GEOLOGINEN TUTKIMUSLAITOS

BULLETIN

DE LA

COMMISSION GÉOLOGIQUE

DE FINLANDE

N:o 162

GEOLOGIC STRUCTURE OF THE LATE PRE-CAMBRIAN INTRUSIVES IN THE ÅVA AREA, ÅLAND ISLANDS

BY

SIMO KAITARO

WITH 37 FIGURES IN TEXT, 6 TABLES AND ONE MAP

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Helsinki 1953. Valtioneuvoston kirjapaino

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PREFACE

The field studies for this paper were begun in the summer of 1948. The preliminary observations brought out some interesting facts, which gave rise to a more detailed mapping of the area. The mapping was mainly carried out in the summer of 1949 and completed and partly revised in the following summer.

The indefatigable interest in the granite problem of my teacher, Professor Pentti Eskola of Helsinki University, has inspired me to carry out the investigations dealt with in this paper. Professor Eskola has also been kind enough to read the manuscript and to offer many useful suggestions. For all this I owe him a debt of gratitude.

To the Director of the Geological Survey of Finland, Professor Aarne Laitakari, I am greatly indebted for his kindness in agreeing to have this work published by the Geological Survey. I am also very grateful to Dr. Erkki Aurola, State Geologist of the Geological Survey of Finland, for his encouragement.

Mr. H. B. Wiik, M. A., Mr. M. Tavela, M. A., and Mr. M. Mäntynen, M. A., have carried out the chemical analyses of this research. Mr. P. Ojanperä, M. A., has performed some determinations of BaO. Miss Thyra Åberg has drawn the map and some pictures. Mrs. Joyce Preston, M. A., and Miss Maire Lehikoinen have given me valuable help in preparing the manuscript. Professor Etta McDonald and Mr. Paul Sjöblom, M. A., have corrected the manuscript. To all these persons I offer my best thanks.

Geological Survey of Finland, Helsinki, December, 1952.

Simo Kaitaro

INTRODUCTION

The Åva area lies in the northeastern corner of the Åland Islands (Finnish Ahvenanmaa), one of the most exceptional archipelagoes in the world. It consists of an outermost group of larger islands against the Gulf of Bothnia and numerous skerries in the parish of Brändö. On the east it is bordered by Kihti, a north-southerly directed trough between the archipelagoes of Åland and Turku. The region is mapped for the first time in the summer of 1887. The published map, in the scale 1 : 200 000, including both the superficial deposit and bedrock, is, however, only a general one. Owing to the incomplete study of the pre-Cambrian geology of Finland at that time, it was not to be expected that this first mapping would give an adequate picture of the complicated structure of the area. In his explanation to the map sheet of Kumlinge, Moberg (1890 and 1891) suggests that the porphyritic granite occurring in these islands between the two large rapakivi areas of Vehmaa and Åland is probably identical with rapakivi, but no special attention was paid to the area.

The real discoverer of the area was Sederholm, who has elucidated the pre-Cambrian geology of Finland more than anybody else. He visited the region in several summers during his prolonged studies in the archipelago and has pointed out many very interesting features in this small area. His observations were first time discussed in Swedish in a paper about the gneiss-granite problem (Sederholm, 1924). But a more coherent presentation of his studies in the Åland Islands was included in the third part of his monograph on the migmatites and associated pre-Cambrian rocks in Southwestern Finland (Sederholm, 1934). In these memoirs he has presented many of his outstanding researches which are mainly based on his observations off the coast of Southern Finland. The late professor J. Sederholm did not have time to finish this last part, but it has been edited posthumously by his assistant and co-worker Dr. E. Mikkola.

Sederholm included the Åva granite in the granites of the third group in his classification of pre-Cambrian granites of Finland and Sweden. These granites are nearest to the rapakivi granites both in structure and age. They are, however, more non-homogeneous and show more metamorphic features than the latter. Hence Sederholm considered this group somewhat older than rapakivi. He named it Åva granite, after the largest island on which it occurs. He also called the basin in the middle of the area »Åva Fjärden». This is, however, erroneous, because it is called in the maps and by the people of the neighbourhood, at least to-day, Ängskärsfjärden after the island near its centre. He first directs attention to one of the most peculiar phenomena in the area, the radial lamprophyric dikes. In his Åland memoir the description of the Åva granite and associated rocks, forming one of the most interesting parts of the Åland Islands, is fairly short and concise, comprising only about four pages. It is more or less a preliminary report or summary but he was aware of the special character and the importance of more detailed investigations in the area. This work of Sederholm has inspired the present investigation and provided many fruitful ideas, having served as a good starting point in taking the problems as a whole under consideration.

The present study has been undertaken mainly from the structural standpoint, because it seems to the author to be the most fruitful approach under the special conditions prevailing in the archipelago. The bare rocks along the shore, polished by Nature, virginal as if just risen from the sea, will charm every geologist and allow very detailed study and the well-exposed islands and skerries will give grand geological structures. Even in the larger islands the bedrock is for the most part covered only by lichens and mosses.

Recently the prevailing tendency among geologists has been to make geology more quantitative and exact. Making measurements in the laboratory is not, however, the only way to this end. The more natural way for the ordinary geologist is to measure the size, form, and relation of rock masses, i. e., map in very great detail and use the result for an exact interpretation of the geologic development.

In many connections Sederholm has emphasized the importance of the study of macroscopic structures for the petrological problems. It may give us the proper clue to right understanding of the processes. He himself has made detailed maps of typical exposures and photographed innumerable outcrops. These excellent illustrations in his studies help to make his observations especially comprehensible. But even such a structural study must be combined with microscopical research.

Sederholm's procedure is also followed by the present author. By careful field study of the Åva granite and other late pre-Cambrian intrusives and by observation of the features of their structure several facts were discovered which have an important bearing on the form and mechanism of the intrusions and have application in other regions where detailed research of this kind is not possible. The petrographic and petrologic facts presented here are to be considered as preliminary. Their description is as condensed as possible with the aim of giving the reader the important characteristics of the rocks which have not been given in previous studies.

The first intention was to map only the Åva granite and related intrusives. It proved, however, reasonable to reproduce also the main structures of adjacent migmatites. This mapping has been more general, not only because it is less important to the present study, but also because the contacts in such migmatite areas are not always exactly determinable. The mapping is based mainly on nautical cards and aerial photographs. In such scantily forested terrain, which shows so clearly the relationship between the morphology and geological structures, the photogeologic methods are suitable. The great structural pattern is as plainly seen from a bird's eye view as the other major structures are to one travelling along the shores. The discovery of many general features would have been possible only by the merest chance without the use of aerial photographs and, particularly, the tracing of many dikes would have been very time-consuming if not impossible.

MORPHOLOGY AND GENERAL STRUCTURE

The crater-like morphology of the area is very attractive (Fig. 1). Accordingly it is of great interest to study the relationship of the curvilinear topographic pattern to the geologic structure of the district. The basin in the centre of Ängskärsfjärden is relatively shallow. In a few places the depth may be 20 m or more, but that of the channels and straits around the basin is generally still much less, the broadest sound to the north being the only one over 15 m. Thus a small part of the central mass is exposed to direct observation. It appears, however, that granite and monzonite underlie the main part of the central area, about 20 km^2 in extent. They seem to be more readily disintegrated than the most of the adjacent older migmatites. Probably because of their coarseness and closely spaced jointing, they are not so tough as these. In the area where there are inclusions or other remnants of the country rock in the granite, the morphology is more rugged, while the islands consisting of granitic and monzonitic rocks are flat and the rock surface of many islands surrounding the basin is generally very gently inclined toward the centre of the area.

The circular outlines of the central stock are, however, not the only reason for the peculiar morphology of the area. It has been mainly produced by the concentric framework around the intrusive stock or the almost concordant strike of the older gneissose rocks near the stock and the arcuate concentric sheets of granitic ring intrusions. The persistent geometry of the rock structures is particularly accentuated in strong relief on the eastern and southern side. The large islands, Långö and Bolmö, nowadays separated only by a valley, and Åva form a broad island arc. Their pattern is established in the contours of the islands in the map, but may be seen still better in their morphology. There are some annular ridges over 20 m high and marked by steep slopes and gorges. On the western side the arcuate pattern appears only in Raden (earlier called Långskär) and adjacent islands. In the large island of Fiskö it is no longer present.

Another characteristic feature, perhaps not quite so conspicuous in the general morphology, is a radiating fracture system surrounding the area and resulting in clefts and radial valleys in the eastern island arc. On the other sides it does not appear so well in the morphology. Many of these fractures have been filled by lamprophyric dikes, which probably are in many other cases undiscovered and even unexposed. Such is the case also with the fractures directed to the northeast, which are often occupied by diabase and quartz-porphyry. This can be noticed by comparing the morphological pattern (Fig. 1) with the geological map. This northeasterly jointing shows some variations in its direction, perhaps because it mostly has a tendency to form cross joints and fractures. This is to be perceived on comparing it with the northwesterly lines south of the central complex. This system, which in the western part curves to the west-northwest, follows the foliation of adjacent migmatites (cf . Fig. 2). It is partly the same with the northwestern and east-west directions in the northern part of the area represented in the map.

The two structural elements, which go through, and usually beyond the area independent of the geological structures, are the north-south and north-northwestern lines. The former element seems to be more common in the eastern part, where it is represented by the big trough of Kihti. The latter again appears in the southwestern corner of the map as the long trough of Lappvesi. Both of these may be caused by the uplift of the Brändö horst as suggested by Hausen (1947). He has not, however, discussed the problem and has given no definite age for this event, and it is also beyond the scope of this study; but it is apparently one of the youngest features. The main direction of the only sandstone dike found on the skerry of Kummelören also trends north-south.

THE COUNTRY ROCKS

As the nature of the country rock is not pertinent to the main problem of this study, the adjacent migmatites will be discussed here only briefly. The name migmatites was adopted by Sederholm who emphasized it as a structural term. This term is, however, associated also with some petrological definitions and it is always genetically associated with granite or granitization.

When Sederholm (1907, p. 110) proposed the adoption of the term migmatite, he used the word »elements» in referring distinctly to the structural appearance of a coarsely mixed rock, especially because he later confirmed that they »look like mixed rocks» (Sederholm, 1926, p. 136). The »two elements of different genetic value» of Sederholm are, as defined by P. Niggli (1948), a stereogenic paleosome and a chymogenic neosome of

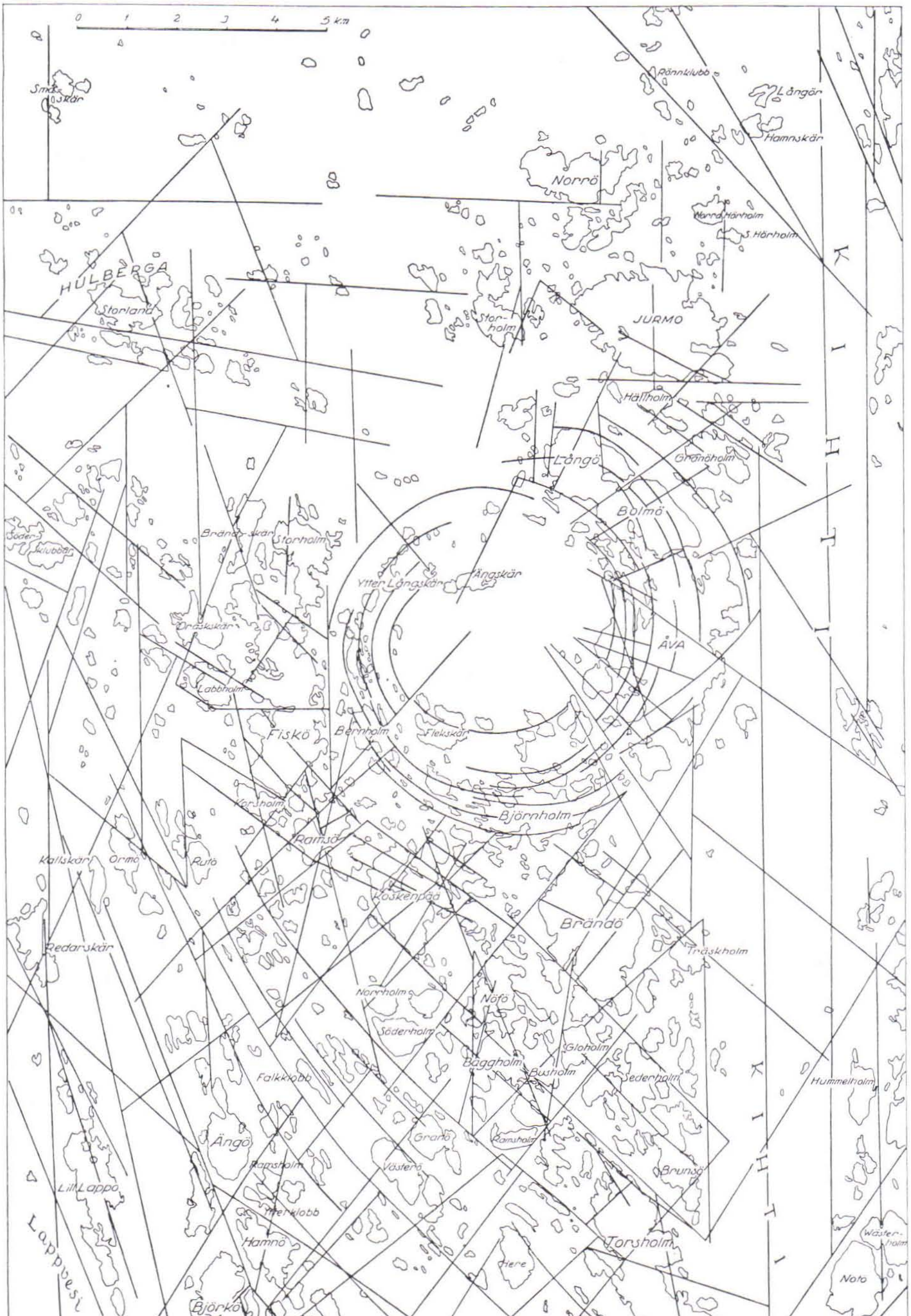

Fig. 1. The morphologic joint systems around the Åva area. The lines have been drawn mainly according to aerial photographs and nautical cards.

granite which may be of exo- or endogenic origin. The word »element» has not the same meaning as it has for hybrids, where the mixing may not be so much structural as material (cf. Harker, 1909, pp. 333). Hybrids may even be structurally homogeneous, because this term is of petrological character. The present author does not agree with Read (1944, p. 63) in including homogeneous rocks under migmatites, even if Read has »seen in Finland masses of homogeneous rock which Sederholm himself demonstrated as migmatites». The occasional misuse of a term is not a sufficient reason for enlarging the conception. Read has taken it merely as a question of scale, but the result of mixing depends upon the character and stage of the process. Sederholm in his literary works has called migmatitic granite those more homogeneous rocks, perhaps still with ghostly paleosome. The Hangö granite with all possible transitions to ordinary migmatites is an example of these (Sederholm, 1924). If homogeneous rock covers only a small area, it can not, however, be shown in the map. Thus in the general maps of Sederholm considerable areas of granite and schist are included under migmatites.

Migmatites which are eruptive breccias formed by the intrusion of the granite Sederholm defined as agmatites because of their structurally quite special character. Agmatites are mainly merismitic, while other migmatites may have a general foliation producing stromatitic structure. This appearance is very typical for the large migmatite areas. Agmatites may occur everywhere in connection with granites, while the stromatitic migmatites would originate when the whole rock mass is near the melting point and in plastic condition. Migmatitic granite has also been called nebulitic, but often the inclusions in the granite generally do not have at least macroscopic transitional borders. This does not mean that the inclusions are not granitized, on the contrary they may be as a whole very much granitized. Thus in such instances the name skialitic is to be preferred.

The term migmatite, despite its misuse as a »waste basket» term, is useful in a migmatite terrain with very complicated and heterogeneous rocks and where mapping on a large scale is possible only if we do not define the composition of all basement rocks nor neglect to draw quite definite contact lines. Even in such a case as in this structural study, where the recognition of the more detailed character of the country rock is not necessary and not even essential, the term migmatite can be used.

In the map only a general structural pattern of the older migmatites is given and no attempt is made to distinguish the borders between different rock types. As anyone who is familiar with migmatite terrains knows, the mixing has also been on a greater scale. The migmatites include older granites and granitized schists, amphibolites, etc., but very much mixed. These rocks forming the country rock of later intrusions have the same character as those in some adjacent areas (Hietanen, 1943 and 1947) and in the other parts of the Finnish Archipelago (Edelman, 1949). Most common among these rocks in the Åva area are gneissose granite (granodiorite) and migmatitic microcline-granite with inclusions partly predominant, passing into mica-gneiss or garnet-mica-gneiss (kinzigite).

Gneissose granite, from fine- to medium-grained biotite-granodiorite with well-developed foliation, is the main rock in the southern part of the map area. It is hardly ever homogeneous. It contains at least veins of somewhat coarser hornblende-granite. Regionally reddish granitic veins are very common, sometimes forming the main mass of the rock as transitions into migmatitic microcline-granite with stromatitic »schlieren» of mica schists and gneiss even of greater extension. Within these schists there are irregular flecks or layers of coarse crystalline limestone found on the northwesterly shore of Brändö Island, the northeastern peninsula of Åva, and in the northern part of Kalvholm (northwest of Långö). They seem to form a continuous zone, which curves just outside of the eastern island arc and is apparently one cause for the arcuating outer contours. In the northeastern part of the map area there are continuous zones of sedimentogenous rocks, kinzigites and banded hornblende schists with many still visible supracrustal structures. These zones are, however, more concealed than the migmatitic granite, which is exposed in the main islands.

GENERAL STRUCTURE OF THE ENVIRONS

It is not intended to offer a more detailed tectonical analysis, because no studies of the tectonics of this pre-Cambrian part of Finland are available. Some facts essential to the present problems may be noted. One of the most important features is the conformable strike, and the almost invariable steep inward dip of the country rock in the periphery of the intrusive complex. Further away the dip is mostly vertical with deviations on both sides. This feature as well as the general inwardly inclined platy parallel arrangement of minerals in the central stock rejects the idea of dome structure, which is otherwise typical for many granite batholiths.

The fold axes are mostly observed in minor folds and they are given in the map only when they are parallel with the lineation and are not subject to purely local changes. When the country rock is more intensely folded, the axial observations may vary so much that it seems unnecessary and even impossible to show them in the map.

The fold axes in the southern part of the map area have a very regular gentle or moderate southeasterly pitch, but in other parts they are more variable, apparently owing to more complicated folding, which is locally visible even in the map. But it is also a general rule that the axial directions observed are relatively gentle, with general tangential arrangement around the central stock, or they plunge outward rather than inward.

The problem of the distortional effect of intrusions to regional structures is very important to this study. There is no doubt that the environs of the intrusive centre have been greatly disturbed during the magmatic activity. The circular structure can not be pre-intrusive, but, upon going further, we meet some difficulties in reconstructing the eventual pre-intrusive structures. It is possible to give only some tentative ideas, which have not been controlled by mapping a larger area to discover the general character of the pre-intrusive structures.

The broad zone of the arcuated structure in the eastern and northeastern part of the map area is apparently modified by the pre-existing curve in the strike of general structure, which turns from the north-northeast strike in the southeastern part of the area almost to the east-west in the islands of Hulberga outside the area shown in the geological map but visible in Fig. 1. In this case the later deformation has intensified the older arc structure. The fold structures visible in the area northeast of Långö are apparently pre-intrusive. On the other hand in the zone of Brändö—Koskenpää—Fiskö an ostensibly slight outward bending of the assumed older structure is observable. The relation of the hypothetical pre-intrusive structure to the present general structure is schematically illustrated in Fig. 2. It shows how the emplacement of intrusive bodies is at least to a great extent compensated by the structural adjustment in the invaded rocks. This is also visible in profile because the deformation has not only been pushing aside the walls but also settling the overlying roof (Fig. 3).

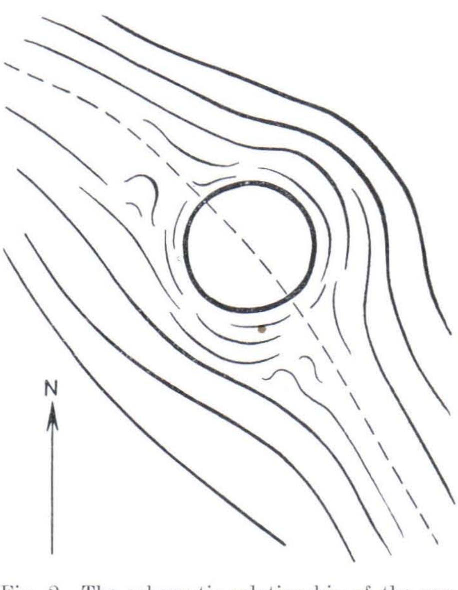

Fig. 2. The schematic relationship of the generalized structure of the invaded older migmatite (solid lines) to the central complex (circle in the middle). The broken line shows the general strike of the assumed pre-intrusive structure.

