Hausen (19), and I wish to make only one addition to his results. Some nearly horizontal joints in migmatites and gneisses are almost at right angles to the folding axis and seem hence to be regular cross-joints (Fig. 23 Pl. IV).

The greatest part of the steep or vertical joints belongs to the following two types: joints parallel with the foliation or bedding plane and joints perpendicular to the folding axis, the cross-joints. Joints in other directions occur in general more irregularly and are more frequent in the slightly foliated granites. The faulting seems commonly to have used the cross-joints, but this may be illusionary, as faults along bedding or foliation planes are much more difficult to recognize.

The brittle alkali-calcic igneous rocks are often rather irregularly jointed, *e. g.* in the area around the islands of Storö, Falkö, Hummelholm and Flisholm. The morphologic joints of this area are rectilinear, but often oblique to the direction of the foliation (Fig. 28 Pl. VII). Fig. 24 Pl. IV shows a set of joints parallel with a morphologic joint in this area. It is remarkable that joints are much closer in the pegmatite dike than in the gabbro. This fact depends probably on a difference in brittleness.

CONCLUDING REMARKS.

PLASTICITY.

The difference in brittleness or plasticity of the different rocks is often mentioned in the foregoing pages and its importance as regards many structures is also discussed (intrusion, boudinage *i. a.*). Notwithstanding the lack of experimental facts some general conclusions can be drawn from these instances. The word »plasticity» means in the present paper the megascopically fractureless deformation of the rocks and is here used in a field-geological sense, regardless of the theoretical explanation. The plastic deformation of rocks is probably due to a combination of minute shearing, various deformations of the crystal lattice, solution and recrystallization etc.

Granitization has made the rocks, even the basic ones, more plastic (Fig. 6 Pl. I, Fig. 13 Pl. III). The basic rocks are, however, commonly more brittle than the acid ones (Fig. 15 Pl. III). Homogeneous igneous rocks are generally more brittle than bedded and foliated supracrustal rocks (Figs. 11 and 12 Pl. II). In other cases the acid rocks, again, are more brittle than the basic ones (Fig. 13, Fig. 24 Pl. IV). The joints are in these cases probably produced at a low temperature, because the joints in Fig. 24 Pl. IV are connected with a crushing zone in the clastosphere and in Fig. 13 with a solid pegmatite. Fig. 22 Pl. IV shows another instance, where the brittle rock probably is more acid than the ductile one but in this case the difference in coarseness may also have had an effect on the plasticity.

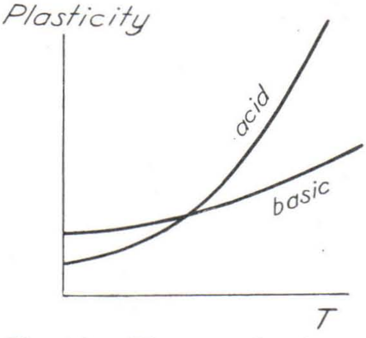

Fig. 16. Diagram showing a possible connection between the plasticity and the temperature of acid and basic rocks.

The diagram in Fig. 16 may give an explanation of the above-mentioned facts. If the plasticity of the basic and acid rocks varies unequally with the temperature, it is very possible that the curves of plasticity cut each other. Hence at low temperatures basic rocks may be more plastic than acid ones. Every geologist knows from experience that basic rocks, especially hornblende-bearing, are much tougher than acid ones and that trimming of specimens of basic rocks commonly is very difficult.

COMPARISON.

The chronologic scheme (Table 1) resembles in its main features the evolution of other parts of the Svecofennides (17, 29, 35, 36, 39, 55, 59, 62, 71, 72). The greatest difference is that the intrusion of the alkalicalcic laccoliths in the area described here seems to have taken place at least partly before the first folding. Another difference is that Wegmann (72), Kranck (29, 30), Metzger (39), and Hausen (19 p. 14) have assumed an Alpine style with thrust folds for the first folding phase, whereas here no signs of such thrusts are found. The folds of the primorogenic phase seem to be sinuous folds similar to those found farther N. by Hietanen (25, 26).

Sederholm's »Sub-Bothnian hiatus» (55, 56, 57, 58, 59) is represented by the quiet intra-orogenic phase with the amphibolite dikes. This quiet phase between the two folding phases is, however, scarcely a geologic period between two orogenies. Most geologists seem nowadays to assume that the »Sub-Bothnian hiatus» was only a quiet interval in the same mountain-making process or orogeny (17, 29, 36, 39, 71, 72).