The relatively constant direction of fold axes in the southern part of the area presents apparently the old Svecofennidic folding; it occurs also in the northeastern part, but in turned positions. The fold structures in the island north of Fiskö, as well as the less visible similar structures in the islands northeast of Brändö are surely to be ascribed to the intrusion because of their regional position. The mutual relation between the pre-intrusive and the present structural pattern in these particular areas implies intensive deformation.

The variable strike in these parts may have been caused according to Sederholm (1934) by rearrangement

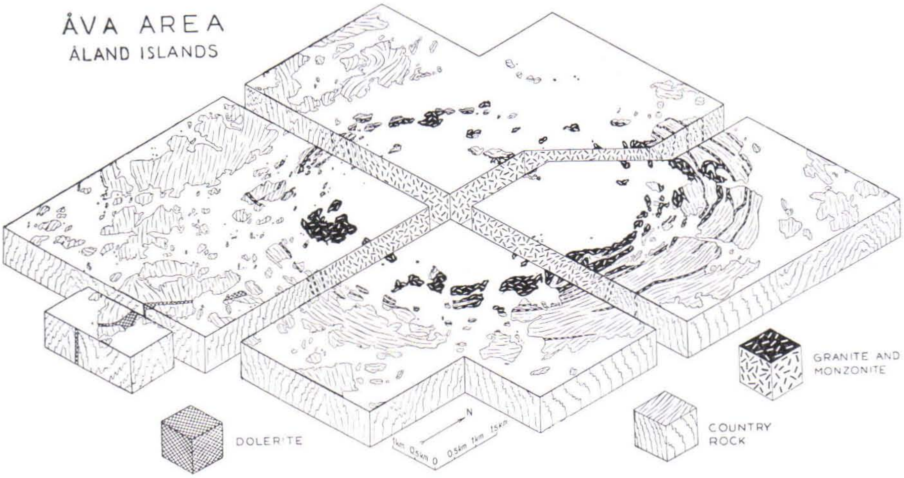

Fig. 3. The block diagram of the Åva area.

of shattered country rock. This has, however, been apparently less important, because dikes of granite are not so common as they ought to be in order to form major eruptive breccias. Such parts, where breccias with rearranged blocks occur, are generally shown in the map as shatter zones.

The most frequently observed axial directions have apparently developed before the origin of the present arc structure. Also at least the more intensive lineation is pre-intrusive. The attitude of pre-intrusive linear features has been modified by the intrusion. If this deformation as a whole has given rise to minor flat lying folds or intensive linear structures, it can not be proved, because their structural relationship is not clear, and they are likely to be confused with the earlier structures that are not interpreted in detail here.

INTRUSIVES OF THE GRANITE-MONZONITE SERIES

GENERAL AND FIELD CHARACTERISTICS AND SHAPE

The central composite stock and the satellitic intrusions form an intrusive complex with rocks clearly belonging to one and the same sequence. Although many structural details and smaller intrusions must be omitted, the map reveals many salient features. The rocks of the central stock ranging from porphyritic granite to monzonite differ from ring intrusion granites mainly in structure and are more coarse-grained and, for the most part, more massive. Granite is apparently the main rock, but monzonite occurs in many separate areas, the form of which mostly conforms with the peripheral structure.

The main granite of the central stock is reddish brown and medium- or coarse-grained porphyritic biotite-granite. The structure varies from foliated to quite massive. The potash feldspar phenocrysts containing strings of perthite and small quartz inclusions are usually 2 cm or more in length, but some smaller ones may occur also. Their amount in relation to the groundmass varies in different parts and they usually have a rectangular form with jagged outlines, but in the foliated part they may be more or less lenticular. Locally they are rounded, particularly in the surface which is parallel with the foliation, giving the rock a rapakivi-like appearance. In some border zones plagioclase may even occur locally as a mantle around the phenocrysts. Mainly owing to the great number of phenocrysts, potash feldspar is in almost all varieties predominant over plagioclase, which generally is albite-oligoclase. Particularly in the well-foliated rocks potash feldspar always shows a cross-hatched structure, while in more massive granite it may be orthoclase. It is, however, mostly turbid, owing to submicroscopic inclusions or beginning alteration. Light grey or sometimes bluish quartz shows, particularly in well-foliated rocks, undulatory extinction, which is otherwise absent or not very strong. Both myrmekite and micro-pegmatitic structure occurs. The amount of mafic minerals is variable from rocks with groundmass very rich in biotite to reddish rocks with merely leucocratic minerals. Biotite alone is generally present, and hornblende occurs occasionally in addition. Most common accessories are apatite, pyrite, magnetite, sphene, zirkon, and fluorite. The latter occurs interstitially in variable amount. In some crushed rocks epidote with quartz occurs as crack filling.

Typical monzonite is brownish-green and relatively dark, although there is a slight predominance of salic constituents. The dark tint is due to the brownish colour of the feldspars. These, especially potash feldspar, form larger grains than the other minerals, often giving the rock a subporphyritic structure, which is, however, seldom clear. The ordinary phenocrysts of potash feldspar similar to those of the porphyritic granite are up to 2 cm in length and mostly scarce, also often irregularly scattered and mantled by plagioclase. The grain size varies from fine to coarse, the more fine-grained varieties having smaller distribution, the medium- and coarse-grained being more common.

Monzonite is essentially composed of plagioclase, potash feldspar, biotite and green hornblende. In potash feldspar cross-hatching is less common than in the porphyritic granite. Potash feldspar is apparently mainly orthoclase. Andesinic plagioclase is sometimes zoned with a more albitic border zone, the whole individual crystal is within the limits of andesine and forms mainly subhedral grains in the hypautomorfic groundmass. The relative amount of mafic minerals is somewhat variable and biotite is mostly predominant. Both biotite and hornblende are always present and occur together mainly in ragged flecks. Hornblende seldom forms wedge-shaped crystals and contains generally a large amount of small inclusions of quartz and accessories. Quartz is always present in the typical monzonite, however, sparsely filling as minor grains the interstices. Therefore the general name monzonite is preferred instead of quartz-monzonite, although even more silicic transitional or heterogeneous members are designated in the map as monzonite. Quartz also occurs sometimes in myrmekite. Sphene, as well as ore minerals, is closely connected with the mafic minerals and is in some thin sections found in quantities greater than that of an accessory mineral. Prisms of apatite are common as well, occurring as inclusions in all essential constituents. Fluorite is only occasionally and very sparsely present and then only in the more silicic varieties.

Around the Ängskärsfjärden the area is so well exposed that the contacts, where they are sharp and distinct, can be defined. The relation of the central stock to the ring intrusions is not clear, because the central part of the area is sparely exposed and therefore it is not always possible to determine the real borders of the composite central stock. The first visible contact from the centre may as well be the wall of a ring intrusion. This does not seem to be essential, because in the central stock there are arcuated strips of older rock (see p. 27) and in the outer part of the ring complex the structure is so developed that the screens form the major part and are separated by narrow ring intrusions. Therefore the definitive ring structure develops gradually. In some parts the intrusions are so numerous that later and perhaps less regular dikes have destroyed the older structures. In the islands southwest of Långö and Bolmö there occur irregularly shaped intrusions of fine-grained granite, which distinctly transect and brecciate the porphyritic granite. It is more resistant than the enclosing porphyritic granite and therefore it is relatively more exposed than its real distribution implies. Because of its irregular character, as compared to the ring intrusions, it must be omitted in the map.

The pink or reddish-brown fine-grained granite is almost aplitic and contains only minor amounts of biotite. Feldspars are commonly very much altered. Quartz shows generally an undulatory extinction. The structure is not quite equigranular, but some coarser areas made up merely of quartz and feldspar commonly occur.

Because it is probable that the borders of the central stock and the whole ring intrusion are mostly foliated parallel to the contact, the attitude of the contact against country rock may also be established when it is not actually visible. So it can be seen that the dip of the first visible contact from the centre is variable, being both inwards and outwards. The latter is a less common case and it is observed only as a very steep platy parallelism (see p. 25). Most actual contacts are found to be inward-dipping high angle contacts. In the western part of Åva island, however, there are found many low angle contacts (see p. 18).

The contact and foliation of all characteristic ring intrusions nearest to the centre are merely inwards and dip mostly 70°—80°. In order to define the shape of ring intrusions, the attitude of contacts is of special interest. The British geologists even use different names for the inward-dipping intrusions, or cone sheets, and for the vertical or outward-dipping intrusions, or ring dikes (Bailey and others, 1924). The last term (Ringgänge), H. Cloos (1936) has used in the wider sense for both kinds of intrusions. Also in the present study such a general name seems to be more useful; but, to avoid misunderstanding, both kinds of intrusions are called ring intrusions.

The ring intrusion granites are from medium- to fine-grained porphyritic granites, the outer ring intrusion being always more fine-grained than the inner, which forms transitions to the marginal granite of the central stock.

In the inner ring intrusions the phenocrysts are over 1 cm, while in the outer intrusions they are for the main part smaller. In most fine-grained types the porphyritic character is not usually distinct.

In the area investigated the contacts of the ring intrusions are in many places plainly visible. In the map pattern they are generally almost concordant with the wall rock structure, but in detail slightly discordant or at least accordant (Fig. 4). In the vertical sections found in some short slopes it can be established that they generally are in vertical or steeply inward-dipping positions. The latter form the inner zone of these intrusions, the outermost being vertical. The inclined ring dikes are found all round the area while the outer zone of vertical ring intrusions is characteristic of the eastern side. Between the inner and outer zones some intrusions may have both types of dip and, as it seems, both the inward-dipping and vertical ring intrusions are caused by the same force, as will be discussed later on (see p. 61). These circumstances make it even unreasonable to use different terms for them.

Most ring intrusions shown in the map are 15—40 m in thickness and the narrower are shown only when they form the continuations of broader intrusions. Because many ring intrusions taper gradually, the ring structure will be more clearly visible when its narrow part is also given in the map pattern. Terminations of this kind are common in the eastern and southern part of the complex. The ring intrusions never form complete circular structure, but some can be traced through more than 90°. They do not always have regular, gradually tapering ends. Some dikes can often be followed many hundreds of meters without significant change in their breadth, but then they may have quite abrupt ends. In such instances the dike does not terminate completely, but it may be found again at one side, where it begins just as abruptly as it ended. The offset may be about equivalent to the breadth of the dike as on the western part of

Fig. 4. Contact of a ring intrusion steeply dipping to the right (almost to the east) viewed from the south. The country rock (schistose rock) is visible on the shore line and the hammer stands next to the contact. The northern peninsula of Bernholm in the eastern periphery of the Åva area.

Långö. In such instances, when after an abrupt end, its continuation is not shown in the map, the offset may be greater or the continuation, for some reason or other, is not easy to be found. The offsets of the ring intrusions are visible only in the map pattern. Their character cannot be followed in a continuous exposure. At these offsets there is always a narrow radial valley. On the western shore of Långö and its neighbourhood these valleys or dells are occupied by lamprophyre dikes. If we consider only one individual offset, all features point out to later faulting. But in the western part of Långö it can be observed that the fault has not disturbed the other structural lines, e. g. the ring intrusion near-by. If we still like to explain the structure in the manner mentioned, the direction of the fault must be the same as the dip of the outer ring intrusion, i. e. almost vertical. Thus the fault should cause an offset only in the inner, steeply inward-dipping ring intrusion. But it is equally possible to regard this feature as comparable to apparent offsets in the course of the lamprophyric dikes (see pp. 35, cf. Kaitaro, 1952). Then the offset is brought about by a radial fracture intersecting and connecting two concentric ones. This compound fracture has opened during the formation of the ring intrusion.

Fig. 5. Amphibolitic breccia with very spare neosome of porphyritic granite. Southern Långö, Brändö.

In the southeastern part of this island, and in the northern part of Bolmö there is a larger area relatively sparely exposed. The granite intrusions there seem to have more irregular shapes. The wall rock is for the main part brecciated amphibolite, where porphyritic granite occurs as a network of small dikes. The shattered blocks still have a general trend and it seems that they have not moved very much from their primary position (Fig. 5). There the granite intrusions may have branched shapes and the map gives the impression of the granite network in the country rock. The ring intrusions sometimes, though relatively seldom, have turns in their regular arc form. In the middle part of Åva a ring intrusion has a bend with an obtuse angle. This point is occupied by a valley, which goes across the island. Also elsewhere that such irregularities occur in ring intrusion, it is mostly less exposed, apparently owing to the fracturing of the country rock, which has merely been the apparent reason for its irregular course.

The character of different intrusions is quite visible in the vicinity of the village of Å v a. As the structure is too complicated to be shown in the map, it seems advisable to give a summarizing description. The westernmost intrusion is not an ordinary ring intrusion in the same sense as the others; it is separated from the central stock merely by a zone of a merismitic eruptive breccia, a shatter zone composed of great fragments of variable orientations up to many m^2 in size and transecting dikes of granite. It is not a real screen as is the case between the ring intrusions. Also in the eastern part of Kalvholm there are found fragments of different size in very striking quantities as continuation of the same shatter zone, which consists, however, of more granitic material; it is therefore shown in the map as porphyritic granite. Here it is quite certain that the later intrusion has shattered the older rocks. The small granite quarry in the western part of Åva is situated in this intrusion. It is here called »Quarry intrusion» on account of its special character, and in addition to the central stock and the ring intrusions, it forms one of the main structural units of the central complex. It appears in the map to have irregular borders and, contrary to other satellitic intrusions, shows flatter lying contacts both against the country rock and between the silicic and subsilicic varieties of the Åva granite (Fig. 6).

The composite Q u a r r y i n t r u s i o n is composed of rocks similar to those of the central stock. Granite is in the southern part mainly leucocratic and medium-grained and the colour of feldspar is pinkish. Both biotite and muscovite occur in variable amounts. On the northern ridge, where the quarry is located, it is more brownish. There in the quarry, granite also has more biotite and when the light constituents are coloured the rock is relatively dark. This main rock type of the Quarry intrusion differs from the central granite in its structure and has only a tendency to porphyritic structure. The oblong phenocrysts of about 1.5 cm lie in a medium-grained groundmass, in which the bluish or bluish-grey quartz forms the main part. Among the essential minerals those which display crystal forms, being mostly subhedral, are mainly feldspar. Contrary to most of the central granite, plagioclase rich in albite is slightly predominant over potash feldspar. The brownish green monzonite in the southern part is similar to that of the central stock.

The next intrusions to the east are already, for the main part, ring intrusions and can be followed from the southeastern peninsula of Åva, called Bockholm, and the adjacent island where they form the major part of it. They do not, however, form quite definite intrusions, but they are alternating zones of silicic and subsilicic varieties, the western part being clearly more subsilicic. In Bockholm the easterly ring intrusion becomes gradually non-homogeneous and apparently tapers gradually. Where the contact of the main intrusion against the wall is visible, it is steeply inclined inwards, as is the foliation in the granite. This zone of intrusions is very conspicuous in the morphology. The ridge of migmatitic granite separates it from the western monzonite intrusion, which also follows a valley, and is for the most part concealed. These intrusive zones can be

Fig. 6. A vertical slope across a contact between monzonite with closely spaced flat lying sheeting and porphyritic granite (in the uppermost part of the picture). The hammer lies in the transition zone slightly below the demarcation line. Quarry intrusion northwest of the village of Åva, Brändö.

followed to the north also across the village of Åva, but they do not form single dikes and are much simplified in the map pattern. In the cliff near the harbour of the village of Åva one of them very clearly dips to the west and truncates distinctly the flat folds in the screen (Fig. 7), but in the broadest part north of the village the dip of the platy orientation of feldspar is not more than 45° to the west and even on its western border it is, like the shistosity of the wall rock, more gentle. Because of its gentle dip, the horizontal section shown in the map is broader than the other ring intrusions which are generally in steeper positions. There it contains many inclusions and passes in the north gradually over into very leucocratic granite. Its wall rock, particularly near the western upper contact, is very brecciated, but apparently not much disturbed, because the strike is relatively constant. The easternmost of the next two ring intrusions shown in the map is mainly formed by a pair of parallel granite dikes separated by a merismitic zone with amphibolitic paleosome, and remarkable insofar as it continues in gneissose granite only as a shatter zone with very spare granite material. The westerly intrusion, on the contrary, widens and changes into very homogeneous porphyritic granite. In the northwestern corner of Åva it contains a slab of the country rock.

The southern border of the ring complex is less exposed, but it may be noted that the ring intrusions are more heterogeneous than they generally are in the Åva area. They are shown in the map as monzonite

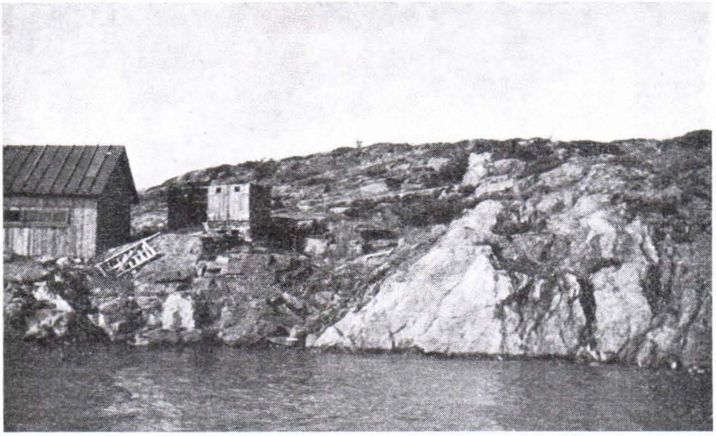

Fig. 7. The contact between monzonite (dark rock on the left) and older migmatite viewed from the southwest. Near the pier of the village of Åva.

even if the general composition is more silicic. These chorismites are mostly stromatitic ophthalmitites with ellipsoidal or lenticular monzonitic fragments in a porphyritic neosome (Fig. 8). Farther to the west they in part gradually pass into porphyritic granite. In some islands north of Björnholm the ring intrusions do not seem to be quite concentric, as they apparently cut and touch each other (pp. 27).

The island group of Raden is a good example of closely spaced ring intrusions. There are at least five separate intrusions of 20—80 m in breadth (the map is simplified). Where the contact has been observed, it is always steeply inclined to the east (cf. Fig. 4). Both to the south and to the north the ring structure is less exposed and apparently some screens taper. The intrusions partly touch each other and some of them fork.

In the northwest the basin of Ängskärsfjärden is bordered only by a narrow row of small islands and skerries. The only continuous screen goes almost along their outside margin. One island situated a little way outside the main island row, however, consists of almost massive medium-grained porphyritic granite with a haphazard orientation of minerals. Therefore, it is obvious that there is a broader intrusion, but the relation of this to the central stock is concealed and cannot be unravelled. A connection over the northern trough with the central stock is most probable.

Upon comparing the structure near the stock with that of the ring structure in the outer part of the eastern island arc, we find that just as the ring intrusions are incomplete, i. e. not closed rings, the screens near the margin also tend to have a discontinuous overlapping character. This

Fig. 8. Ophthalmic monzonite, subsilicic fragments in porphyritic granodiorite. The small island southwest of Långholm, Åva.

is characteristic of the marginal structure of the central stock. The ring structure may also to some extent be considered as a closely spaced system of screen-like inclusions.

In addition to the ring intrusions, numerous smaller and more irregular dikes are found. Generally, they can not be traced over long distances, but they are always sharply bordered. Also, outside the fine-grained ring intrusions, there are irregular dikes of porphyritic granites quite similar to those of the central stock or inner ring intrusions. On Hällholm and Granöholm they may be considerable in size and can be followed over the islands.

In the same areas the dikes of porphyritic granite, apparently also belonging to the Åva granite, may be quite sheared. Sederholm has described two such dikes in the middle island of Renkubbar, north of the quartz-porphyry dike. They are parallel with each other but transect the foliation of older gneissose granite. They strike N 40° E, being sheared in the same direction and are in vertical or very steep position. The dikes contain inclusions of wall rock and it is possible that the screen between them is only a zone of inclusions. Similar sheared dikes are also met with at Hummelörarna and southern Jurmo.

The dikes further away from the centre are granitic, but in northern Fiskö in the western part of the map area there is one dike of mainly massive monzonite. It has a special character in many respects. It has a zig-zag course with two alternating, quite precise directions, N—S and N 60° E, with quite sharp intersections. In the northeastern part of the dike, fissures in the latter direction are predominant and in relation to the structure of the country rock they have the character of cross joints. In the southwestern part, on the contrary, the north-south fissures are pronounced. The dike is less exposed than the country rock, but it seems to be very uniform in breadth, which is about 20 m. Only the connecting link between two main parts over the cove in the western shore may be narrow and more irregular. It may be only an offshoot of granite which is visible between the parts. The dike is very seldom homogeneous. The structure is merismitic or phlebitic with the paleosome of fine-grained monzonite with feldspar porphyroblasts (Fig. 9). The neosome of porphyritic granite is coarser-grained. Only in places there are transitions to almost purely granitic parts of the dike.

Fig. 9. Monzonitic dike with granitic neosome in northern Fiskö. The breadth of the area presented in the figure is about 3/4 m.

CONTACTS AND INTERNAL STRUCTURE

Contacts between the major intrusions and their country rocks are well exposed in many places also in vertical sections. Megascopically, they are mostly quite sharp and smooth. However, particularly in the eastern part of the area, eruptive breccias on the border of the granite separate the so-called Quarry intrusion from the central stock (see p. 18). Injection veins in walls of the country rock are relatively rare, and also the narrow veins are usually distinctly connected with the major intrusives. Melting, assimilation or other similar features between granite and the adjoining wall rock have been apparently slight. Narrow bleached zones accompanying the rectilinear contacts of a dike of porphyritic granite occur in gneissose rock (Fig. 10). Some migration of granitic material into the wall rock is, however, probable, because, in the islands of Raden and also in other places at the contact and specially in the screens the migmatite is more reddish than elsewhere. Sahama (1945) has made distinct observations of this feature at a rapakivi contact. The present author has, however, made no detailed investigations for determining this hybridization. Apparently the granitization of the adjacent migmatites has mainly taken place before the intrusion of the Åva granite, but the role of the Åva granite is an unsolved problem. Granitization on a large scale has probably not been caused by the Åva granite, but in many places, particularly on the western shore of Bolmö, well preserved mica schists are found in immediate contact with the granite.

Fig. 10. A dike of porphyritic granite cutting gneissose rock with a narrow bleached zone in a small island east of Raden.

In contrast to the contacts against the country rock, the contacts between granite and monzonite are only occasionally quite sharp. There is generally a zone of at least some decimeters of hybridic rocks. It is typical that in all places where there is a more or less vertical section, the contact is almost flat and the monzonite is below the granite. In general such contacts are also sharper than others. Closely spaced sheeting occurs in the monzonite near the contact, but it does not occur in the homogeneous rock on both sides of the contact (Fig. 6). A peculiarity of this area is that monzonite occurs more generally in the southeastern part of the ring complex and in many places the granite grades in this direction over to the monzonitic rocks. In the gradual contact the monzonite is very much affected by the granite, as will be described later in this chapter. At the same time, the granite is very homogeneous even near the apparent contact where more or less definable demarcations occur. In every case, the transitions from monzonite to granite seem to be more extensive than the reverse, i. e. at the contact the monzonite shows generally marked changes while the granite is often essentially similar up to the contact.

A typical flat lying contact between monzonite and granite is exposed on the western shore of Åva, where the former rock lies on the shore and the granite forms the upper part of the hillside and the top. The ledge of monzonite is flat and has a jointing gently inclined towards the centre of the basin. The monzonite is only partly homogeneous and in the greatest

Fig. 11. Lenticular porphyritic flecks in monzonite on the western shore of Åva.

Fig. 12. Potash feldspar phenocrys tin monzonite. The western shore of Åva.

part there are irregular veinlike or lenticular flecks of feldspar crystals passing to separate phenocrysts (Figs. 11 and 12). Some fissure dikes of granite cut the monzonite below the slope, where it appears that monzonite goes under the granite, which is, in its upper part, a very leucocratic porphyritic granite. Near the contact, there are various fragments. Some fragments are monzonite or fine-grained granite rocks. The basic fragments particularly show more rounded outlines. In both kinds of rock inclusions phenocrysts similar to those in the porphyritic granite are developed. Quite similarly, the contact can be seen dipping under the granite at a steep slope in the Quarry intrusion farther east (see p. 18).

Most contacts of other kinds between the major intrusion of monzonite and granite are more gradual, if visible in a flat surface. This is true especially in the southern part of the central stock. Only one sharper contact at a high angle has been found in the southwestern promontory of Långö.

F o l i a t i o n. Parallel or subparallel arrangement of feldspar phenocrysts is very common in granite, but generally it does not occur in the most subsilicic monzonites. Also other lamellar minerals, particularly in the most well-foliated rocks, are distinctly oriented. If some oriented inclusions or heterogeneous stripes in granite exist, they have generally the same direction as the general arrangement of minerals. Some local anomalies may occur. The linear parallelism is, however, always uncertain. Ring intrusion granite near the contact is always distinctly foliated and also in the middle part the feldspar phenocrysts show at least a tendency to subparallel arrangement. It is so regular that it has not been shown in the map by symbols. The structure would be also too detailed to be given in the scale of the map.

In border zones of the central stock the granite has the same general platy parallelism, whereas the rocks in the central part lack any parallelism. It has been found also that the parallelism conforms with the shape of the central intrusion and generally dips steeply to the centre in the border zone, but if the parallelism has developed more in the centre the dip is gentler. This observation is, however, only general and there are many local anomalies. The foliation or parallelism is more conspicuous in some zones than in others, and it is apparently very much disturbed by exceptional contact directions, major inclusions, etc. In the southwestern peninsula of Långö, where there is a protrusion of eruptive breccia (see p. 17) into the central stock, the platy structure conforms with it and dips outwards. An exception is the Quarry intrusion in western Åva which is in the middle part massive and only in contact zones the phenocrysts show a parallel arrangement. The afore-described structure is generally believed to be primary and caused by arrangement of minerals in the plane of lamellar flow (H. Cloos, 1936, Balk, 1937). Flow layers have apparently developed during continuous movement by slow consolidation. If there is deviation in the orientation of schlieren or inclusions and of phenocrysts, the former shows the direction of movement at an earlier stage. The phenocrysts grown into inclusions indicate their origin at a later stage of consolidation by metasomatic replacement. Farther down, convergence of flow layers with inward-dipping contact gives the impression of a funnel-shaped body. The later fine-grained granite and also massive porphyritic granites, e. g. the Quarry intrusion, have apparently consolidated during a quiet period.

J o i n t P a t t e r n. The interpretation of the structural pattern of igneous rocks has been greatly stimulated by the pioneering work of Hans Cloos and his collaborators. The first intention of the present author was to make magmatectonic analyses according to Cloos' method, using mainly joint systems. But it turned out, that actual joint observations do not reveal the best evidence in reconstructing the history and mechanism of intrusions in the Åva area.

Jointing in the Åva granite, as well as in the country rock, is abundant and complicated. The main elements appear from the morphology (p. 9), but the details are confusing and too numerous to allow of a definite interpretation. Therefore, it is generally not possible in this study to analyse and interpret the joint pattern and the forces that have caused it, because no detailed observations have been made in a more extensive area. Their correct and explicit interpretation is difficult enough, as the rocks of the southwestern archipelago in Finland have a complicated jointing, part of which is probably quite recent (Edelman, 1949). Joints of different age may have the same direction and in such a case the meaning of the different joints is not easy to study.

The numerous dikes offer good possibilities for studying the meaning of some jointings. This is particularly important, because in this study we are chiefly interested in the local jointing as related to the Åva intrusions. When the fractures have been filled by material or have a characteristic relationship to other features, they are useful for studying their cause and age relationships without the risk of misinterpretation. In general, the joint directions also correspond well with the spacing of the dikes observed, i. e. the dike directions also represent jointing, which thus are at least as old as the dike intrusions. The compound dike fractures and some other irregular structural forms may be due to pre-granitic jointing in the country rock. These problems will be discussed more in detail in connection with the treatment of the dike systems.

One characteristic jointing, which no doubt has a local relationship to the intrusion of the central stock also if not occupied by dikes, is flat lying with a character partly of sheeting. This jointing has a clear relationship to other structures and occurs in nearly all the islands that consist of granite-monzonite rocks in the immediate vicinity of Ängskärsfjärden. It is closely spaced and mainly gently inclined to the centre of the ring complex, but has no constant attitude in the large surface because it generally conforms to the topographic surface of the islands. This jointing is, in general, much more gently inclined to the centre than the foliation of the granite and the orientation of the inclusions in the granite (Fig. 13). In the southern part of the area it appears even in some steeply dipping ring intrusions also outside the actual central stock. This jointing has the same apparent character as the marginal joints in the batholithic structures, but they have not the character of cross joints where the walls of the intrusion are outwardly inclined as in typical batholiths, and the space relationship is quite different. This jointing, as sheeting in general, may also be parallel with the contact of the granite body. This seems, however, less probable in this case, because it does not explain the relations to the other structures. As there are many pegmatites in the same position as these joints, it is certain that an upward motion or drag has been exerted by the intrusive mass as late as the period of formation of these fissures.

I n c l u s i o n s. In the central stock, inclusions of variable composition and size are common in places. They are very irregularly scattered in the whole area and particularly great patches of country rock may be found quite in the centre of the area. Ängskär, for instance, consists mainly of

Fig. 13. Flat lying jointing forming a small angle with the platy parallelism represented by feldspar phenocryst and fine-grained stripe. The slope is viewed from the southwest. The western shore of Åva.

gneissose granite, and porphyritic central granite is only in part the predominant rock, forming dikes everywhere clearly truncating the older gneissose rock. The latter has, however, a relatively constant strike. There are also similar great patches of country rock in the southern part of the area.

Some remnants, too small to be shown in the map, are certainly screens, e. g., wall rock remnants between two separated intrusions, as in the island of Killingsören, north of Björnholm. There a slab of reddish migmatitic granite extends along the northern shore, penetrated in the south by typical, homogeneous leucocratic Åva granite. In the west the migmatitic granite is next to the sea, but more eastwardly it is penetrated also on the north side by porphyritic granite which appears on the shore. The wall rock slab tapers gradually between two granite intrusions, which are certainly separate intrusions. The contacts against the wall rock remnant are very steeply (75°—80°) inclined to the centre.

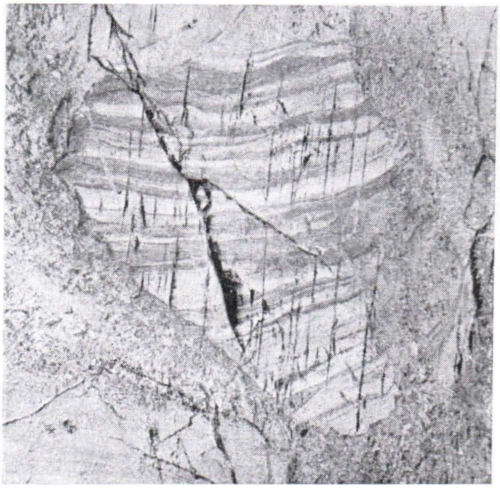

Fig. 14. Corroded inclusion of banded hornblende gneiss in porphyritic granite. The western shore of Åva.

The inclusions in the porphyritic granite have a partly angular or subangular shape and are certainly xenoliths of older rocks. They are banded gneisses, mica schists, etc. They sometimes show absorbtion phenomena along the borders. In some of the layered hornblende schists it appears that the surrounding granite has assimilated the light bands a little more than the dark, mafic bands. In these cases the xenoliths are mostly quite sharply bordered and surrounded by an even-grained contact variety (Fig. 14). Because all xenoliths are usually not of the same character as the neighbouring wall rock, they must be at least partly hypoxenoliths.

Another kind of inclusions besides the angular xenoliths is more rounded and shows plastic forms which are also sometimes elongated (Fig. 15). They have a composition similar to that of the monzonitic rock. As compared to the country rock xenoliths, the different character of those subsilicic blocks makes it probable that it is cognate representing an earlier subsilicic rock, which has been shattered by later granite before its final consolidation. It is, however, not impossible that they represent highly reworked, softened basic xenoliths which have gone upwards along with the magma. When they are found without certain transitions besides the more angular xenoliths, this is improbable.

Inclusions of brownish fine-grained granite with lenticular outlines, seldom more elongated, also have a character similar to these monzonitic inclusions. Especially near the border they have phenocrysts of potash feldspar similar to that of the surrounding granite. Sometimes the phenocrysts have grown from the host rock into inclusions. Similar phenocrysts are very common in the monzonitic inclusions, too (Fig. 15).

In the ring intrusions xenoliths of the country rock are less common, and when present they are near the contact and mostly angular. They are generally similar to the wall rock and apparently epixenoliths even if they do not seem quite to fit the neighbouring wall. Some hypoxenoliths, cognate inclusions and the heterogeneous character of some ring intrusions are discussed in another paragraph (pp. 13).

Fig. 15. Rounded inclusions of fine-grained granite (on the left) and monzonitic rock (right) with feldspar phenocrysts in porphyritic granite. The western shore of Åva, Brändö.

GENERAL PETROLOGY

The petrology of the granite-monzonite series offers many interesting features, which can not be discussed in detail in this paper, because the chemical data available are not satisfactory. Analyses of the rocks are given in Table I. According to the field and microscopic aspects they form a series from potash-soda granites to monzonites.

The analysis of the Quarry granite (Table I, no. 1) published previously by Sederholm (1924 and 1934) does not represent the most common granitic rock type of the area (cf. p. 18). It apparently reveals, however, the general petrological characteristics of granitic rocks, although the central granite is partly richer in potash, as indicated by the great quantity of potash feldspar phenocrysts, but plagioclase is always noticeably present. The Niggli numbers of analysis accord closely with those of the rapakivi magma type of P. Niggli, the ratio *c/fm* nevertheless being somewhat too great.

The analysis of hornblende-biotite-monzonite of Österskär (Table I, no. 2) represents the composition of a homogeneous subsilicic member of the series. It belongs definitely to subsilicic rocks rich in alkalies. Especially because the content of potash is almost as great as that of soda, it is an exceptional rock. Similar rocks do not occur very commonly. According to the Niggli numbers, it belongs to the potash-dioritic magmas, but it is not distinctly included in any of the subdivisions of P. Niggli (Burri and P. Niggli, 1945). It is a transitional type between sommaite-dioritic and lamprosommaitic magmas. Still worse it fits the earlier classifications of magmas rich in potash (P. Niggli, 1923). There it belongs to monzonitic magma types, but it does not at all fit its subdivisions.

Table I. Chemical analyses of the rocks of granite-monzonite series.

	1	2	3	4
SiO_2	72.63	52.47	51.24	47.52
TiO_2	0.29	1.64	1.76	2.21
Al_2O_3	13.33	15.48	16.11	15.87
Fe_2O_3	0.72	3.74	5.35	6.95
FeO	1.72	5.91	4.88	5.75
MnO	0.04	0.16	0.18	0.18
MgO	0.63	5.23	4.07	4.61
CaO	1.88	6.53	6.87	7.34
BaO	0.08	0.23	0.34	0.36
SrO	0.00	n. d.	0.10	0.21
Na_2O	3.07	2.62	2.60	1.76
K_2O	4.82	3.33	4.26	3.97
P_2O_5	0.19	0.82	1.07	1.51
H_2O+ / H_2O-	0.31	1.14	0.40	0.75
S	0.11	0.26	0.38	0.39
Cl	0.09	n. d.	0.16	1.12
CO_2	—	—	—	0.33
	99.91	99.54	99.77	99.83
si	384	144	141	123
al	41.5	25	26	24.5
fm	15.5	43	39.5	44
c	11	19.5	20	20.5
alk	32	13	14.5	11
qz	+256	+ 8	+ 9	— 21
k	0.51	0.46	0.52	0.60
mg	0.32	0.50	0.42	0.40
ti	1.1	3.4	3.6	4.2
p	0.1	0.9	1.2	1.6
c/fm	0.69	0.45	0.51	0.47

1. Granite. Quarry N. W. of the village of Åva, Brändö, Åland. Analyst Elsa Ståhlberg (Sederholm, 1924).
2. Monzonite. Österskär, Brändö, Åland. Analyst Matti Tavela (BaO has been controlled by P. Ojanperä).
3. ? Monzonite. Åva, Brändö, Åland. Analyst Elsa Ståhlberg (Sederholm, 1924).[1])
4. ? Rock fragment in Åva granite. Åva, Brändö, Åland. Analyst Elsa Ståhlberg (Sederholm, 1924).[1])

[1]) See discussion on the following page.

The last two analyses in Table I have been published by Sederholm (1924), but he has not included them in his later Åland studies. They are included in this paper, because they have been published also in another connection (Lokka, 1934) and later used by P. Niggli (1946) in his calculations. The reason why Sederholm later omitted these analyses is not definitely known to the present author. It seems, however, that the analyses as presented by Sederholm may not be correct. The analysis of the »symmictite» is similar to the composition of some lamprophyres (cf. Table II), while the »rock fragment» closely resembles the rock which has been called monzonite in this study. It similarly has a potash-dioritic composition, but *fm—al* is smaller and *k* is still greater. According to these characteristics it can be included under the monzonite-dioritic rock types (Burri and P. Niggli, 1948).

In its other aspects the »symmictite» of Sederholm corresponds with the monzonite of the present author (see p. 65). Hence the analyses may have been changed and misplaced at some phase, and Sederholm already found some unreliabilities. Perhaps it is because the rock fragment according to analysis is more silicic than the »symmictite» or homogenized eruptive breccia, which apparently according to his idea has originated from fragments of similar composition mixed with granite. In his Åland studies he also says: »There are in the contact breccias of the Åva granite fragments of older rocks of quite the same composition as the lamprophyric dikes». According to this sentence Sederholm has been aware of the apparent error, otherwise he would have referred to the composition of »symmictite».

On the basis of all these facts the analyses given in the foregoing table are changed. The »rock fragment» is entitled monzonite and »symmictite», »rock fragment». Because, however, the matter can not be positively established, the report has in each case been supplied with a question-mark.

LAMPROPHYRIC DIKES

DISTRIBUTION AND TREND

Lamprophyric dikes, numbering 50 or more, are located near the central stock and its offshoots, the ring intrusions. As can be seen from the map they are not equally distributed. Most of the dikes are disposed in certain parts around the granite massif as dike sets and they are more numerous in the eastern part of the area.

The dikes are mostly vertical and a few of them have a dip of less than 80°. They have a tendency to form a radiating system, but there are many exceptions so that often two adjacent dike groups may have remarkably divergent directions. A feature brought out by mapping is that the dikes are in most localities about at right angles to the foliation of the wall rock, where it is developed. Because of this cross character the dikes can be easily distinguished from subsilicic »schlieren», which may in the field be similar to the lamprophyres.

Some dikes shown in the map represent a pair of neighbouring dikes or a set of smaller ones. The dikes extend generally farther to the northeast and southwest than in other directions. The outermost dikes are found about 5 km from the centre of the stock. Most dikes start in the central body or just outside of it, but have mostly an irregular course with apparent offsets, as will be described later. Many times this makes it difficult to trace the dikes; in such cases it seems as though there were several dikes but it is more reasonable to believe that they are connected with each other.

The general trends of the dikes, visible in the map have a more radial arrangement than the strikes of individual fissures observed. This relation can be brought out by comparing the course of an individual dike in the map with the more detailed shape of the same dike in Figs. 18 and 19. The predominance of some dike directions visible in the map is not achieved only by the unequal distribution of the dikes. Some directions seem to be more readily developed than others. Among the exceptions to the general arrangement, those of regional character are more important. In the eastern island arc where the periphery of the area of the major intrusions is more completely exposed, it appears that the trends of different dikes do not grade into each other. The directions of the adjoining dikes, unless they are parallel, form an angle of 20°—30° and the intermediate directions are not observed at all. In the massive rock their direction is evidently more variable than elsewhere. For example, in the western promontory of Åva the closely spaced dikes trend in different directions, the southern dike even changing its direction.

The general trend of the whole dike is also due to other factors. In the relative frequence of the different directions of fractures, attention must be paid to the distribution of exposures in the area. In every case the predominance of N 50°—60° E, N 10°—20° E, E—W and N—S directions of fractures is clear. It also appears that the corresponding directions are not always equally predominant on both sides of the area.

SIZE AND SHAPE

The broad framework of the radial system of these dikes is a peculiar feature, but there are excellent possibilities for detailed study of their structural pattern where it is well displayed in numerous exposures. The lamprophyric dikes are smaller than the diabase dikes, only the broadest one, in the island of Ytter-Långskär, being over 2 m (Fig. 16), while the majority are between 0.5—1.2 m in thickness (Fig. 17). Quite narrow dikes are found only near the broader dikes parallel to these.

Fig. 16. The broad dike on the western shore of Ytter-Långskär viewed from the west. On the shore it is divided into two parts by a stripe of wall rock, porphyritic granite, which is sheared with the dike. The narrower part on the left tapers gradually, while the other widens in the background up to 2.3 m.

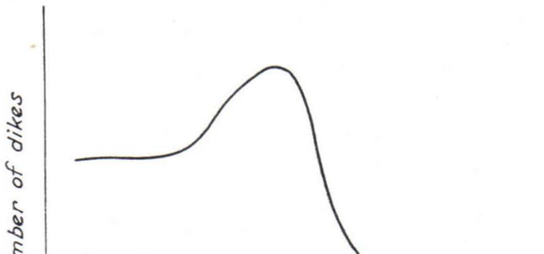

Fig. 17. The relative frequency of individual lamprophyric dikes of different breadth in the Åva area.

The shape of the dikes is very variable and while most of them have the characteristics of dilation dikes, others show irregular configurations. At first sight it seems difficult to find any general manner of emplacement for all dikes. The question arises that perhaps they belong to different series. The dikes with a different petrological character generally show as great variability in form. Petrology and shape do not generally depend on each other or, if they do, as in the case of sheared biotite lamprophyres, it is only apparent and does not mean a greater difference in age (cf. p. 41). Therefore more than one series of lamprophyric dikes of different ages may not be plausible.

In making a geometrical analysis of all dikes it would be better to take into account first only the more regular dikes, which have, at least in the main part, straight walls, and then pass to the more irregular ones. After these analyses are made, one can better find a mechanism common to all dikes.