During the ser-orogenic folding phase the migmatitic granites were rising upwards, simultaneously causing steep or vertical dips and axial pitches (29, 30, 38, 39, 75). The better preserved rocks in the sinking areas were compressed and the primarily semicircular folds became isoclinal or V-shaped (38 p. 186, 39 p. 96), whereas the folds of the expanding and rising domes were smoothed out. The rising granites have probably caused many of the curves or garlands, which are rather common in the Svecofennides (Fig. 15) (30 p. 89). The causal connection between the curves and the migmatitic granite is obvious in the Gullkrona area.

Pehrman's opinion, that the basic rocks of Jermo peninsula belong to two differentiation suites, has been discussed in an earlier paper (10 pp. 80—81) and my later investigations have not brought to light any proof of his opinion.

The area SE. of Stockholm in the swedish part of the Svecofennides seems to be structurally very like, almost identical with the Gullkrona area (64, 65), but Sundius' explanation differs noticeably from that presented here. His arguments — the alleged impossibility of a plastic deformation in the crystalline state on a great scale (64 pp. 23—24), and the amphibolite dikes unaffected by the granitization (65 p. 36) — are contradicted by the facts presented above. But the conditions in the archipelago of Stockholm may be different from those in the Gullkrona area.

Also Väyrynen has expressed some thoughts about the plasticity of the rocks during the different phases of the Svecofennidic orogeny, but they are almost contradictory to the ones presented above. He thinks that the rocks not until the ser-orogenic phase have been brittle enough for Alpine thrusts (68 p. 262).

In the absence of younger formations the relative as well as the absolute age of the post-orogenic events are very obscure. At the bottom of the Pemarfjärd and of the Gullkronafjärd remnants of younger formations, as indicated by erratic blocks, may occur, but also in that case the age of the Gullkrona basin would be rather difficult to determine with certainty. No fault trough or basin in S. Finland has been structurally analysed and step-faulting has been described from only two places in the same area (5 Fig. 6, 66 Figs. 150 and 151).

I hope that this paper in some degree has elucidated the movements and the structures and especially the chronology of the events in the E. part of the Gullkrona area and that the results may help to understand the evolution of other parts of the Archaean Svecofennidic mountain chain.

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EXPLANATIONS TO THE PLATES.

Plate I.

Fig. 1. Breccia containing medium-grained gabbro (grey), fine-grained schistose gabbro (dark), gneissose granite (light grey) and aplitic dikes. The hammer handle is directed towards the north as in all figures. S. shore, Flisholm, Kimito parish.

Fig. 2. Gneissose granite with dark inclusions. S. shore, Lökholm, Pargas parish.

Fig. 3. Fold in a supracrustal amphibolite. The radial tension cracks are filled with quartz, whereas the light layer is leptitic. 100 m. NW. of Nyäng cottage, E. part of Jermo peninsula, Pargas parish.

Fig. 4. Rotated quartz-filled cavity in a leptite. The light clod $^1/_2$ cm. from the under margin of the figure. Rundharu islet, 3 km. S. of Högland, Dragsfjärd parish.

Fig. 5. Folded amphibolite-leptite suite. V-shaped shear-folding. 250 m. S. of the flashing light, W. shore, Attu, Pargas parish.

Fig. 6. Folded amphibolite dike in a veined gneiss. Islet $^1/_2$ km. W. of N. Bergskär (W. of Holma), Hitis parish.

Plate II.

Fig. 7. Granitized veined gneiss. The irregular pegmatites have seemingly not disturbed the older structure. Garnet has formed in the pegmatites. W. shore, Trollholm island, 1.6 km. S. of Lökholm, Nagu parish.

Fig. 8. Migmatitic granite with alternating garnet-bearing and garnet-free layers. The dark spots are garnets. W. of the triangulation point, Vånå, Stortervo island, Pargas parish.

Fig. 9. Gneissose granite (beneath the hammer head), amphibolite layer (dark) and coarse-grained nebulitic migmatitic granite. A dike belonging to the gneissose granite cut all these rocks, but it is granitized by the migmatitic granite. NW. shore, Nämanland, about 15 km. S. of the area described here, Hitis parish.

Fig. 10. Tension cracks (feather joints) filled with recrystallized pegmatitic material from the surrounding gabbro. The light rims are plagioclase, the dark nuclei amphibole. The direction of the tensile stress was striking NE. and the movement in W. consequently directed towards S. The strike of the layers is almost 0° and the dip 20—40°W. Central Attu, Pargas parish.