Only simple dikes are quite uniform in width and any changes are gradual. The contacts are always sharp and the walls at least of the main fissure are almost even, except for some sinuous details. Projections may be found, but they are mostly angular and sharp and the opposite side has a corresponding re-entrant so that the dike is clearly formed by a simple widening of a fracture (e. g. Fig. 18 g). Some dikes have a typical echelon structure with overlapping tapering ends. More typical and even more common, particularly in the broader dikes, is a pattern of similar framework, but with parallel or at least approximately parallel parts of the dikes connected by a link formed by a transverse fracture. This fracture is very seldom perpendicular to the main fissure, but is mostly clearly inclined or curved towards the direction of the lateral movement along the dike as seen in the horizontal surface (Figs. 18 a and d). A feature connected with this is that the opened part of the main fissure has a gap more commonly than it has an overlap. A greater overlap has been found only in one dike (Fig. 18 b). In addition most dikes in these displaced sequels have no change in their thickness and the ends of the main fissure are blunt in contrast to the dike echelons. Less common are cymoid curves in the dike pattern (e. g. Figs. 18 c and e).

The amount of an apparent offset is variable in different dikes, but in an individual dike it is suprisingly uniform and usually not very much greater than the breadth of the dike (cf. Fig. 18). It is easy to note when it is not much broader than the dike, but offsets of some meters have been found. A great offset makes it difficult to trace the dike, although the pattern is continuous and the sequel is usually to the same side. If it is not well exposed, it is not possible to say whether it is a sequel or another dike of the same swarm. This is not essential because adjacent dikes may have a connecting link also.

If the offset is small, it has caused only pinching. The link-character is revealed by the offshoots or apophyses extending in the main direction of the dike from the outer edges of the offset so that stublike protrusions are formed (Figs. 20 and 21). This kind of offset in comparison with struc-

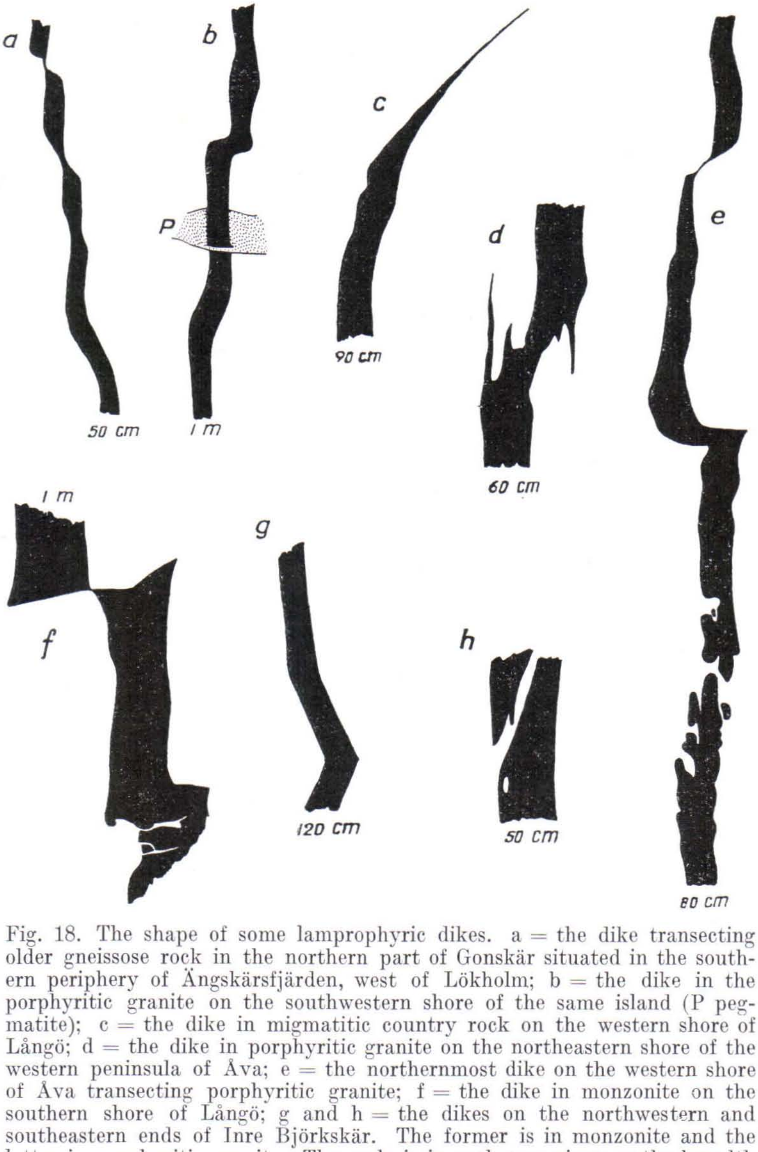

Fig. 18. The shape of some lamprophyric dikes. a = the dike transecting older gneissose rock in the northern part of Gonskär situated in the southern periphery of Ängskärsfjärden, west of Lökholm; b = the dike in the porphyritic granite on the southwestern shore of the same island (P pegmatite); c = the dike in migmatitic country rock on the western shore of Långö; d = the dike in porphyritic granite on the northeastern shore of the western peninsula of Åva; e = the northernmost dike on the western shore of Åva transecting porphyritic granite; f = the dike in monzonite on the southern shore of Långö; g and h = the dikes on the northwestern and southeastern ends of Inre Björkskär. The former is in monzonite and the latter in porphyritic granite. The scale is in each case given as the breadth of the dike.

tures caused by transecting fault has been discussed by the present author in another connection (Kaitaro, 1952). The following of the criteria given in this previous paper are of importance in this case.

The hypothesis of a later, even healed, transverse fault is evidently to be rejected because of the presence of a fine-grained contact against the transverse wall and of the discontinuity of the link, or transverse fissure, into the wall. It is usually quite apparent that lamprophyric dikes occupy compound fissures. The movement during the opening of the dike fractures may not be entirely tensile, because many features can be explained only by the additional assumption of lateral movement along the fissure (Figs. 18 a and b).

Anderson (1951, p. 22) suggested that the lateral or vertical movements along a dike fissure are probably due to the filling of a pre-existing fault by a later dike intrusion. The irregular course of lamprophyric dikes does not in this case favour this possibility and it is to be rejected, at least as an only interpretation, because the internal structure of the dike also indicates movements (p. 41).

Pinching and breaking at the dike offset, as well as swelling in some dikes (Fig. 18 b), depend on the direction and amount of slip in relation to fracture. It is noticeable that the dikes are more commonly pinched than swollen. In the jagged dike the strike slip visible in the horizontal surface is usually very slight or up to some decimetres, and it does not generally exceed the breadth of the dike. In simple dikes it may be more conspicuous. One feature, which also is in agreement with the primary origin of offset structures, is an offshoot over the »fault» in the main direction of the dike (Figs. 21 and 22). This feature even points out that the transverse fissure has developed later than the main fissure and apparently during formation of the dike. The non-coincidence of the development of different parts of the compound fracture is apparently based on the following consecutive processes. It has first formed a zone of tensional overlapping gashes, but later, when tension has gone over to shear, the diagonal link fissure has been formed by breaking the wall rock stripe in between. By its formation, the shear has played a most important role to the extent that the fracture may not have essentially opened. This is suggested by the observation of displacement parallel to the link fracture. A few dike fissures have a structural pattern which may not be caused by one simple movement, but first by a simple separation of the walls and then a slip along the main fissure (Fig. 18 a).

As already mentioned the walls of the main fissures are generally even, but the connecting link fissures are only relatively seldom so well developed. Especially in massive granite they may be very irregular (Fig. 18 d) and even have a resemblance to flexure or folded structures. This has led Sederholm to some erroneous interpretations. He has considered some features as deuteric, i. e. as originating before the final consolidation of the country rock (Sederholm, 1924). This may have played an important part (see p. 39), but only the dikes transecting the Åva granite can thus be explained.

It is hardly necessary to remark that the presence of the apparent offset in some localities does not exclude the possibility of a later fault or folding, where a real trace of fault (Fig. 19) or fold structures is visible in the wall rock, but such examples seem to be few.

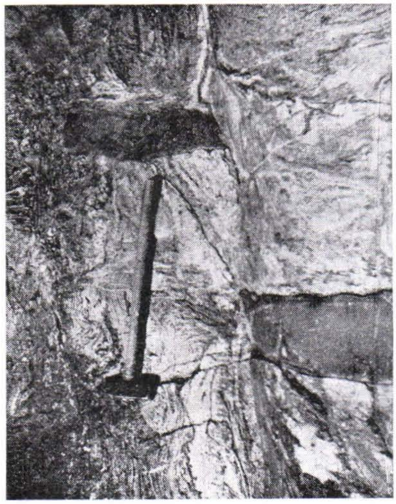

Fig. 19. A lamprophyric dike in mica-gneiss displaced by an apparent fault. Långören, west of the southern part of Bolmö.

The analysis of the aforementioned structural pattern is made generally in the horizontal plane view, using mainly the shape of the dike itself, especially the transverse fissures and stubs, to measure the tensile and lateral relative displacement of the wall rock blocks. In most instances the mechanism already described is sufficient to explain the different forms. A complete analysis of the pattern of the dikes is, however, not possible in one plane, unless the dikes are very steep. It is necessary to show the shape of the dike in space revealing the divergent dip of different structural planes. When the whole shape of a dike is analysed, it can usually be shown that a strike slip alone does not give a satisfactory explanation of some of the details just analysed as an example. The strike slip determined from different transverse fissures and pre-existing structures of the wall rock along the same individual dike may have a different value (e. g. Fig. 18 f). If the tilted, vertical, and even rotational displacements are considered as is done in some localities discussed in this chapter, the different strike slips and different forms at the offsetting in the same dike are due to a divergence in the attitude of the three-dimensional structural features, which can not always be established exactly because observations have been made in a flat rock surface. Along some broad dikes there are scarps, where there are some possibilities of seeing a vertical section. So many of the analysed structures imply vertical, tilted or rotational movements that these movements must have been essential for the origin of dike structures. Often it is not even possible to compare the markings in the opposite walls, which may just be a result of greater relative displacement. This feature is apparently more common in some dikes with curved tapering ends caused by the displacement of a partly curved fracture, with shear along one flank grading into rupture at the other part. The best exposed example of such a dike form is one on the western shore of Långö (Fig. 18 c). The main fissure (N 15° W) is inclined 70° to the east, but the curved part having a northwestern direction is inclined 80° E and the tail (N 30° W) is vertical. In such a case the vertical movement (uplift of the eastern part) may cause the rupture. This is here probable, because it is not possible to compare the markings in the opposite walls. The dike is cut by very thin, straight aplitic veins.

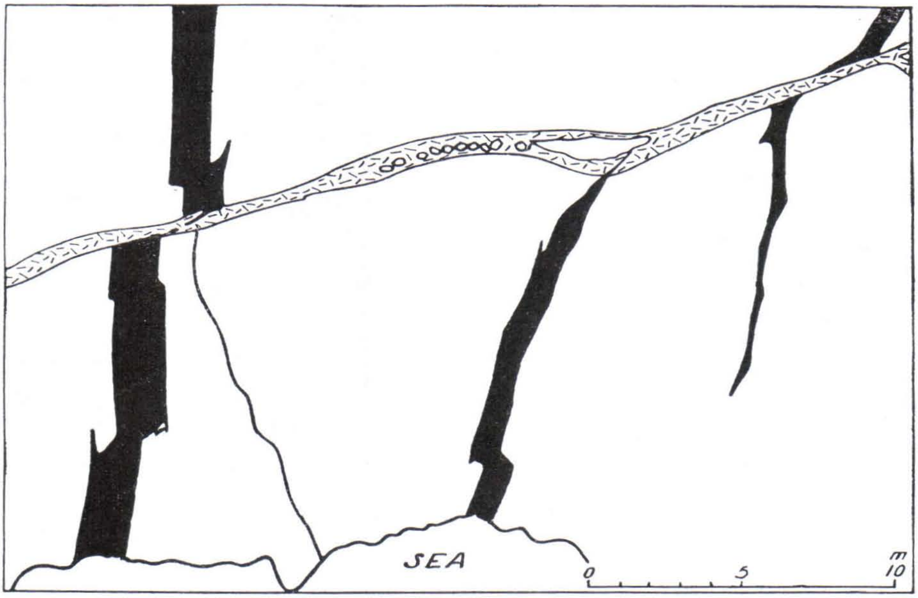

Fig. 20. Lamprophyric dikes (solid black) with the general E. S. E. direction in porphyritic granite (left blank). Pegmatite (hachures) contains pure quartz masses and a great lens of wall rock in the middle part of the figure. The western promontory of the Åva island (cf. Sederholm, 1934, Fig. 31).

If it seems that the dilation mechanism can not be applied to some individual dikes, the reason may be one or more of the following. If both contact lines do not fit quite well, it can be explained by a difference in strike of the transverse fissure in the deeper level and by a dip slip fault. Some irregularities may be caused by stoping, but larger xenoliths are rare and usually near the walls of the dikes (Fig. 18 h). All the xenoliths that have been found are of Åva granite and mostly epixenolithic in character.

Sederholm has given a detailed drawing of the dikes in western Åva (Sederholm, 1934, p. 49). This almost classical locality has been most visited by geologists. It shows many typical features, but they are not as well exposed as those in the other localities, where the origin of the general structural pattern is clear (cf. Figs. 20—22). A more detailed investigation of the localities, when all possible cover of lichens and mosses has been removed, has shown that the drawing of Sederholm is rather misleading and his interpretations are not quite satisfactorily proved. According to his drawing the offsets of the dike fissure are flexure folds. Fig. 20 shows the structure of the dikes according to the revised mapping of the author. The interpretation of the structure is not, however, quite simple, but the following analysis may explain it. In the broader dike

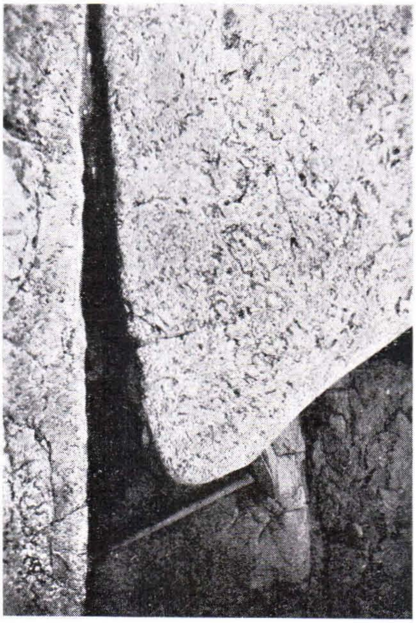

Fig. 21. An offshoot at the first offset from the shore line in the northern lamprophyric dike in Fig. 20. The main direction of the dike in vertical position in the picture (the handle of the hammer pointing North). In the middle of the picture a small apophysis may be seen extending from the offshoot into the granite.

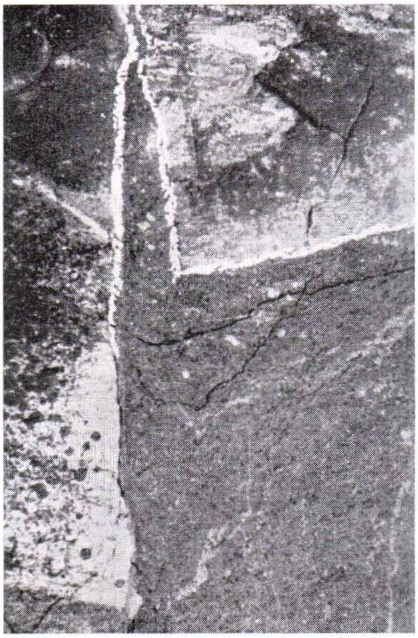

Fig. 22. Detail of the stublike protrusion (identical with that in Fig. 21) in the lamprophyric dike on the western shore of Raden. The contact against migmatitic schists is partly drawn out. The main direction of the dike is vertical in the figure. The breadth of the area presented in the picture is about 1 m.

fissure the strike slip by diagonal fracture dipping to the east at the first offsetting from the shore is greater than that by fracture dipping steeply to the west at the second offsetting, supposing that the pegmatite wall represents the direction of the transverse fissure. It means that the slip has had such a direction that the southern wall has moved upwards and at the same time to the east. In the narrower dike somewhat to the south, vertical movement seems to be the opposite way, the southern wall having moved downwards, but here the dip of the diagonal fissure cannot be so exactly established. The country rock between these dikes is thus apparently like a shear wedge. The contact relation with pegmatite is not quite as simple as described by Sederholm, but that will be discussed later (p. 58).

Some dikes in granite (Fig. 18 e) or near its contacts in the screens have a curved irregular shape, but a few dikes have quite abrupt bulges. If we suppose that these fissures have opened during or just after the consolidation of the granite, the wall rock may have been still plastic and so caused the irregularity of the fissures. It is peculiar that just such dikes have no chilled margin and granite may disrupt the lamprophyric dike. It means that the temperature of the intruded material and wall rock has made no considerable difference, probably because the granite has still been warm and therefore in part easily remolten.

PETROGRAPHIC CHARACTERISTICS AND INTERNAL STRUCTURE

The lamprophyres are melanocratic dike rocks, mostly grey or greyish black in colour, some reddish rocks being exceptions. In field study the dark constituents are of importance, because they are easily determinable. The determination of feldspars in the field is not possible. Sometimes it is difficult even under the microscope, if the rock is very fine-grained and the feldspar is turbid or altered. Therefore mainly two types have been distinguished according to the dominant dark constituent, hornblende- and biotite-lamprophyres. The variation is imperceptible even within certain individual dikes. The relation of hornblende to biotite may vary greatly in the direction of the dike and still more commonly the fine-grained border zone is darker and richer in biotite than the centre of the same dike. Therefore a more accurate determination of the petrographic character of each dike is not even essential.

According to the dominant feldspar, when it is determinable, most dikes are syenitic lamprophyres, vogesites and minettes, and a few are kersantites. The latter have not been found transecting the Åva granite, but they occur in the neighbourhood in such a position that they can be included in the same dike system. Their space relation is, however, somewhat questionable (see pp. 44). Nearly all intermediate varieties between these are found, the hornblende- minettes and biotite- vogesites being the most common rock types.

Hornblende occurs in general megascopically as phenocrysts or spots, but under the microscope the porphyritic character is not so clear, because a close examination reveals that the phenocryst mostly has the character of hornblende aggregate, giving the structure a more porphyroclastic character. Needles of hornblende occur also in the groundmass. Quite fine-granular rocks occur in contact zones and narrow dikes. The more metamorphozed dikes are always rich in biotite, while the hornblende-lamprophyres, especially the typical vogesites, are more massive. They may differ from the others also in their green colour, owing to the hornblende.

Biotite and feldspars occur mostly in the groundmass. The former may form dark dots with hornblende, though seldom alone. Potash feldspar occurs also as big corroded or skeletal phenocrysts. They are similar to the phenocrysts of porphyritic granite, which may form the very neighbouring wall as it clearly is the case with the xenocrysts in the offshoot of the northern dike on the western shore of Åva (Fig. 21). In such instances they can be definitely considered as xenocrysts. Megascopically visible crushed quartz grains with undulatory extinction and surrounded by a zone of hornblende are found in some dikes, and they may have a similar origin. Otherwise quartz occurs very seldom in lamprophyres. Xenoliths up to a microscopic scale, are found near the contacts of the dike. They are mostly quite distinctly fragments of the adjacent wall.

Apatite is common and often very abundant as an essential mineral. It may form relatively large prisms, while sphene mostly does not have a definite crystal form.

If the shape of the lamprophyric dikes is heterogeneous, their structural and textural variation is perhaps still greater. The structure mainly depends on the different grade of metamorphism within the dike. The question arises of the relation of metamorphism to the age of formation of the dike. In many respects geologists have a tendency to consider the grade of metamorphism as a criterion for the age of the rock. From other points of view it is not reasonable to group the dikes according to a different relationship to the granite (p. 58). Because lamprophyric dikes in massive granite may be sheared it is evident that metamorphic features depend on the local conditions and the manner of formation of the dike. On the basis of these principles, which are in agreement with many other field aspects, the most consistent way to discuss the internal structure would be to account for the general development of a dike, as based on other observations.

Fig. 23. Sheared lamprophyric dike followed by pegmatite. The flow lines indicate the direction of the shearing movement. The northwestern peninsula of Granöholm.

Fig. 24. Lamprophyric dike 40 cm in breadth with slightly sinuous contacts against banded gneiss and transected by a narrow carbonatic dike presented mainly by a fissure. The eastern shore of Bernholm.

The dikes are generally more or less sheared, and the orientation of mafic minerals, light dots and small veinlets, is conspicuous. This gives the rock the appearance of ophthalmitic to phlebitic stromatite. This orientation is commonly at an acute angle to the direction of both the dike and the structure of its walls. When a dike is considerably sheared, the foliation is in the direction of the dike or only at a slight angle to it (Fig. 23). Often the angle between the direction and foliation of the dike may vary, going from the border zone to the middle part of the dike. The former is generally more massive and homogeneous.

Besides dots and ductless strings of granite, many dikes are transected by straight, continuous narrow granitic veinlets (Fig. 16). These occur mainly within lamprophyric dikes, but do not generally pervade the neighbouring wall rock. Narrow carbonatic dikes transecting lamprophyre have also been found (Fig. 24).

The following analysis of a dike in a small skerry north of Hummelörarna is presented as an example of the relation of the different structural features in the same individual dike (Fig. 25). The very shape of the dike indicates lateral movement of the opposite wall rock blocks. This force couple is shown by arrows in the key of the figure. It may be primary or, when it has resulted by compression, secondary. This is shown in the strain ellipse together with the corresponding tension.

One of the two shear planes, which is parallel to the couple, is represented by the fissure filled by granitic material near the contact. Along this plane movement has taken place and brought about local brecciation and tensional gash-like cracks extending to the middle part of the dike, where the deformation has been more plastic. The foliation of the dike represents the direction of the other general shear plane in turned position, which further off the contact is more turned, i. e. almost parallel with the direction of the dike. The foliation is partly perpendicular to the direction of the compression and has been modified by it, but it is essentially a shear plane, because the structure shows obvious movement along it. The small light

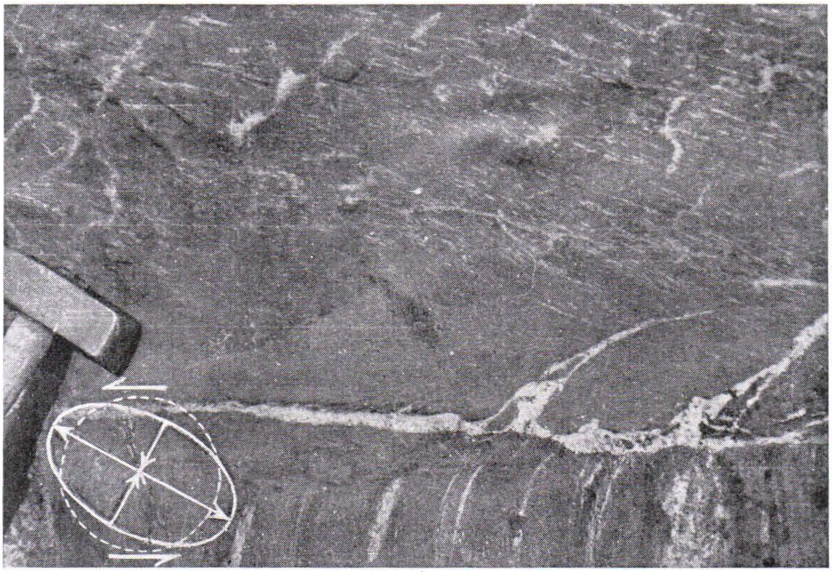

Fig. 25. Lamprophyric dike sheared in an oblique direction to that of the dike (horizontal in the picture). The wall rock, banded gneiss, is visible in the lower part of the picture. The narrow aplitic dike occupies and brecciates the contact on the right, but it transects the lamprophyric dike on the left. The strain ellipse shows the relation of shear to tension and compression. A rocky islet northwest of Hummelörarna between Bolmö and Granöholm.

dots lie parallel to the foliation, but bigger strings occur clearly in tensional openings. The structural difference between the contact zone and the middle part of the dike is apparently achieved by the different physical state towards the end of the process. It indicates that the movement was contemporaneous with the dike intrusion, continuing after the consolidation of the contact zone, while the middle part was still crystallizing. The magmatic action penetrated the crystallized mafic minerals and produced the foliation. The still fusible material was squeezed out of the main mass and formed the strings and dots.

GENERAL PETROLOGY

In spite of their great petrographic heterogeneity the lamprophyric dikes have many general characteristics as shown by the analyses in Table II. In fact the variability is, however, apparently somewhat greater than that given by the present analyses, if the structurally heterogeneous rocks, which are not represented among the analysed rocks, are also taken into account. Because this heterogeneity may not be quite primary, this procedure has been well-grounded.

The petrology of lamprophyric dikes reveals plainly the character of the rock complex. Despite their lower value of *si*, the values of *k* are generally still greater than those in monzonite, while *mg* is also generally but not so definitely greater.

These melanocratic dike rocks rich in alkalies have, however, still a »monzonitic» character with an almost equal amount of both alkalies, while potash is generally only slightly predominating. Instead of the small positive value of *qz* in monzonite, the lamprophyres have a great negative value. It is for the most part accounted for by the presence of sphene, apatite and magnetite as well as, mostly, biotite. Sometimes it may be achieved by aluminous hornblende. The high value of *al* in vogesite (Table II, analysis 2) indicates this possibility, while the alteration of feldspars to such a great extent is not probable.

The great phosphorus and titanium content is typical of monzonite, but also in this respect the lamprophyric dikes are still more extreme. Especially the phosphorus content, even with great variability, is sometimes quite unusually high, approaching 2 % P_2O_5. This is to be expected, because apatite occurs as an essential mineral. The content of barium is in the rocks of granite-monzonite series considerable, but it is still more typical of lamprophyres except hornblende-vogesite (Anal. 2). It is very remarkable that the contact zone and generally the lamprophyres rich in biotite, have a higher content of barium.

It is noticeable that all dike rocks in a silicic country rock (Table II, analyses 1, 2 and 6) have a higher value of *si* than those transecting monzonite (Table II, 3—5). This may be a clue for understanding the heterogeneity of the dike rocks. The study of their behaviour is well-founded.

The first analysis (Table II) represents the composition of a homogeneous narrow dike transecting the Åva granite. The low value of *fm* is considerable, while the negative value of *qz* is relatively small. Analysis 2 of vogesite represents a dike also transecting a silicic rock, the Åva granite. It shows very similar values of *si* and *qz* as well as of *fm*. The high value of *al* is as suprising as the low value of *c*. They are apparently due to the aluminous hornblende as the only mafic mineral. The potash content is unusually high for vogesite. From analyses 3 and 4 it is seen that the contact is slightly more silicic, but the other values show more differences. The values of *al*, *c* and *alk* are greater in the contact zone, while *fm* is smaller. In the same manner *k* is greater in the contact zone contrary to *mg*. Analysis 5 has many general characteristics common with analyses 3 and 4 and it may be considered as a transitional member between these two, except for the slightly higher values of *si* and *al*. The last analysis in Table II has the highest value of *si* and many other values are different from those of other lamprophyre dikes described previously, but they are in many respects closer to those of monzonite. It is very peculiar that just this hornblende-kersantite, a transitional member between kersantite and spessartite, is one of the most doubtful dikes. Its regional and structural relation to the central complex is not quite clear, but because of its characteristical content of barium it most probably belongs in the lamprophyric dikes, connected with the central complex. Its special character may have resulted from its different petrologic development.

Table II. Chemical analyses of lamprophyric dike rocks

	1 %	2 %	3 %	4 %	5 %	6 %
SiO_2	47.73	46.94	44.57	44.38	47.44	50.42
TiO_2	1.91	2.16	2.08	1.92	1.60	2.00
Al_2O_5	15.86	19.86	15.42	14.75	16.07	16.22
Fe_2O_3	4.31	3.27	3.67	4.59	4.49	4.04
FeO	5.89	5.46	6.21	6.36	6.15	7.09
MnO	0.18	0.15	0.19	0.12	0.15	0.15
MgO	5.36	5.52	7.17	8.58	6.68	4.20
CaO	7.56	4.70	8.02	7.69	7.12	7.86
BaO	0.43	0.10	0.62	0.49	0.50	0.44
SrO	0.24	~0.05	n. d.	n. d.	n. d.	n. d.
Na_2O	2.06	2.91	2.42	2.70	2.22	2.78
K_2O	5.10	4.27	4.56	3.81	4.52	3.36
P_2O_5	1.35	1.27	1.82	1.35	0.95	0.77
others	[1]) 0.78	—	—	—	—	—
H_2O+	0.68	2.80	2.92	2.59	1.54	1.07
H_2O-		0.44	0.27	0.28	0.23	0.11
	99.44	99.90	99.94	99.61	99.66	100.51

	1	2	3	4	5	6
si	121	124	106	101	116	132
al	24	31	21.5	20	24	25
fm	41.5	41	45	49.5	45.5	40
c	21.5	13.5	21	19	18	22.5
alk	13	14.5	12.5	11.5	12.5	12.5
qz	—32	—34.5	—44	—45	—33	—18
k	0.62	0.49	0.56	0.48	0.57	0.44
mg	0.49	0.53	0.57	0.59	0.53	0.41
ti	3.6	4.3	3.7	3.3	2.9	3.9
p	1.6	1.4	1.8	1.2	1.0	0.8
c/fm	0.52	0.33	0.47	0.39	0.42	0.56

1. Lamprophyre. The southernmost dike in western Åva (see Fig. 20), Brändö, Åland. Analyst Elsa Ståhlberg (Sederholm 1924).
2. Lamprophyre (hornblende-vogesite). The eastern shore of the western peninsula of Åva (see Fig. 18 d), Brändö, Åland. Analyst Matti Mäntynen.
3. Contact modification of the lamprophyric dike. The southern shore of Långö (see Fig. 18 f), Brändö, Åland. Analyst H. B. Wiik (BaO has been determined by P. Ojanperä).
4. Middle part of the same dike as in Anal. 3. Analyst H. B. Wiik (BaO has been determined by P. Ojanperä).
5. Lamprophyre. The western part of Inre Björkskär (see Fig. 18 g), S.W. from Långö, Brändö, Åland. Analyst H. B. Wiik. (BaO has been determined by P. Ojanperä).
6. Lamprophyre (hornblende-kersantite). Hällholm, Brändö, Åland. Analyst H. B. Wiik (BaO has been determined by P. Ojanperä).

[1]) Including CO_2 0.29 %, S 0.42 %, and Cl 0.07 %.

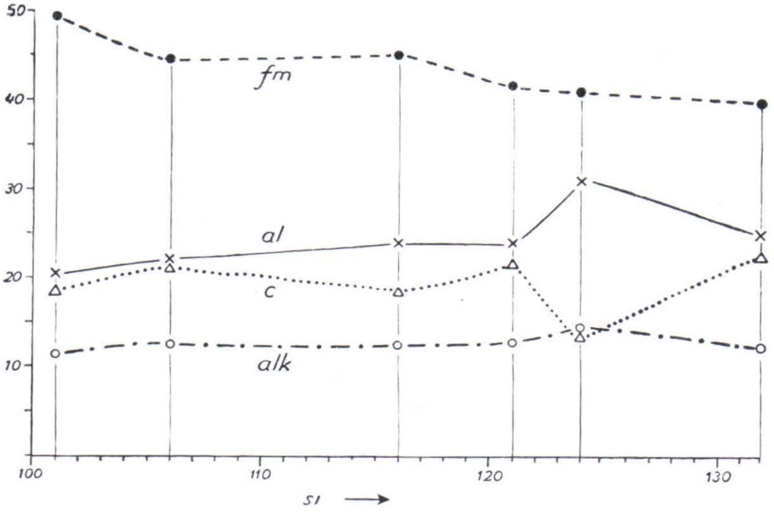

Fig. 26. Variation diagram of the lamprophyric dikes.

While some values are variable, *alk* is relatively constant. *k* and *mg* are also generally about 0.5. If we omit the extreme types, vogesite and kersantite (Analyses 2 and 6), the variability is in many respects small. All the remaining analyses, in which only the relation of hornblende to biotite varies to some extent, are also petrographically very similar. Only *fm* still shows relatively great variability. The average composition of this limited group has a lamprosommaitic character (Table III, 3 and 4). The variation diagram (Fig. 26) also shows that the petrographically exceptional rock types do not fit well into the general variation. The decrease of *fm* with increasing *si* is clear, but the increase of *al* is not so definite and it is only general. The value of *c* shows no clear tendency and the increase of *alk* is only slight. The *k—mg* diagram of all rock reveals very well the special character of the province. In spite of the great range of *si* all points come very near to each other in a small area (Fig. 27).

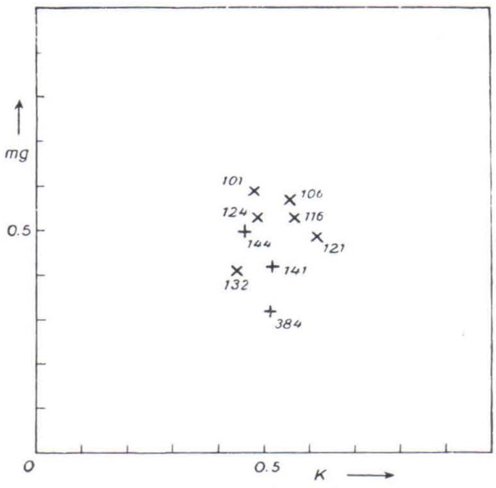

Fig. 27. k—mg diagram. The numbers indicate si-values.

Table III

	1	2	3	4
si	101 —132	101 —121	111	135
al	20 — 31	20 — 24	22.5	22.5
fm	40 — 49.5	41.5 — 49.5	45	46.5
c	13.5 — 22.5	18 — 21.5	20	18
alk	11.5 — 14.5	11.5 — 13	12.5	13
qz	—18 — 45	—32 — 45	—38	—
k	0.44— 0.62	0.48— 0.62	0.56	0.5
mg	0.41— 0.59	0.49— 0.59	0.55	0.6
ti	2.9 — 4.3	2.9 — 3.7	3.4	—
p	0.8 — 1.8	1.0 — 1.8	1.4	—
c/fm	0.33— 0.56	0.38— 0.52	0.45	—

1) Variation of the analyses of the lamprophyres (Table II, Anal. 1—6).
2) Variation of the lamprophyres (Anal. 1, 3—5) excluding the extreme types.
3) Average values of the analyses included in 2.
4) Lamprosommaitic magma (Burri and P. Niggli, 1945).

PEGMATITES AND APLITES

Pegmatites, often connected with veins of aplitic granite, are very common particularly in the eastern part of the Åva granite area. In the same area there occurs fine-grained Åva granite representing the last stage of the granite intrusions (p. 13). The aplite is very similar to the fine-grained granite, but it is still lighter in colour. Both of these rocks are apparently closely related genetically, and such aplitic rocks, which are connected with pegmatites, are here considered as aplites.

Pegmatites do not form as regular dike systems as the other dikes. They may be radial as well as tangential. Particularly narrow fissure pegmatites often clearly represent some predominant fracture systems of the wall rock, which in the neighbourhood may be occupied by other dikes. Also the flat-lying fractures are often occupied by pegmatites. Most important larger pegmatites seem to occur in the eastern border zone, except the large pegmatite in Ängskär, which occurs more in the centre. Some of pegmatites in the islands southwest of Bolmö appear to be very large, but in some sections their flat-lying position is visible.

Outside the Åva intrusions it is not always possible to distinguish in the field which pegmatites belong to the Åva granite and which are older. Typical Åva pegmatites have, however, some characteristic features that can be used as criteria. By this means it has been possible to discover that pegmatites distinctly belonging to the Åva granite have not generally been found far from the central stock; and, if found, they have been small.

Two different structural types of pegmatite have been found. Some of them have a resemblance to fracture fillings sharply penetrated by the wall rock (Fig. 19), while the others are more or less irregular lenticular bodies (Fig. 18 b). The latter group includes the greatest pegmatites and is more important. Both types may have the same mineralogical and other characteristics.

Some pegmatites are composed exclusively of quartz and potash feldspar, which is more reddish than in the older pegmatites and mostly forms well-shaped large crystals. It commonly has only very sparse quartz inclusions. Many pegmatites have distinct zones. Quartz occurs generally in the centre, where some big feldspar crystals, up to over 0.5 m in diameter, may lie in the quartz mass (Fig. 28), while the margin is of potash feldspar.

Fig. 28. Coarse pegmatite on the southwestern shore of Kalvholm, near Åva.

In another textural type of pegmatite these minerals form graphic feldspar. Some small dots of biotite or muscovite have been met with in such pegmatites. Graphic feldspar may form the outer zone of a pegmatite. Sometimes, particularly in monzonitic country rock, pegmatites have an outermost zone rich in plagioclase and they are also regularly followed by aplitic granite while in the porphyritic granite the relation may be quite reverse, a dike of aplitic granite may have coarser pegmatitic borders. Only fissure-filling pegmatites are found to transect monzonite.

A special mineralogical feature of the pegmatites of the Åva area is allanite (orthite) first found by Sederholm in a large pegmatite on the western shore of Åva. It has been later investigated by Lokka (1950), who has analysed this mineral. The result is quoted in Table IV. The mineral has not been found any more in this locality. Probably, all that was visible has been removed by explosive charges. The author has found similar minerals in three other localities. It has not, however, been exactly determined, which would require a chemical analysis.

The other three localities referred to above include a large pegmatite in the southern peninsula of Ängskär, a little patch on the northwestern shore of the same island, and a narrow fissure pegmatite in the western part of Långö. In all these places allanite does not occur in as large quantity as it did in the pegmatite of Åva, where it has been found as jetty lumps. It occurs only as dark laths or crystals of about 5 cm, which may be up to 2 or 3 cm in breadth (Fig. 29). It is commonly connected with biotite, partly in the same lath, and there may also occur magnetite in the same pegmatite.

Fig. 29. Dark lath of allanite in pegmatite in the southern peninsula of Ängskär.

Table IV. Allanite. Western shore of Åva, Brändö, Åland. Analyst L. Lokka (1950).

	%	Mol. prop.	At. prop.		
SiO_2	31.26	5 205	Si	5205	= 3 × 1375
TiO_2	0.71	89	Al	2688	5159=Y=3 × 1720
Y_2O_3	0.68	27	Ti	89	
Ce_2O_3	21.03	637	$Fe^{\cdots}$	440	
ThO_3	0.53	20	$Fe^{\cdot\cdot}$	1604	
Al_2O_3	13.70	1 344	Mg	263	
Fe_2O_3	3.52	220	Mn	75	
FeO	11.52	1 604	Ca	2152	3500=X=2 × 1750
MnO	0.53	75	Y	54	
MgO	1.06	263	Ce	1274	
CaO	12.07	2 152	Th	20	
Na_2O	0.29				
K_2O	0.06				
PbO	0.03				
F	0.21		$Y_2Y_3Si_3$ (O, OH, F)$_{13}$		
H_2O+	2.53				
H_2O-	0.04				
	99.77				
$-O = F_2$	0.09				
	99.68				

Table V. Potash feldspar. Pegmatite on the western shore of Åva, Brändö, Åland. Analyst H. B. Wiik (BaO has been determined by P. Ojanperä).

	%	Mol. prop.	
SiO_2	64.81	10 791	
TiO_2	0.00	—	
Al_2O_3	18.85	1 849	
Fe_2O_3	0.44	28	
MgO	0.00	—	
CaO	0.42	75	Or : Cn : Ab : An = 70.7 : 1.2 : 26.0 : 2.1
BaO	0.65	42	
Na_2O	2.90	468	
K_2O	12.00	1 274	
H_2O+	0.21	116	
H_2O-	0.00	—	
	100.28	—	

In Table V there is given an analysis of a potash feldspar from the same pegmatite on the western shore of Åva as the allanite investigated by Lokka. The analysed material has been taken from a big crystal and has not been separated. According to the microscopic aspects it is turbid and contains small inclusions of quartz and sericite as well as ore pigment and strings of perthite. The latter is abundant and seems to be almost equally distributed. It is apparently exsolution perthite and consequently the analysis may be considered as the composition of the primarily formed feldspar. According to calculation feldspar is abundant in plagioclase, comprising over 28 %, which approach the maximum amount found generally in potash feldspars of granite pegmatites. Barth (1951) suggested the use of the soda content of potash feldspars as a temperature indicator of their formation. In the present case it means that pegmatite is formed in a high temperature. This is in agreement with the conclusions of Fersman (1931) regarding the crystallization temperatures of pegmatites. According to him allanite occurs in the pegmatites of relatively high temperatures belonging to epimagmatic (700°—800° C) or pegmatitic phase (600°—700° C).

A geochemical fact of petrological interest is the extremely high content of barium, which calculated as barium feldspar, celsian, is 1.2 %. This may have arisen from the conditions referred to above, because the potash feldspar of high temperatures contains more barium, but in this case the value is too high for characteristic granite pegmatite (Engelhardt, 1936).

DIABASE AND QUARTZ-PORPHYRY DIKES

GENERAL STATEMENTS AND DISTRIBUTION

As clearly as the lamprophyric dikes form a radial system, the diabase dikes form a parallel swarm, the general trend of which is to the northeast, in the southern part with a northerly deviation and in the northern part with a more easterly deviation. Particularly the bigger dikes seem to be more numerous in a line which goes through the central stock. From these the big dike of Koskenpää (p. 55) and the dike about 10 m broad in Bergholm and in its neighbourhood southeast of Jurmo may be mentioned. The other dikes are up to 2 m. Many adjacent dikes are in echelon. In the southern part the dikes are more numerous than elsewhere and the trends of the dikes are visible in the morphology. It is even apparent that the visible dikes are generally only narrow representatives of the swarm, the broader unexposed dikes of which are traceable in the morphology.