Fig. 11. Pegmatites belonging to the migmatitic granite cut rectilinearly through fragments of an alkali-calcic breccia. The breccia was entirely healed and brittle when the pegmatite-filled joints originated. W. shore, Hummelholm, Kimito parish.

Fig. 12. Irregular pegmatites in supracrustal amphibolites or gneisses. The difference in shape between these pegmatites and the pegmatites in Fig. 11 depends on the plasticity of the country rock during the intrusion. Close to the flashing light, W.shore, Attu, Pargas parish.

Plate III.

Fig. 13. Basic or ultrabasic clod in a veined gneiss. The folding is quite plastic. NE. of Sildala, W.part, Stortervo island, Pargas parish.

Fig. 14. Amphibolite layer in an almost entirely granitized veined gneiss. The amphibolite is folded by shear. N. of the manor-house, Mågby, Stortervo island, Pargas parish.

Fig. 15. An instance of intrusion in solid state. Rotated fragments of a porphyrite layer in a veined and banded leptite. The plastic leptite has intruded the opening joints between the fragments, causing a boudinage. Some pegmatitic material has crystallized in the joint. W.shore, Kargskär (Kolaskär), 4 km. S. of Högland, Dragsfjärd parish.

Fig. 16. A symmetric boudinage with a rotated boudin. The N. side has moved towards E. N.shore, Halsholm, 400 m. E. of Heisala, Pargas parish.

Fig. 17. Initial stage of the origin of a boudinage. The N. side has moved towards E. The brittle layer has broken along shear joints perpendicular to the strike and the plastic layers have intruded in the opened joints. NW. shore, Lilla Bergskär, about 1 km. S. of the area described here. Hitis parish.

Fig. 18. Fault along a shear plane in a brittle layer, monocline in the adjacent plastic one (in the upper right-hand corner). This structure may develop into a boudinage-like shape, but the shear planes are primarily at an angle of 45° to the strike and to the compressive stress, which is perpendicular to the layers. S. shore, Långholm, 1 km. S. of Holma, Hitis parish.

Plate IV.

Fig. 19. S-shaped fold due to a couple. The NW. side has moved towards SW. W.shore, Söderö, Hitis parish.

Fig. 20. Dikes of migmatitic granite (the contacts are drawn with ink), faulted and cut by pegmatites. Country rock gneissose granite. The »schistosity» of the dikes is parallel with the contacts; the schistosity of the granite is emphasized by the amphibolite bands. Bay, E. shore, Stor Ängskär, 2.5 km. SE. of Holma, Hitis parish.

Fig. 21. Banded gneiss-amphibolite cut by parallel joints which are filled with granite. A narrow lamina (beneath the hammer head) is partly granitized and gives the dike a schistose appearance. W. shore, Gråskär, 1 km. S. of Holma, Hitis parish.

Fig. 22. Pegmatite broken into sharp-edged fragments in a entirely healed leptite. W. shore, Korsholm peninsula, 2 km. NE. of Flisholm, Kimito parish.

Fig. 23. Pseudo-sheet joints. Horizontal cross-joints at right angles to the vertical axis and lineation. S. shore, close to the harbour, Holma, Hitis parish.

Fig. 24. Joint set parallel with a morphologic joint. The joints are more frequent in the pegmatite dike, which crosses the figure from the lower right-hand corner to the middle of the left-hand side, than in the surrounding gabbro. NE. shore, Linjen island, 50 m. E. of Storö, Dragsfjärd parish.

Plate V.

Fig. 25. Sketch-map showing the distribution of the supracrustal rocks (dotted), the alkali-calcic igneous rocks (black) and the migmatitic granite (white) in the area around the E. part of the Gullkronafjärd. Mr. H. B. Wiik's observations from Kimito island are used. The dashed line shows the E. limit of the map Fig. 30 Pl. VIII. Scale 1 : 200 000.

Plate VI.

Fig. 26. Joint system produced by a dome-like upwarping according to H. Cloos. Drawing according to Fig. 18 in Cloos' paper 8.

Fig. 27. Sections of the summit levels along the dashed lines I, II and III in Fig. 28 Pl. VII. The lines II and III show a dome-like upwarping of the summit level of Kimito compared with I, the summit level of the mainland and the islands E. of Kimito. The crest line of the upwarped dome lies on the continuation of the long axis of the Gullkrona basin.

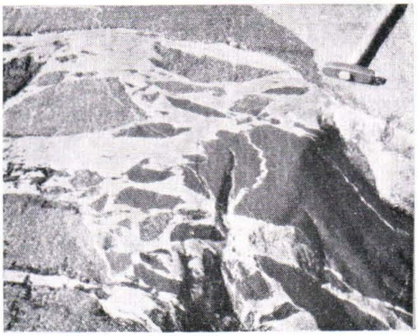
Plate VII.