The diabase dikes have the same general character as the other diabase dikes (ossipite) described by many authors (Sederholm, 1934, Hietanen, 1943, Edelman, 1949, etc.). Their petrology will therefore not be dealt with in this connection. Such is the case also with quartz-porphyry dikes (Sederholm, 1895, Pehrman, 1941, etc.). Their relationship to the diabase dike is, however, more definite in the present area than perhaps in any other area in southwestern Finland. The map reveals clearly their regional relationship. The quartz-porphyry dikes often follow the general trend of the diabase dikes, but they are generally smaller than these. Their direction is, however, much more variable. The diabase dikes are vertical or very steep, but the quartz-porphyry dikes may dip more gently; e. g. the dikes in both the western and eastern continuation of the composite dike of Långö as well as the southeasternmost dike in Åva are generally inclined to the south or the southeast and mostly about 60°. Quartz-porphyry dikes occur mostly in the same parts as the diabase dikes. In the map area, especially in the neighbourhood of the island of Koskenpää, they are close to diabase dikes occurring mostly in the continuations of bigger diabase dikes and some even parallel to their general trend. The same system can be traced to the southwest, where a quartz-porphyry dike up to 12 m in width has been found in the island of Norrholm (see Fig. 1) in the direct continuation of the big dike of Koskenpää and in alignment with it. Sederholm (1934) noticed quartz-porphyry dikes further to the southwest in the islands of Falkklobb, Ramsholm and Ytterklobb. In about the same direction near Kumlinge he again noticed many diabase dikes. More detailed tracing will apparently show that all these diabase as well as quartz-porphyry dikes belong to the same zone, which goes along the southeastern border of the rapakivi area of Åland up to Föglö (Frosterus, 1893, and Sederholm, 1934). Similar dikes occur also elsewhere in the southwestern archipelago, but they do not seem to be as common as in this area.

SHAPE AND STRUCTURE

Most diabase dikes have an essentially rectilinear shape with parallel walls. The contact lines against the wall rock are sharp and straight. Sinuous contacts are very rare. A distinct chilled margin is always present. In two localities, on the southern shore of Bernholm and in Österskär, there occurs a narrow, a few cm broad brecciated zone of the dike rock nearest to the northwesterly contact. The former dike also has in the southeasterly wall an apparent branch some cm broad almost at right angles to the direction of the main dike. The character of this offshoot is not quite definite, because a narrow fissure separates it from the main dike at the plane of contact. Narrow apophyses are seldom found. From this general rule there is mainly one exception, the composite dike of Långö, which will be discussed later (pp. 54).

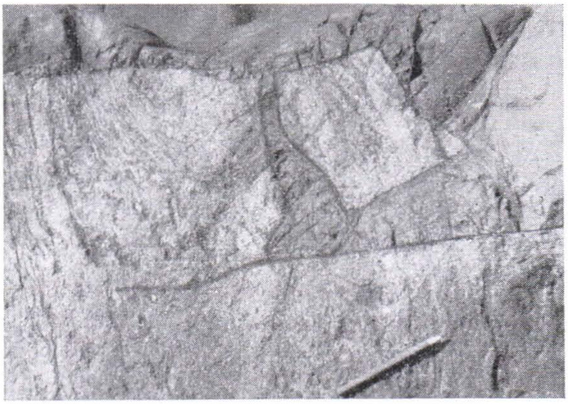

Fig. 30. Blocky contact of a diabase dike on the northwestern shore of Brändö. The general direction of the dike is horizontal in the picture.

The inclusions in the broader diabase dikes are mostly of labradorite or coarse-grained diabase. Xenoliths in diabase are commonly angular and near the wall or, as is often the case, attached to one wall (Fig. 30). Sometimes there even occur straps bridging both walls (Fig. 31). These xenoliths occur especially in northern Brändö and in some skerries in its neighbourhood where the contact line of the dike has a sudden turn or a zig-zag form. Stublike forms may occur, but they are generally smaller than the corresponding forms in lamprophyric dikes. Only in quite narrow dikes these stubs may reach the breadth of the dike. If the inclusions described in the foregoing are filled back into the places at the adjacent contact, it is generally deduced by visualizing both walls that they match. The inclusions have been formed by the opening of the fracture. The following interpretation is in agreement with all field observations. An echelon set of joints has been opened by tension. The ends of the neighbouring fractures have approached each other upon widening further (Fig. 31). This has been favoured by the primary, slightly different direction of the adjacent joints or by their turning against each other during the dike formation. The slab between the neighbouring parts of the dike first forms a bridging inclusion and by opening further the fracture becomes continuous (cf. Figs. 30 and 31).

The quartz-porphyry dikes are not always quite as straight as the diabase dikes. Dikes with a zig-zag fissure have been encountered e. g. in Flekskär, and those with a curved trend, in Långö and southern Åva. The dike may also have in detail more or less irregular, mostly blocky

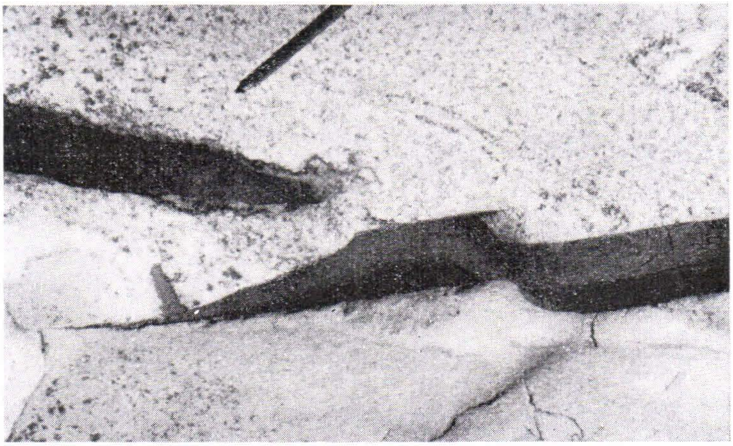

Fig. 31. Small diabase dikes in echelon separated by a partly broken stripe of the wall rock. The northeastern shore of Lammholm north of the eastern peninsula of Brändö.

contact lines. The irregular configuration of the rock slope does not always mean that the shape of a dike is irregular. E. g. on the western shore of the island northeast of Fiskö there occurs an apparently very irregularly shaped dike (Fig. 32). The shape is, however, achieved by the gently westerly inclined narrow sheet extending from the approximately 70 cm broad main dike, which is relatively steeply inclined (70°) to the east. This shape of the fracture is apparently caused by irregular fissuring in the coarse-grained granite, which there forms the country rock.

Especially in broader dikes of quartz-porphyry xenoliths are much commoner than in diabase. These may sometimes be very big and separate the dike into different parts. This difference from the diabase dike is apparently caused by the greater density gradient between silicic magma

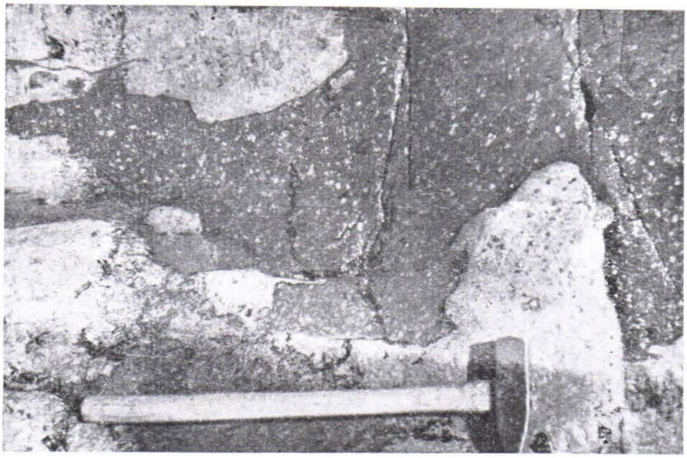

Fig. 32. Irregular configurations of the sheet of quartz-porphyry on the western shore of Pålholm east of the northern peninsula of Fiskö.

and the wall rock than that between subsilicic magma and its silicic wall rock. These circumstances have been favourable for magmatic stoping, especially in inclined dikes.

Quartz-porphyry often shows flow lines, but generally the rock is very homogeneous. The dense contact zone as well as the narrow dike as a whole is dark or dark brown, while the central part of the broader dike is brown. The amount and general size of feldspar and quartz-phenocrysts may vary to some extent in different dikes, but in an individual dike they are equal, with the exception of the contact zone, where greater phenocrysts are lacking.

Sometimes the dike rock is sheared, but in general only slightly. A structurally very interesting relationship has been found in a dike which goes over southeastern Åva. In its southwestern part the dike rock is quite similar to the other quartz-porphyries, but at its northern end it becomes gradually more sheared. The colour of the ground mass changes from brown to grey and its grain size increases, being no more dense but still very fine-grained.

COMPOSITE DIKES

The close association of diabase and quartz-porphyry dikes is still more definitely revealed by the composite dikes than by their regional connection mentioned above (p. 51). In the Åva area there are two dikes in which diabase or dolerite is associated with leucocratic rocks. In the composite dike of Långö the silicic rock clearly is quartz-porphyry. At both ends this dike is composed of mere quartz-porphyry, which in the western part forms a dike only 1—2 m broad, but widening eastwards.

The composite part shown in the map as diabase (D) may be over 10 m broad. Diabase is found on both sides of the ring intrusion visible in the map, but unfortunately the dike is not exposed when crossing it. At the transection the diabase dike has an offset, which may be interpreted to be due to the later formation of the ring intrusion. But, since in other localities diabase dikes have been found clearly transecting the Åva granite, this possibility can be overlooked. The deviation is apparently caused by the different brittleness of the ring intrusion granite and adjacent migmatites at the formation of the fissure of the composite dike (cf. Newhouse, 1942, p. 13).

Diabase clearly forms the border zones of this composite dike and is for the most part irregularly transected by silicic dikes (Fig. 33), which taper upon approaching the wall rock of the dike, gneissose granite. The silicic dike rock differs from the quartz-porphyry dikes in its somewhat smaller amount of quartz. This porphyry has no chilled margin against diabase as it has in the sequels against the older country rock. The contact between the diabase and its wall rock, gneissose granite, is still more peculiar. The contact line is sinuous and in some places there occur potash-feldspar porphyroblasts, partly with plagioclase rims (Fig. 34). These features are very surprising, when we note that the contacts of the diabase dikes are in general straight or blocky and show no visible hybridization.

The lack of a chilled margin in quartz-porphyry is apparently caused by the immediate succession of the diabase and quartz-porphyry intrusions. If the latter intruded before the diabase cooled, it may also have favoured hybridization at the diabase contact. The process has been similar to that in diabase contacts in the Satakunta area described in detail by Kahma (1951).

The dike of Koskenpää. A great dike of mainly doleritic diabase is located in the eastern part of the island of Koskenpää and in the neighbouring island of Söderholm northeast of it. It has in the map an unusual irregular shape. In the main rock type the ophitic structure is very conspicuous, being especially clear in the weathered surface. Plagioclase forms a pattern of light lath, mostly 1—1.5 cm in length. It differs from the diabase dikes mainly in its coarseness, while the composition is similar. Because of its partly medium- or coarse-grained and less altered character it is called dolerite.

In all visible places the contact against the country rock is fine-grained or dense. The main dike is in the southern part 40—50 m broad and in the middle part medium-grained. On the eastern shore of Koskenpää it forms two separated distentions to the east.

Dolerite forms there the main part of two hills in the village of Koskenpää. The main rock may be cut by some fine-grained or more silicic dikes. Around the hill south of the village the contact against the country rock

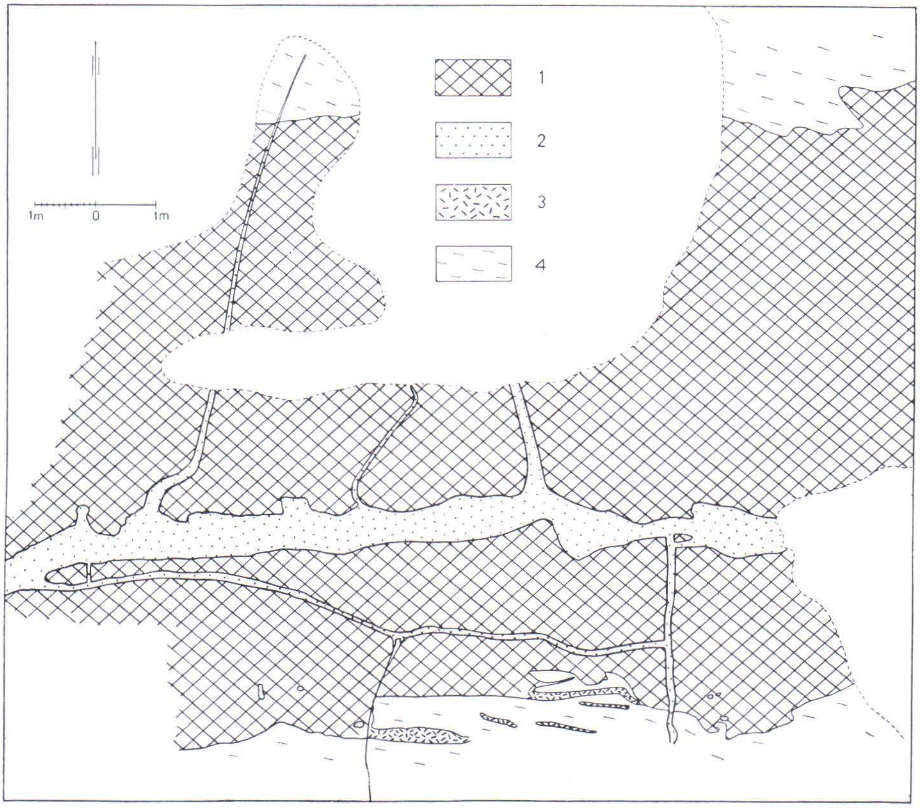

Fig. 33. Composite dike in the western part of Långö. 1. diabase, 2. quartz-porphyry, 3. hybridized contact zone of diabase with feldspar porphyroblasts, 4. country rock, gneissose granite.

Fig. 34. Porphyroblasts of potash feldspar in the contact zone of the composite dike of Långö. Light rock in the upper part of the figure is the wall rock. Picture is taken of the middle part of the southern contact represented in Fig. 33.

is visible only in a few places. The southern border extends along the hillside, where, as on the western side, apophyses of diabase transect the country rock. All well definable contacts are steep and sometimes with arcuate embayments.

The other distention is situated almost in the centre of the village. The top of the hill is dolerite, but in the eastern part the country rock, coarse-grained granite, is always exposed on the lower slope. On the northern, more gentle slope the fine-grained contact is often up to some metres in width.

The northernmost distention differs in many respects from the aforementioned. It consists only in part of dolerite, while a medium-grained syenitic rock forms the centre of the rock mass. It is well exposed on the western shore of Söderholm and forms the whole western slope. The contacts between this syenitic rock and dolerite are sharp but not rectilinear. All exposures close to the country rock are dolerite.

AGE AND CONTACT RELATIONS OF DIFFERENT INTRUSIONS

The contact relations have been as far as possible carefully studied for determining the relative age of the different intrusions and have been repeatedly described in the preceding chapters. The relations may sometimes be very confusing. As we have noted, the rocks of the granite-monzonite series form a sequence of intrusions (pp. 13). All similar intrusions have not, however, been contemporaneous, because a sharp contact between two separate granite intrusions may occur within the central stock (Fig. 35). The monzonite seems to be older than the adjacent granite, because it is hybridized and transected by dikes of granite in the contact zone. The age difference is apparently very slight and the granite had intruded before the complete solidification of the monzonite, as marked hybridic contacts have been found in the monzonite, but not in adjacent migmatites (p. 23). The age relation of the lamprophyric dikes to the granite-monzonite series is also confusing. Many dikes transect the major intrusives, but the shape of the dike sometimes indicates that

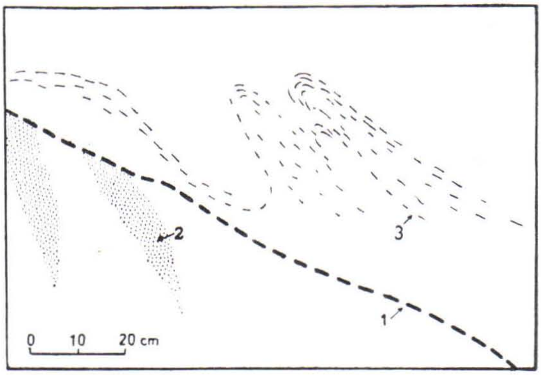

Fig. 35. Definitive contact (1) between two separate intrusions of porphyritic granite (blank). The inclusions (2) in the older granite are cut by the other with stripes of biotite showing the flow lines (3). The southwestern peninsula of Ytter-Långskär. Drawn according to a photograph.

the fissure may have been formed before the final consolidation of the granite (p. 39). If we further note that the bigger dike in Raden does not occur in a ring intrusion but only in the screens, it points out that some lamprophyres may be older than the latest granite intrusion, even if the immediate crossing of the dike and the ring intrusion is not exposed. Especially in Raden and its neighbouring islands inclusions occur in granite with a composition and structure similar to those of lamprophyric dike rocks. In part they form rows of inclusions, proving that the granite has been in a plastic stage after the formation of the lamprophyric dike. We have no evidence of the different ages of lamprophyric dikes (cf. p. 41).

The contact relations of lamprophyric and pegmatitic dikes offer some interesting examples. The intersections in western Åva seem at first to agree with the definitely younger age of pegmatite, as suggested by Sederholm (1934, p. 49). More detailed investigation gives the retrieved contours represented in Fig. 20. The lamprophyric dikes are not definitely cut by pegmatite, because narrow stripes of lamprophyre may occur in pegmatite. The southernmost transection is mostly occupied by a fissure and there the relation is not visible and lamprophyre is not shown within pegmatite. This structural relationship makes it probable that the lamprophyric dike had not faulted during the formation of the pegmatite, but the offset structure is primary (cf. p. 40). But it may be better to leave the question of age unanswered and to study the contact in some other localities.

A very interesting contact relationship is to be seen in the lamprophyric dike in the southwestern promontory of Gonskär, west of Lökholm. In adjacent granite the pegmatite is broad and with a less distinct demarcation against the wall rock, but it transects the lamprophyric dike only as a narrow fissure dike (Fig. 18 b). The contact of lamprophyre against granite is almost straight but wavy when pegmatite forms the wall rock. These features as well as their general irregular shape invalidate the dilation character and are attributable to the replacement origin of the pegmatite. The granitic wall rock has been especially amenable to replacement, while pegmatite has not been able to replace lamprophyre, and the pegmatite fissure in the lamprophyric dike represents the initial stage in the development of pegmatite, the pathway for pegmatite-forming fluids. Similar wavy contacts have also been found in the transections of the lamprophyric dike with granite in the southern part of Hummelörarna and they apparently have a similar origin, i. e. achieved by later metasomatic processes in the wall rock (Fig. 36).

The diabase and quartz-porphyry dikes are clearly younger than the other intrusive rocks discussed in the foregoing. As the structure of the composite dike of Långö shows, they belong to the same sequence. Quartz-porphyry cannot be older than diabase as suggested by Sederholm (1934, p. 53) or we must assume the existence of two generations of quartz-porphyries. The metamorphic features, which may occur in the porphyry only locally, do not necessarily mean an age difference, but may be as well brought about by the different dynamical conditions during the dike formation.

Fig. 36. Wavy contact of the lamprophyric dike (on the left) against fine-grained granite brecciating the wall rock. The southern dike in Fågelholm.

The sandstone dike found in Kummelören is also of interest in determining the geological age of the rock complex. The sandstone is very similar to the other occurrences in southwestern Finland, which are of Cambrian age (Tanner, 1911, Eskola, 1913). The age of the material gives no distinct evidence of the age of the fissure, because no internal stratification has been found. It is, however, most probable that the wall rock of the sandstone dike is at least sub-Cambrian. It may be that the fissure has opened later and the Cambrian material has fallen off from the first overlying unfastened strata.

The chemical studies of allanite by Lokka (1950) are of great interest, because they determine the absolute age of the Åva granite. From analyses of radioactive allanite he has calculated the age at 1 116 million years.

In his last study Sederholm (1934) regarded the Åva granite as Archaean and classified only the different diabase dikes and rapakivi granites, together with related rocks, as later pre-Cambrian. The main general evidence of Sederholm is that the granites of the third group show some cataclastic phenomena. Such metamorphic features have not been found in rapakivi rocks. Eskola (1941 and 1946) modified his idea and considered the granites of the third group as postkinematic intrusions of Svecofennidic orogenesis and the rapakivi granites as post-Karelidic. The age relation of the granites of the third group, including the Åva granite, is not, however, evident and some authors are of the opinion that they are not essentially different in age from the rapakivi granites (Wahl in Eskola, 1946, Edelman, 1949). Sederholm himself sometimes doubted whether it was legitimate to use the grade of metamorphism as a criterion of geological age. The metamorphic structures may be deuteric as well (Sederholm, 1924). The present author prefers the intrusion mechanism and the level of consolidation in the case at hand, as the most important agencies in producing the protoclastic structure.

The age difference between the Åva granite and its country rock, adjacent migmatite, seems to be greater than that between the granite intrusion and the diabase dikes and it is quite evident that these younger intrusives have not been in the Svecofennidic orogenesis, which has given the adjacent older pre-Cambrian rocks their complicated structure. The aforementioned facts establish that the late pre-Cambrian age of the intrusive complex is probable.

The age of the central complex is noticeable even in the respect that the known ring complexes of granitic rocks are generally younger than pre-Cambrian. Among similar complexes the most excellent ring structures of Scotland (Bailey and others, 1924, Anderson, 1936, etc.), New England (Billings, 1945, etc.) and Nigeria (Greenwood, 1951) may be mentioned. Only the intrusions in Plateau Province in Nigeria occur in a pre-Cambrian territory, but they may be younger as well. None of the mentioned complexes shows structures and relations quite similar to those in the Åva area, or at least the details are not as plainly exposed. In relation to diastrophic processes in space and time all ring complexes are, however, post- or atectonic.

STRUCTURAL DEVELOPMENT

The first process in the formation of the ring complex was the plastic deformation of the country rock. The upward push of magma first caused the dome shape of the roof and the further rising of magma apparently led to the formation of a plug with steep walls. This compliance changed the structure of the country rock into the present arc pattern (p. 12 and Fig. 2). Magma may not have at this stage reached the present land surface. It is more probable that earlier the differential movements forced the rock complex to an upper level, where the plasticity of the wall rock decreased to such an extent that the country rock no longer yielded, but fractured. Particularly in the zone where the pressure exceeded the strength of the roof, the bending appears as a continuous concentric arc of conic shear fractures close to each other. These inward-dipping ring fractures, which form the inner fracture zone around the central stock, indicate very definitely a strong upward magmatic pressure (Anderson, 1936, Bemmelen, 1937, and Balk, 1937) and give a good reason for concluding that the intrusions emplaced themselves by forcing the overlying roof upwards.

It is to be noted that usually the shear fractures caused by the intrusion are inclined about 45°, but around the Åva granite they mostly dip 70°—80°. It has been shown by experiments that fractures at highest confining pressure have shear surfaces inclined to the direction of compression at low angles (Griggs, 1936). High angle shear fractures thus indicate great strength in the overlying crust. Experiments have been made (Chamberlin and Link, 1927) that well illustrate these intrusion mechanics, and from them it is apparent that the upward-pushing magma follows inclined pathways or, in other words, it has injected the rupture of shear fractures, while the drag has been conspicuous. The same compression which has brought about the inclined shear fracture has also caused vertical jointings and radial fractures formed by tangential tension as well as outer concentric ring fractures, which probably are extensional in origin (Bridgman, 1938) and later intruded by granite. The radial fractures are also sometimes intruded by narrow dikes of granite, but the fractures filled by lamprophyre are more noticeable. In some localities lamprophyre has intruded in the same fracture with the granite.

In the centre a strong upwelling of magma has completed the shattering of the roof and the earlier arcuate slabs and formed local zones of intrusive breccias. The internal structure of the central stock indicates that within it various eventual composite granite-monzonite intrusions have taken place. It grades to the ring structure, where the ring intrusions also represent series of intrusions, with the magma having moved in the direction of the thrust.

It seems that the magma has carried fragments rather upwards than it has passively risen by stoping, because the inclusions show partly plastic forms and are assimilated much more than the adjacent wall rock.

The structural pattern of the border zones with the parallel orientation of minerals may show primary flow lines, but the association of this foliation with the undulatory extinction and crushed quartz makes it probable that it has at least partly developed after the main solidification of rocks. As some rocks belonging to the same intrusion sequence show no signs of such a metamorphism, it has been caused by mechanical friction during the movement of magma rather than by later forces.

The primary reason for radial fractures now filled by lamprophyric dikes is the tangential tension connected with the upward push of the main intrusion, but it is not certain whether the lamprophyric intrusion has been contemporaneous. It is also problematical whether the force which has opened the fractures is connected with the invasion of lamprophyric magma or whether the tectonic movement independent of the lamprophyre intrusion has caused the rupture which has then been filled by the material available. Most of the lamprophyre dikes show a dilation character as defined by Goodspeed (1940). The shear movement or slipping is characteristic of the fractures of lamprophyric dikes.

It is apparent that after the strain had relaxed upwards by a thrust and the formation of ring intrusions, the mechanical conditions greatly changed. At such a period the magma may no longer exert strong upward pressure, but the tangential pressure is more conspicuous. The tangential stress caused the characteristic shape and structure of the lamprophyric dikes during their intrusion. The definite relation of a shear movement to the central complex indicates clearly the association with the same magmatic activity. The pairs of shearing couples have been at a small acute angle, apparently about 20°—30°, which is now visible in the different direction of the neighbouring dike. As we have no real reason to consider the more metamorphosed sheared dikes as older than the others, it is probable that they were deformed when the movement still continued after the consolidation of the dike (p. 43).

Farmin (1941) has suggested that the relation of tension and shear characterizes the process of rock deformation and is due to different static loads. Applying this idea of the different character of the rock failure to the different level, it is possible to treat the mode of development of some fractures at various depths. This is diagrammatically presented in Fig. 37, which shows how a shear fracture at a lower level splits into a fracture echelon at an upper level. It is well-known how a pure shearing stress can cause tensional fracture echelons (H. Cloos, 1936 and Nevin, 1931).

Considering the similar relationship of tension and shear related to the forces of the shearing couple, we get the relation illustrated in both extreme and intermediate cases in the keys in Fig. 37. By diminishing compressive

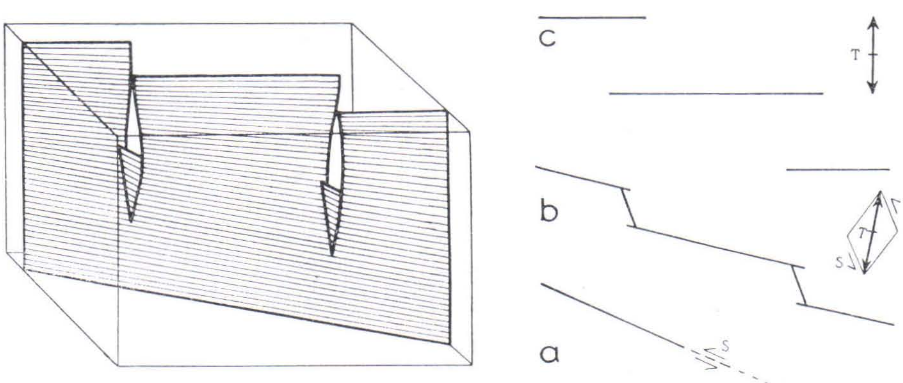

Fig. 37. The block diagram on the left shows a continuous shear fracture at the base of the block splitting into fracture echelons on the upper level. a. The trace of the shear fracture at the base of the block; b. The horizontal structure of the hybrid fracture in the middle part of the block; c. The tensional fracture echelon on the upper surface of the block. The keys show the strain relations, T = tension, S = shear.

pressure the tension component results in a deviation of fracture and its splitting first into tensional openings, which by shear development tend to be connected with link fissures, and finally in the surface conditions they remain completely separated. These events are shown in the figure above in an exaggerated form. It presents the splitting into lopes with one single connecting link. It may, however, form numerous links or a curved fracture as well. These features may vary greatly at a different level, the lastmentioned fracture type being apparently more characteristic of such a lower level, where the splitting begins because there the shear is more conspicuous. The course of the fracture system at a different level indicates that the direction of the main fracture turns in passing to the upper level; but the general trend of the fracture system remains unchanged.

It may even be that greater single offsets are more likely at the upper level and, when the relation of tension to shear is greatly on the increase, caused by some acute change in physical conditions. In this theoretical discussion the shearing stress has been horizontal, though the same tentative idea is also correct, when it is gently tilted; but the fissure may have some changes even at the same horizontal level. Also when the fracture goes over the contact of two physically dissimilar rocks, the feature may change its character. The form in Fig. 37 b has all the most characteristic features of the shape of lamprophyric dikes. The offset in an individual dike is very regular and generally on the same side, only short offsets in the opposite direction having been found. Some irregularities may be explained by the intersections of earlier dikes, consisting of pegmatite, along which the breaking has occurred more easily and further than expected.

Many other field observations agree also extremely well with the origin presented above. The difference which lamprophyric dikes show in structures produced by fault movement along an irregular fracture surface, as described by Newhouse (1940 and 1942) in connection with the ore veins, is remarkable. In such a fracture the transverse part has a greater tendency to open, while it is exactly the opposite in the lamprophyric dikes. These features are thus presumed to be principally different. This has even caused the author to develop the idea of various origins of main and transverse fissures, especially when the latter are in most cases distinctly younger. The shear character of transverse fissures related to general shearing stress mentioned in the foregoing is also generally proved to be correct by the right arrangement of tension and shear to the displacement of both wall blocks.

Anderson (1951, pp. 58—59) discussed a similar development of dike echelons, but he considered it only a result of the change in the direction of tensional stress at a different level. In the aforementioned mechanism it finally caused splitting and local strike of fracture, but the basic reason was a shearing couple, and the development of shear even at the upper level gave rise to characteristic continuous hybrid fractures. The origin of their main fracture is regarded as tension and the oblique transverse fracture as shear.

If, as considered in the foregoing, tension was not the primary force causing the rupture, the mechanism of the dike intrusion itself may be a passive rising of the magma available rather than a forceful injection. In such a mechanism the size of the dike may rather increase than decrease at the upper level, where the pressure of the magma may exceed the static load. This agrees also with the fact that the main fissure of the dikes does not taper essentially, even though extending further from the centre of the intrusion. The discontinuous character of the surface pattern of most dikes (Fig. 18 etc.), allowing no free horizontal flow of magma, makes it even apparent that after the splitting of the fissure the lamprophyric magma has moved more vertically than horizontally, but at the lower level the continuous straight shear fracture may have formed suitable pathways for the lateral spreading of the lamprophyric magma.

The striking apparent offsets in the course of the lamprophyric dike have a very great resemblance to the round-nose and dike-fault offsets in the sills of the Highwood area, Montana, described by Griggs (in Hurlbut, 1939). Particularly the dike-fault offsets show quite identical configurations. The structural relationship is, however, quite different. These sills have intruded mainly parallel to the sedimentary strata and they crosscut at the offset. The intrusion also had a distortional effect on the sediments immediately above and below. Owing to the greater solidity of the wall, this feature has not developed in the Åva area.

Noble (1952, p. 34—49) has later discussed similar structures connected with rhyolite dikes in the Black Hills, South Dakota, intrued into metamorphic pre-Cambrian schists and he considered flow structures and faults at the bluntnosed ends of dikes as a result of the forcible intrusion of the dikes. These definite conclusions can not be valid in the Åva area, because, as discussed in the foregoing, similar shapes will develop without a forceful injection, when more passively rising magma has filled simultaneously formed fractures.

The general distribution of bigger pegmatites, with their partly flatlying position in the periphery of the central stock, indicates that the latemagmatic solution has risen along shears. The original fracture has been essentially widened by the replacement of the granitic wall rock (p. 58). The lenticular dikes commonly have all the attributes of replacement dikes.

The almost constant trend and shape of the diabase dikes indicate their tensional character as apparently having been brought about by the bending of bigger rock blocks. The regional relation of this dike swarm to the Åland rapakivi area indicates that the diabase dikes are connected with rapakivi intrusions (Sederholm, 1934). The more variable trend and the less regular shape of the quartz-porphyry dikes indicate different causal factors from those caused by the tension of the northwest-southeast direction. The earlier joints and other pre-existing rock structures reversed the tendency, apparently because the tension had then been less effective. As the inclined quartz-porphyry dikes may have a general dip to the southeast, their formation may be connected with the vertical movement and the relative subsidence of the northwesterly rock block.

Because of its extraordinary character the structural relations of the great dike of Koskenpää are of special interest. For a correct understanding of its formation, we have to bring the facts mentioned (p. 57) into consistency with the dilational mode of the emplacement of the diabase dike. It seems most probable that the southern distentions have been formed by a flat-lying rupture between two vertical echelon fractures. This may be favoured by the uplift of the western rock block, because the distentions continue over these echelon fractures only to the east. The upper part of this sheet is exposed south of the village of Koskenpää, while the other distention has a visible floor. It is to be noted that the formation of the sheet has been favoured by the relatively greater brittleness of the coarse-grained microcline-granite, which here forms the country rock. The northern composite part of the dike with apparently steep borders may be explained by the stoping or upward push of large blocks. A larger block or some different blocks are mainly penetrated by fractures in the general direction of the dike system. A piecemeal stoping is improbable, because the borders are so clearly definable and xenoliths are very rare.

PETROGENESIS OF THE FINAL EMPLACEMENT

As the character and structure of granite-monzonite series and related intrusives show, there is no doubt about the mobility of the material intruded into its present position from below. The source of the magma can not, however, be as positively answered as the space problem. The term magma is used in this study in a broad sense, without exact genetic definition, to mean hot mobile rock material (Turner and Verhoogen, 1951), because the present author is not prepared at present to offer a solution to all problems of petrogenesis. Many petrogenetic processes have also played a part in the structural development, on which particular emphasis is laid in this study. These processes may not be those that have really been the most important in the actual petrogenetic development. The petrogenetic history of the rocks begins before the final emplacement, which has mainly brought about the rock structures.

Starting from the standpoint presented above, we may avoid the granite problem and the multiple prejudices involved, and we do not even need to know the location and nature of the parent chamber. The discussions about this subject would be here purely theoretical and not essential for the scope of this study. Our task has been only to present a short review of the processes effected during the rising of the magma and its later development. Sederholm (1924, p. 145) noticed that there are transitions from the subsilicic rocks to eruptive breccias. It is true, but if we consider these monzonitic rocks syntectic, as Sederholm suggests, transitions between porphyritic granite and »symmictite» (homogenized eruptive breccia) would also be formed. These have generally not been found. The transitional series is rather the following: monzonite—breccia—porphyritic granite. This indicates separate subsilicic and silicic intrusions. The different rocks are mainly end members of the rock series and the intermediate ones occur generally only locally and have the striking and obvious character of hybrides.

The magma was apparently differentiated while it was still rising and the differentiation of the magma at present level has been apparently slight. The structure and relation of silicic and subsilicic intrusions makes it obvious that silicic magma rich in volatile material (H_2O, F) has overlain the denser subsilicic one. This makes possible the succeeding different intrusions (Holmes, 1931). The gravitative fractional differentiation has apparently not been the only factor, but nevertheless brought about a distinct tendency. Owing to deep-seated conditions, the magma became charged with more salic material by pure melting or true assimilation and gave to the rocks their special character. This took place mainly at a greater depth, so we have no visible evidence of it in the contacts of country rock but only in inclusions, which have apparently entered with the magma. The differentiation itself has been apparently controlled by gaseous transfers and perhaps also by thermal diffusion combined with convection currents (Wahl, 1946). In the final phase the consolidation as has been shown, contributed to later metasomatic processes. The potash feldspar phenocrysts grown into inclusions suggest relatively late replacements by migrating solutions rich in potash. The presence of microcline in the more sheared rocks indicates that the origin of microcline is favoured by tectonic movements (Eskola, 1929).

The association with lamprophyres suggests also a deep-seated intrusion (Grout and Balk, 1934). It has, however, mostly had a distinct difference in temperature from the wall rock and the dikes have mostly a very fine-grained margin. The lamprophyric dikes represent apparently the same magma as the monzonite rocks, but both have become differentiated in the last stage in different directions. The latter have been more affected by subsequent granitic intrusions, but the lamprophyric dikes by the wall rock of the dike fissure. The composition of the dikes is related to that of the wall rock (see p. 44) and due to assimilation allowed by the considerably high PT-conditions. Included material may not be the only way, but the contamination has apparently taken place directly from the pre-heated wall rock (Bederke, 1947, p. 56) and been favoured by shear movement. The magma has been charged with foreign material the whole way along the narrow fissure and not only in the final position. The generally complicated crystallization sequence of minerals has been considerably affected by shear movements (cf. Smith, 1946). This has not, however, always been of the same character and it has also been the main reason for the heterogeneous structural and textural character of the lamprophyric dikes.

Still more striking than in the granite-monzonite series is the difference between subsilicic and silicic magma in the composite dikes of diabase or dolerite and associated leucocratic rocks. The source of both magmas seems to be materially at least to some extent independent, inasmuch as contacts between these rocks are always sharp and composite intrusions are relatively rare. Both diabase and quartz-porphyry dikes belong, however, to the same sequence of intrusions, differing only slightly in age. If the diabasic or related magma had existed below the complex even during the intrusions of the granite-monzonite series, it is a problem of depths to which the present erosion level offers no visible solutions. Therefore the relationship of diabase and related dikes to the granite-monzonite rocks can not be definitely answered in this local structural study; it also needs further petrological facts. The regional disposition of these younger dikes in relation to the central complex may be only apparent or induced by the pre-existing structure.

SUMMARY OF THE STRUCTURAL DEVELOPMENT

The different features in the Åva area are presented in Table VI. Because the character of processes changes with varying depth, they are listed according to the general physical conditions of formation. In the first column the ratio of tension and shear is given, characterizing the rock rupture at different depths. The oldest feature, the formation of adjacent migmatites during the Svecofennidic folding, is lowest in the table. The younger intrusives are found in conditions of lower pressure and temperature and, moreover, in the order of their general age, which means that during the whole of geological history the ratio of tension and shear has had a general tendency to increase. In the middle part of the table the conditions during the formation of the central complex have alternated and the complex sequence of intrusions been formed. The different structural pattern of lamprophyric and diabase dikes is brought about by the different conditions of formation. The offsets in the course of lamprophyric dikes and their internal structure are affected by shear, while the bridging inclusions and related structures in diabase dikes are formed by a purely tensional opening of the dike fractures. The regional tension has not been so definite during the formation of quartz-porphyry dikes. Both piecemeal stoping and settling of larger rock blocks has been characteristic of this stage.

Table VI.

← high PT-conditions low →

Ratio tension/shear	Intrusion phase	Structural features
Open rift	(Clastic dikes of Cambrian sandstone)	Younger jointings
> 1 Tension fractures	Quartz-porphyry dikes Diabase dikes	Settling of rock blocks, probably vertical Northeasterly tensional fractures
$\overset{=}{<} 1$	Pegmatites and aplites	Replacement of granitic wall rock along shear fractures
Shear fractures, alternating conditions	Lamprophyres	Opening of radial fractures
	Forceful intrusion of granite-monzonite series	Ring fractures and shattering of the roof
$= 0$ No dilation	Formation of granitic and monzonitic magma during the rising of the stock	Concentric arc structure caused by plastic deformation of country rock
	Contamination of magma on a lower level	
Flow stage	Migmatization of country rock	Svecofennidic folding

REFERENCES

ANDERSON, E. M. (1936) The dynamics of the formation of cone sheets, ring dikes, and cauldron subsidences. Proc. Royal Soc. Edinburgh, 56, pp. 128—157.

—»— (1951) The dynamics of faulting and dike formation with applications to Britain. 2d ed., Edinburgh.

BAILEY, E. B. and others (1924) The Tertiary and post-Tertiary geology of Mull, Loch Aline and Oban. Mem. Geol. Survey, Scotland.

BALK, R. (1937) Structural behavior of igneous rocks. Geol. Soc. America, Mem. 5.

BARTH, T. F. W. (1951) The feldspar geologic thermometers. Neues Jahrb. Miner., Abh. 82, pp. 143—154.

BEDERKE, E. (1947) Zur Problem der Lamprophyre. Nachr. Akad. Wiss. Göttingen, Math.-phys. Kl. 2, pp. 53—57.

BEMMELEN, R. W. VAN (1937) The cause and mechanism of igneous intrusion: with some Scottish examples. Trans. Geol. Soc. Glasgow XIX, pp. 479—481.

BILLINGS, M. P. (1945) Mechanics of igneous intrusion in New Hampshire. Am. Jour. Sci. 243 A, pp. 40—68.

BRIDGMAN, P. W. (1938) Reflection on rupture. Jour. Applied Physics 9, pp. 517—528.

BURRI, C. and NIGGLI, P. (1945) Die jungen Eruptivgesteine des mediterranen Orogens I. Zürich.

CHAMBERLIN, R. T. and LINK, T. A. (1927) The theory of laterally spreading batholiths. Jour. Geology 39, pp. 319—352.

CLOOS, H. (1936) Einführung in die Geologie. Berlin.

EDELMAN, N. (1949) Structural history of the eastern part of the Gullkrona basin, SW-Finland. Bull. Comm. géol. Finlande 148.

ENGELHARDT, W. von (1936) Die Geochemie des Bariums. Chemie der Erde X, pp. 187—246.

ESKOLA, P. (1913) On phenomena of solution in Finnish limestones and on sandstone filling cavities. Bull. Comm. géol. Finlande 36.

—»— (1929) On the occurrence of orthoclase and microcline in the Finnish granites and pegmatites. Bull. Comm. géol. Finlande 85, pp. 54—58.

—»— (1941) Erkki Mikkola und der heutige Stand der präkambrischen Geologie in Finnland. Geol. Rundschau 32, pp. 452—482.