Fig. 28. Sketch-map showing the morphologic joints around the Gullkrona basin. The broad lines indicate the faults which border the Gullkrona basin and the Pemar fault trough. The Arabic numerals indicate the height of the summits, the numerals with negative sign the depth of the sea. The dashed lines with Roman numerals show the sections in Fig. 27 Pl. VI and Fig. 29 Pl. VII. The dotted line shows the limits of the mapped area, Pl. VIII. F = Finnby church, H = Hitis church, K = Kimito church, N = Nagu church, Pa = Pargas market town, S = Salo market town, G = the Gullkrona basin. P = the Pemar fault trough. Scale 1 : 500 000.

Fig. 29. Topographic section through Hamnholm and the SW. part of Kimito along the dashed line IV in Fig. 28 Pl. VII. The E. half of the section lies about 150 m. S. of the W. half. S = sealevel. The step-faulting (»antitetische Rotation» according to H. Cloos) of the peneplain is quite obvious.

Plate VIII.

Fig. 30. Geological and structural map of the area around the E. part of the Gullkrona basin. 1 = acid supracrustal rocks: leptites and gneisses, 2 = basic supracrustal rocks: amphibolites and porphyrites, 3 = quartz-bearing alkali-calcic infracrustal rocks: gneissose granites and granodiorites, 4 = quartz-free alkali-calcic infracrustal rocks: diorites, gabbros and hornblendites, 5 = banded rocks containing two or more members of the alkali-calcic suite, 6 = migmatitic granite generally rich in microcline, 7 = orthoclase-bearing granite, 8 = migmatite sign, marking granitic veins in older rocks and remnants of the older rocks in the migmatitic granite, 9 = garnet, 10 = limestone and skarn, 11 = dikes of migmatitic granite, 12 = diabase dikes, 13 = folding axes (pitching 50°NE., horizontal and vertical), 14 = strike and dip (horizontal, 40°NW. and vertical), 15 = faults of importance to the geological map, 16 = the cross-syncline or axial depression of Högland—Hamnholm, 17 = flashing light. Scale 1 : 100 000.



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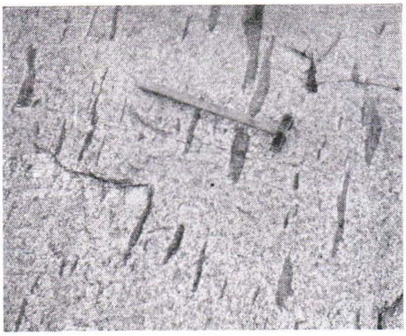

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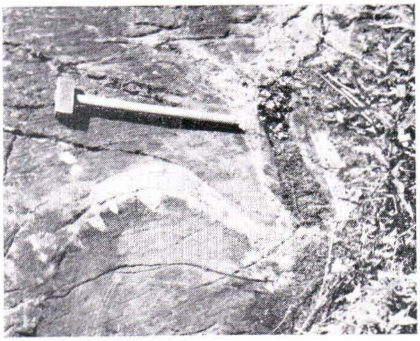

Fig. 3.

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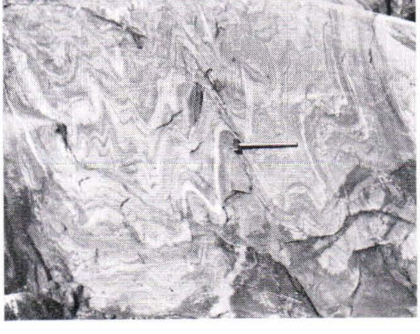

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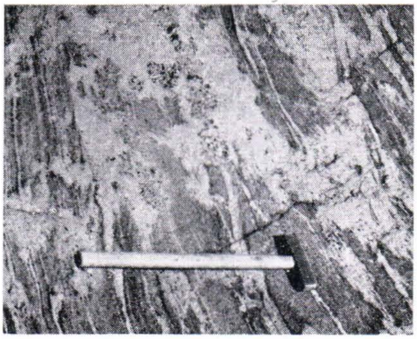

Fig. 7.

Fig. 8.

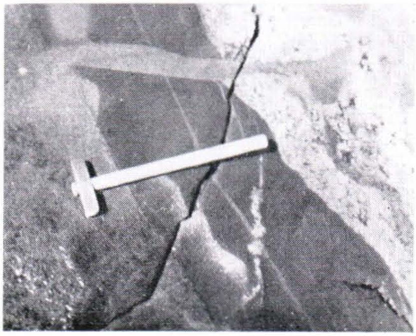

Fig. 9.

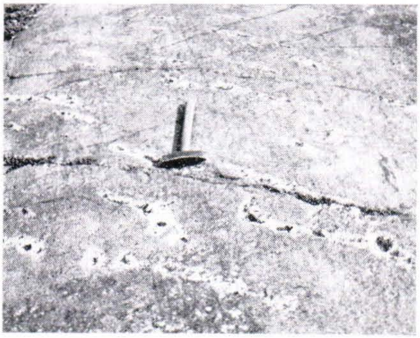

Fig. 10.

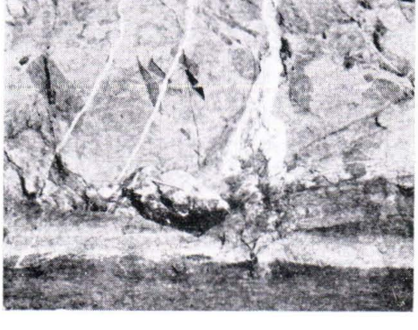

Fig. 11.

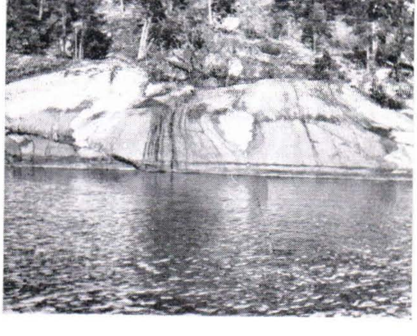

Fig. 12

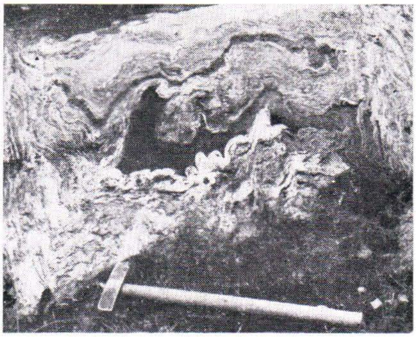

Fig. 13.

Fig. 14.

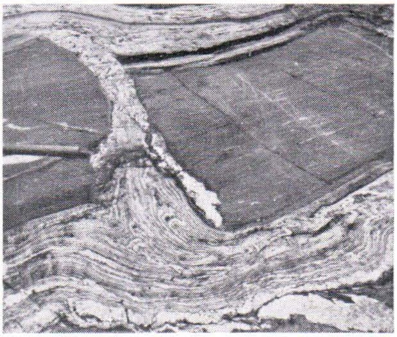

Fig. 15.

Fig. 16.

Fig. 17.

Fig. 18.

Fig. 19.

Fig. 20.

Fig. 21.

Fig. 22.

Fig. 23.

Fig 24.

Fig 28

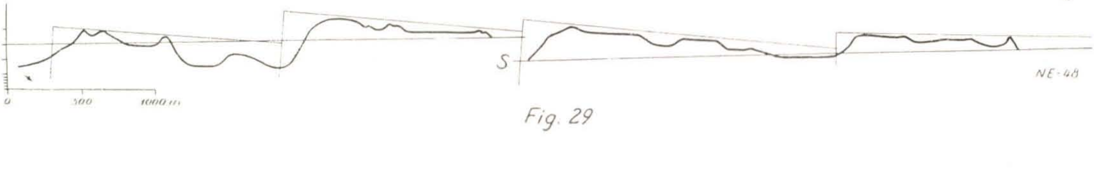
Hamnholm
Jungfrusund
Purunpää
Purunpää viken
Söderlångvik udde
Långvik
Långnäs
Kövik
W
E
S
NE-48

Fig. 29


22° 20'
Storlervo
Heisala
Mielisholm
Attu
Jermo
Korpo
Trollö
Lökholm
Trollholm
Norrland
Högland
Gullkrafjärd
Pemarfjärd
Paimion selkä
Kimito
Ölmoss
N
Rundharu
Kangskär
E. Dömarskär
Helsingholm
Purunpää
Ljusskär
Skogsskär
Norrö
NE-49
Benskär
Högsåra
Kasnäs
Söderö
Holmö
Små Kalskär
Stor Ängsön
60° 10'
60°
1
2
3
4
5
6
7
8
9
K 10
G 11
D 12
13
14
15
16
17
0
5
10 km

Fig. 30

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