—»— (1946) Om Finlands graniter (A lecture with discussion). Geol. Fören. Stockholm Förh. 68, pp. 473—475.

FARMIN, R. (1941) Host rock inflation by veins and dikes at Grass Valley, California. Econ. Geology 36, pp. 143—174.

FERSMANN, A. (1931) Über die geochemisch-genetische Klassifikation der Granitpegmatite. Min. pet. Mitt. 41, pp. 64—83.

FROSTERUS, B. (1893) Om en diabas i Föglö i den åländska skärgården. Geol. Fören. Stockholm Förh. 15, pp. 275—290.

GOODSPEED, G. E. (1940) Dilation and replacement dikes. Jour. Geology 48, pp. 175—195.

GREENWOOD, R. (1951) Younger intrusive rocks of Plateau Province, Nigeria, compared with alkalic rocks of New England. Bull. Geol. Soc. America 62, pp. 1151—1178.

Griggs, D. T. (1936) Deformation of rocks under high confining pressures. Jour. Geology 44, pp. 541—577.

Grout, F. F. and Balk, R. (1934) Internal structures in the Boulder batholith. Bull. Geol. Soc. America 45, p. 877.

Harker, A. (1909) The natural history of igneous rocks. London.

Hausen, H. (1947) Skärgårdsbildningen och dess orsaker. Soc. sci. Fennica, Årsbok — Vuosikirja XXV B N:o 1.

Hietanen, Anna (1943) Über das Grundgebirge des Kalantigebietes im südwestlichen Finnland. Bull. Comm. géol. Finlande 130.

—»— (1947) Archean geology of the Turku district in southwestern Finland. Bull. Geol. Soc. America 58, pp. 1019—1084.

Holmes, A. (1931) The problem of the association of acid and basic rocks in central complexes. Geol. Mag. 68, pp. 241—255.

Hurlbut, C. S. jr. (1939) Igneous rocks of the Highwood Mountains, Montana. Bull. Geol. S oc. America 50, pp. 1043—1112.

Kahma, A. (1951) On contact phenomena of the Satakunta diabase. Bull. Comm. géol. Finlande 152.

Kaitaro, S. (1952) On some offset structures in dilation dikes. Bull. Comm. géol. Finlande 157, pp. 67—74.

Lokka, L. (1934) Neuere chemische Analysen von finnischen Gesteinen. Bull. Comm. géol. Finlande 105.

—»— (1950) Contributions to the knowledge of the chemistry of the radioactive minerals of Finland. Bull. Comm. géol. Finlande 149.

Moberg, K. A. (1890) Beskrifning till kartbladet N:o 16, Kumlinge. Finlands Geologiska Undersökning.

—»— (1891) Kertomus karttalehteen N:o 16, Kumlingi. Suomen geologinen tutkimus.

Nevin, C. M. (1931) Principles of structural geology. New York.

Newhouse, W. H. (1940) Opening due to movement along a curved or irregular fault plane. Econ. Geology 35, pp. 445—464.

—»—, editor (1942) Ore deposits as related to structural features. Princeton, New Jersey.

Niggli, P. (1923) Gesteins- und Mineralprovinzen I. Berlin.

—»— (1946) Die leukogranitischen, trondhjemitischen und leukosyenitischen Magmen und Anatexis. Schweizer. min. pet. Mitt. 26, pp. 44—78.

—»— (1948) Gesteine und Minerallagerstätten I. Basel.

Noble, J. A. (1952) Evaluation of criteria for forcible intrusion of magma. Jour. Geology 60, pp. 34—57.

Pehrman, G. (1941) En gång av kvartsporfyr på Runsala holme invid Åbo. Geol. Fören. Stockholm Förh. 63, pp. 197—202.

Read, H. H. (1944) Meditations on granite II. Proc. Geologists' Assoc. 55, pp. 45—93.

Sahama, Th. G. (1945) On the chemistry of the east Fennoscandian rapakivi granites. Bull. Comm. géol. Finlande 136, pp. 15—65.

Sederholm, J. J. (1895) Über einen metamorphosirten praecambrischen Quartzporphyr von Karvia in der Provinz Åbo. Bull. Comm. géol. Finlande 2.

—»— (1907) Om granit och gneis, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia. Bull. Comm. géol. Finlande 23 and Fennia 26/2.

—»— (1924) Granit-gneisproblemen belysta genom iakttagelser i Åbo-Ålands skärgård I. Geol. Fören. Stockholm Förh. 46, pp. 129—153.

—»— (1926) On migmatites and associated Pre-Cambrian rocks of southwestern Finland II. The region around the Barösundsfjärd W. of Helsingfors and neighbouring areas. Bull. Comm. géol. Finlande 77.

SEDERHOLM, J. J. (1934) On migmatites and associated Pre-Cambrian rocks of southwestern Finland III. The Åland Islands. Bull. Comm. géol. Finlande 107.

SMITH, H. C. (1946) The lamprophyre problem. Geol. Mag. 83, pp. 165—171.

TANNER, V. (1911) Über eine Gangformation von fossilführendem Sandstein auf der Halbinsel Långbergsöda-Öjen im Kirchspiel Saltvik, Åland-Inseln. Bull. Comm. géol. Finlande 25.

TURNER, F. J. and VERHOOGEN, J. (1951) Igneous and metamorphic petrology. 1st ed., New York.

WAHL, V. (1946) Thermal diffusion-convection as a cause of magmatic differentiation I. Am. Jour. Sci. 244, pp. 417—441.

Bulletin de la Commission géologique de Finlande.

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

N:o 21. T a n n e r, V. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. II. Nya bidrag till frågan om Finmarkens glaciation och nivåförändringar. S. 1—127. 10 fig. 6 tafl. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fenno-Scandia. II. Nouvelles recherches sur la glaciation et les changements de niveau du Finmark. 1907 .... 200: —

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*N:o 23. S e d e r h o l m, J. J. Om granit och gneis, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia. S. 1—110. 11 fig. 8 tafl. 1 planteckn. 1 karta. English Summary of the Contents: On Granite and Gneiss, their Origin, Relations and Occurrence in the Pre-Cambrian Complex of Fenno-Scandia. 1907 .... —

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N:o 25. T a n n e r, V. Über eine Gangformation von fossilienführendem Sandstein auf der Halbinsel Långbergsöda-öjen im Kirchspiel Saltvik, Åland-Inseln. S. 1—13. 5 Fig. 2 Taf. 1911 .... 60: —

*N:o 26. M ä k i n e n, E e r o. Bestimmung der Alkalien in Silikaten durch Aufschliessen mittelst Chlorkalzium. S. 1—8. 1911 .... —

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*N:o 30. S e d e r h o l m, J. J. Sur la géologie quaternaire et la géomorphologie de la Fennoscandia. P. 1—66. 13 fig. 6 cartes. 1911 .... —

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N:o 37. S e d e r h o l m, J. J. Weitere Mitteilungen über Bruchspalten mit besonderer Beziehung zur Geomorphologie von Fennoskandia. S. 1—66. 27 Fig. I Taf. 1913 .... 140: —

N:o 38. T a n n e r, V. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. III. Om landisens rörelser och afsmältning i finska Lappland och angränsande trakter. S. 1—815. 139 fig. 16 tafl. Résumé en français: Études sur le système quaternaire dans le parties septentrionales de la Fennoscandia. III. Sur la progression et le cours de la récession du glacier continental dans la Laponie finlandaise et les régions environnantes. 1915 .... 600: —

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*) Loppuunmyyty.
Out of print.

N:o 44. Eskola, Pentti. Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvitraktens metamorfa bergarter. S. 1—145. 5 fig. English Summary of the Contents. 1915 .... 120: —

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N:o 47. Mäkinen, Eero. översikt av de prekambriska bildningarna i mellersta Österbotten i Finland. S. 1—152. 25 fig. 1 karta. English Summary of the Contents. 1916 .... 200: —

*N:o 48. Sederholm, J. J. On Synantetic Minerals and Related Phenomena (Reaction Rims, Corona Minerals, Kelyphite, Myrmekite, &c.). P. 1—148. 14 fig. in the text and 48 fig. on 8 plates. 1916 .... —

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N:o 55. Eskola, Pentti. On Volcanic Necks in Lake Jänisjärvi in Eastern Finland. P. 1—13. 1 Fig. 1921 .... 60: —

N:o 56. Metzger, Adolf A. Th. Beiträge zur Paläontologie des nordbaltischen Silurs im Ålandsgebiet. S. 1—8. 3 Abbild. 1922 .... 60: —

*N:o 57. Väyrynen, Heikki. Petrologische Untersuchungen der granitodioritischen Gesteine Süd-Ostbothniens. S. 1—78. 20 Fig. 1 Karte. 1923 —

*N:o 58. Sederholm, J. J. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part I. The Pellinge Region. P. 1—153. 64 fig. 8 plates. 1 map. 1923 .... —

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N:o 64. Metzger, Adolf A. Th. Die jatulischen Bildungen von Suojärvi in Ostfinnland. S. 1—86. 38 Abbild. 1 Taf. 1 Karte. 1924 .... 120: —

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N:o 69. Auer, Väinö. Die postglaziale Geschichte des Vanajavesisees. S. 1—132. 10 Fig. 10 Taf. 11 Beil. 1924 .... 200: —

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*) Loppuunmyyty.
Out of print.

N:o 70. Sederholm, J. J. The Average Composition of the Earth's Crust in Finland. P. 1—20. 1925 .... 80: —

N:o 71. Wilkman, W. W. Om diabasgångar i mellersta Finland. S. 1—35. 8 fig. 1 karta. Deutsches Referat. 1924 .... 80: —

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N:o 89. Wegman, C. E. und Kranck, E. H. Beiträge zur Kenntnis der Svecofenniden in Finland. I. Übersicht über die Geologie des Felsgrundes im Küstengebiete zwischen Helsingfors und Onas. II. Petrologische Übersicht des Küstengebietes E von Helsingfors. S. 1—107. 4 Fig. 16 Taf. mit 32 Fig. 1 Übersichtskarte. 1931 .... 160: —

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N:o 102. Wegmann, S. E., Kranck, E. H. et Sederholm, J. J. Compte rendu de la Réunion internationale pour l'étude du Précambrien et des vieilles chaînes de montagnes. P. 1—46. 1933 .... 120: —

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N:o 107. Sederholm, J. J. † On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part III. The Åland Islands. P. 1—68. 43 fig. 2 maps. 1934 .... 160: —

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N:o 129. L o k k a, L a u r i. Beiträge zur Kenntnis des Chemismus der finnischen Minerale Glimmer, Pyroxene, Granate, Epidote u. a. Silikatminerale sowie melnikowitähnliches Produkt und Shungit. S. 1—72. 48 Tab. 1943 150: —

*N:o 130. H i e t a n e n, A n n a. Über das Grundbebirge des Kalantigebietes im südwestlichen Finnland. S. 1—105. 55 Fig. 8 Tafeln. 1 Karte. 1943 .. —

N:o 131. O k k o, V. Moränenuntersuchungen im westlichen Nordfinnland. S. 1—46. 12 Abb. 4 Tab. 1944 .... 90: —

N:o 132. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XVI. P. 1—196. 41 diagr. 9 tabl. 3 cartes. 3 fig. 1944 .... 200: —

N:o 133. R a n k a m a, K a l e r v o. On the Geochemistry of Tantalum. P. 1—78. 1 fig. 8 tables. 1944 .... 150: —

N:o 134. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XVII. P. 1—91. 59 fig. 1 carte. 1944 .... 150: —

N:o 135. S a h a m a, T h. G. Spurenelemente der Gesteine im südlichen Finnisch-Lappland. S. 1—86. 12 Fig. 29 Tab. 1945 .... 150: —

N:o 136. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XVIII. P. I—XXXVIII; 1—67. 3 diagr. 11 tabl. 2 cartes. 11 fig. 2 planches. 1945 .... 200: —

N:o 137. R a n k a m a, K a l e r v o. On the Geochemical Differentiation in the Earth's Crust. P. 1—39. 18 tables. 1946 .... 100: —

N:o 138. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XIX. P. 1—120. 7 diagr. 13 tabl. 9 fig. 1 planche. 1946 .... 200: —

N:o 139. B r e n n e r, T h. Om mineraljordarternas hållfasthetsegenskaper. S. 1—77. 11 fig. Summary in English. 1946 .... 120: —

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*) Loppuunmyyty.
Out of print.

N:o 140. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XX. P. 1—302. 37 tabl. 103 fig. 6 planches. 2 cartes. 1947 300: —

N:o 141. Simonen, Ahti. On the Petrochemistry of the Infracrustal Rocks in the Svecofennidic Territory of Southwestern Finland. P. 1—18. 7 tabl. 5 fig. 1948 .... 25: —

N:o 142. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXI. P. 1—129. 45 fig. 1 planche. 4 tabl. 3 cartes. 1948 200: —

N:o 143. Simonen, Ahti. On the Petrology of the Aulanko Area in Southwestern Finland. P. 1—66. 25 fig. 6 tabl. 1 map. 1948 .... 100: —

N:o 144. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXII. P. 1—165. 70 fig. 3 planches. 4 cartes. 1949 ...... 200: —

N:o 145. Salmi, Matti. Physical and Chemical Peat Investigations on the Pinomäensuo Bog, SW. Finland. P. 1—31. 12 fig. 1 table. 1949 ...... 50: —

N:o 146. Mikkola, Aimo. On the Geology of the Area North of the Gulf of Bothnia. P. 1—64. 20 fig. 10 tabl. 1 map. 1949 .... 100: —

N:o 147. Härme, Maunu. On the Stratigraphical and Structural Geology of the Kemi Area, Northern Finland. P. 1—60. 29 fig. 4 tabl. 1 map. 1949 100: —

N:o 148. Edelman, Nils. Structural History of the Eastern part of the Gullkrona Basin, SW-Finland. P. 1—48. 16 fig. 2 tabl. 8 plates. 1949 90: —

N:o 149. Lokka, Lauri. Contributions to the Knowledge of the Chemistry of the Radioactive Minerals of Finland. P. 1—76. 7 fig. 33 tabl. 1950 .. 150: —

N:o 150. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXIII. P. 1—111. 27 fig. 7 planches. 5 tabl. 2 cartes. 1950 250: —

N:o 151. Lokka, Lauri. Chemical Analyses of Finnish Rocks. P. 1—75. 1950 150: —

N:o 152. Kahma, Aarno. On Contact Phenomena of the Satakunta Diabase. P. 1—84. 22 fig. 10 tabl. 5 plates. 1951 .... 200:—

N:o 153. Seitsari, Juhani. The Schist Belt Northeast of Tampere in Finland. P. 1—120. 53 fig. 9 tabl. 2 maps. 1951 .... 300: —

N:o 154. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXIV. P. 1—241. 95 fig. 3 planches. 24 tabl. 1951 .... 400: —

N:o 155. Virkkala, K. Glacial Geology of the Suomussalmi area, East Finland. P. 1—66. 26 fig. 1 plate. 1951 .... 150: —

N:o 156. Marmo, Vladi — Mikkola, Aimo. On Sulphides of the Sulphide-bearing Schists of Finland. P. 1—44. 7 fig. 4 plates. 1951 .. 90: —

N:o 157. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXV. P. 1—148. 35 fig. 28 tabl. 1952 .... 350: —

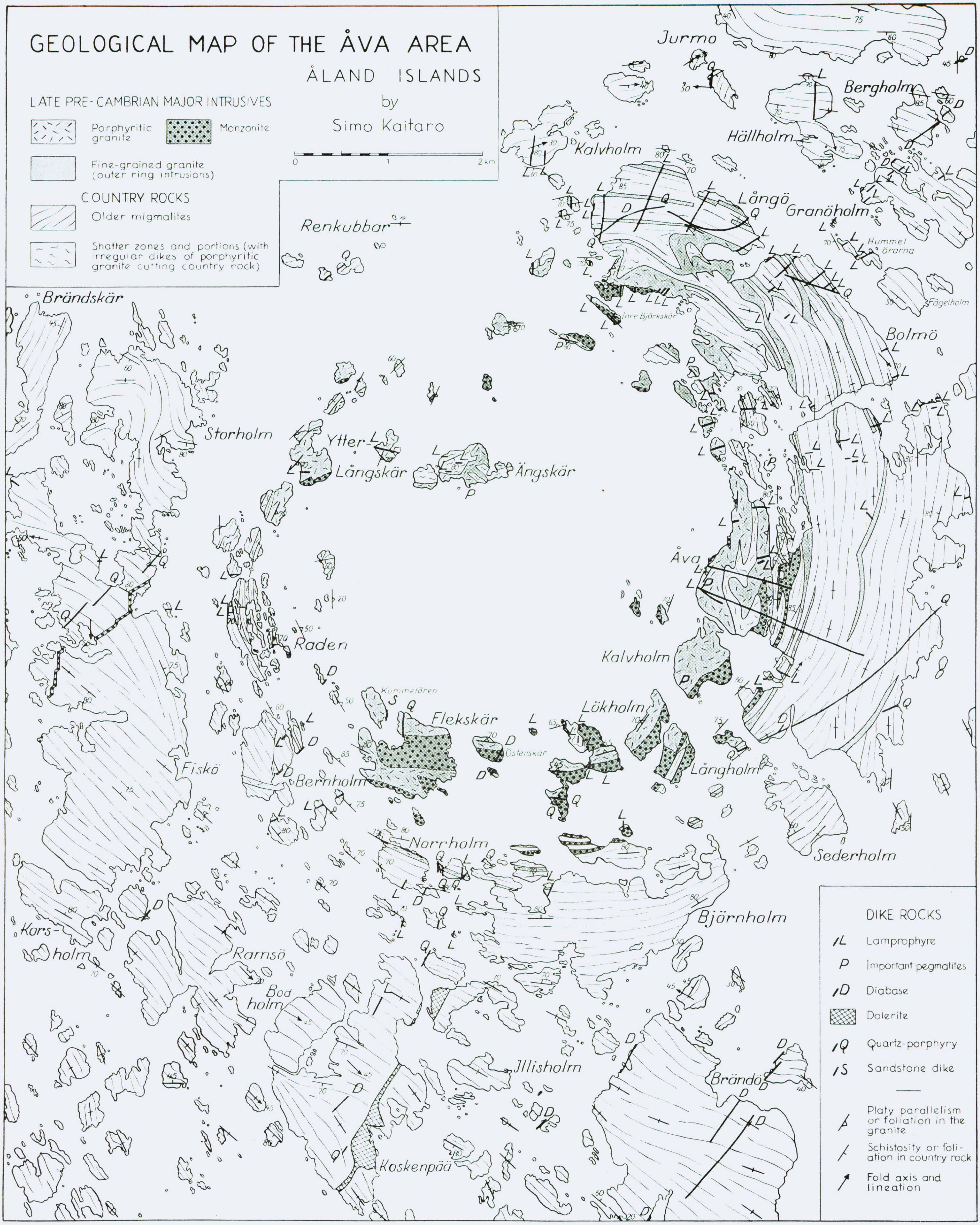
N:o 158. Neuvonen, K. J. Thermochemical Investigation of the Åkermanite — Gehlenite Series. P. 1—57. 7 fig. 12 tabl. 1952 .... 100: —

N:o 159. Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXVI. Painossa. .... —

N:o 160. Simonen, Ahti. Stratigraphy and Sedimentation of the Svecofennidic Early Archean Supracrustal Rocks in Southwestern Finland. P. 1—64. 17 fig. 8 tabl. 2 maps. 1953 .... 150: —

N:o 161. Disler, Jürg. Die Kupferkieslagerstätte von Outokumpu, Finnland. (Ihre Lage, ihre Struktur und ihre Form.) S. 1—114. 39 Fig. 8 Diagr. 4 Taf. 1953 .... 300: —

N:o 162. Kaitaro, Simo. Geologic Structure of the Late Pre-Cambrian Innidic Eerly Archean Supracrustal Rocks in Southwestern Finland. P. 1 map. 1953 .... 150: —



GEOLOGICAL MAP OF THE ÅVA AREA
ÅLAND ISLANDS
by
Simo Kaitaro
LATE PRE-CAMBRIAN MAJOR INTRUSIVES
Porphyritic granite
Monzonite
Fine-grained granite (outer ring intrusions)
COUNTRY ROCKS
Older migmatites
Shatter zones and portions (with irregular dikes of porphyritic granite cutting country rock)
0
1
2 km
DIKE ROCKS
L Lamprophyre
P Important pegmatites
D Diabase
Dolerite
Q Quartz-porphyry
S Sandstone dike
Platy parallelism or foliation in the granite
Schistosity or foliation in country rock
Fold axis and lineation
Jurmo
Bergholm
Hällholm
Kalvholm
Långö
Granöholm
Hummel örarna
Renkubbar
Inre Björkskär
Fågelholm
Bolmö
Brändskär
Storholm
Ytter-
Långskär
Ängskär
Åva
Raden
Kalvholm
Kummelören
Flekskär
Lökholm
Österskär
Bernholm
Fiskö
Långholm
Sederholm
Norrholm
Björnholm
Kors-
holm
Ramsö
Bod
holm
Jllisholm
Brändö
Koskenpää