THE SVANEKE GRANITE COMPLEX AND THE GNEISSES ON EAST BORNHOLM

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The Svaneke granite complex consists of four main types of granitic rocks in a zonar arrangement. Two outer zones of granitic rocks, an intermediate zone with granitic to granodioritic composition and a central part with granitic rocks can be distinguished. West of the Svaneke granite complex occur mainly granitic to granodioritic biotite gneisses and quartz rich gneisses. Additional minor amounts of granitised gneisses, skarn bearing gneisses, and quartzite are found. Pegmatites formed earlier as well as penecontemporary with the Svaneke granite complex are seen. Other rocks penecontemporary with the Svaneke granite complex are composite aplite-leucogranite-pegmatite dykes and bodies and dykes of granite different from the Svaneke granite types. A seperate granite body is the Hallegård granite which occurs west of the Svaneke granites. It differs from the Svaneke granites in containing large amounts of pegmatites entirely composed of granophyric intergrown quartz and feldspars. In the gneisses west of the Svaneke granite complex and partly in gneiss inclusions in the Svaneke granites are recorded at least three periods of deformation and recrystallization.

The area under consideration is situated on the island of Bornholm, which is partly composed of Precambrian rocks and partly of Paleozoic to Mesozoic rocks (Milthers, 1930). East Bornholm has a low relief with maximum heights of about 100 m the bedrock is extensively covered by Quaternary deposits. Outcrops are mainly found along the coast and in the highest part of the area, i. e. in Paradisbakkerne, but fortunately many quarries are found in the Precambrian rocks. Bornholm is regarded as a fault-bounded horst structure, resulting in the existence of a great number of faults. The many faults and the few outcrops make geological work very difficult which means that it was not possible to make systematic petrological investigations, and further, the evaluation of the tectonical relations is very difficult.

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Methods

To overcome some of the difficulties caused by faulting and lack of outcrops magnetic measurements were applied. Mapping of the area was made by aerial photographs in the scale 1:9500, based on which maps in the scale 1:2000 were made over key areas. To administrate the magnetic measurements and the petrographical data electronic data processing was applied.

The petrographical methods applied consist of point-counting and qualitative description of 105 thin sections. The observations were systematised, thus enabling the use of electronic data processing (E.D.P.) in administrating the data.

The point-countings were made as double point-countings. First the light minerals were counted with ca. 500–600 points and secondly the dark coloured minerals were counted with 1000–1300 points, as these minerals normally only occur in an amount of less than ten volume per cent.

As the rocks investigated are rather homogeneous in a textural and microstructural sense the qualitative petrological description could be systematised. The features of interest were: 1) Occurrence of myrmekite in plagioclase 2) Replacement of plagioclase by microcline 3) Zoning in plagioclase 4) Alteration of biotite 5) Alteration of plagioclase 6) Occurrence of primary muscovite 7) Occurrence of two generations of plagioclase 8) Alteration of hornblende 9) Paleosome-neosome conditions.

E. D. P. was applied in recalculating the point-countings and the magnetic measurements. The petrographical data were sorted into the different rock types and the average compositions were calculated for the different minerals. These average compositions were compared statistically. As the E. D. P. system used in the work on East Bornholm has been incorporated in a complete system for E. D. P. treatment of geological field and laboratory data (Platou, in press) no further description will be given here.

The geophysical method applied was magnetic measurements, partly as profile measurements across the boundary between the Svaneke granite complex and the gneisses, and partly as scattered single measurements, to obtain a regional magnetic map.

The western boundary between the gneisses and the Svaneke granites could easily be followed on the magnetic anomaly map (see fig. 15). Further it was possible to trace the influence of the faults on the course of the western boundary.

The petrophysical properties of the different rock types have earlier been published (Platou, 1968).

Nomenclature

In the division of the different rock types is used the nomenclature proposed by Streckeisen (1967) who divides the granite field (see fig. 7) into two parts, i. e. granite (3a) and granite (3b). In the present paper this terminology has been used for rocks, the composition of which corresponds to these two fields.

The term leucogranite is used for rocks with a content of dark minerals less than five volume per cent (Johannsen, 1932). The term pegmatite is used for rocks with an average grain size bigger than the surrounding granites and gneisses which have an average grain size between 2–10 mm. A rock is aplitic in grain size when the grain size is smaller than the grain size in the country rock.

The terms paleosome and neosome are used in their strict meaning, i. e. paleosome are those parts of the original rock which are preserved when the rock recrystallizes, and neosome is the new formed part of the rock. Paleosome-neosome conditions occur in both micro and macro scales.

A rock is called granitised when it has recrystallized to form a rock with a composition more granitic than the original rock, i. e. the granitised rock is found more to the left in the composition diagram (see fig. 7) than the original rock.

The term intrusive is used purely descriptive, disregarding the physical conditions in the rock during the intrusion. The main criterion for intrusive relationships is a sharp discordant boundary between the intrusive rock and the surrounding rock.

Outline of the Precambrian geology of Bornholm

The precambrian granitoids and gneisses of Bornholm have been treated by several authors. The most comprehensive description was made by Callisen (1934). Callisen gave a detailed petrographical description of the rocks and advocated a fully magmatic view on their genesis.

Other important contributions have been made by von Bubnoff and Kaufmann (1932, 1941); these authors also held a magmatic view on the genesis of the rocks.

Later Micheelsen (1961) introduced a completely transformistic view on the formation of the rocks which was adopted by Noe-Nygaard (1963).

The following outline is based on previous work and on work by the present author. The geological map in fig. 1 is based partly on the map published by Micheelsen (1961) and partly on work by the present author.

The precambrian rocks of Bornholm can be divided into two groups. The area west of a line approximately from Gudhjem to Åkirkeby consists of

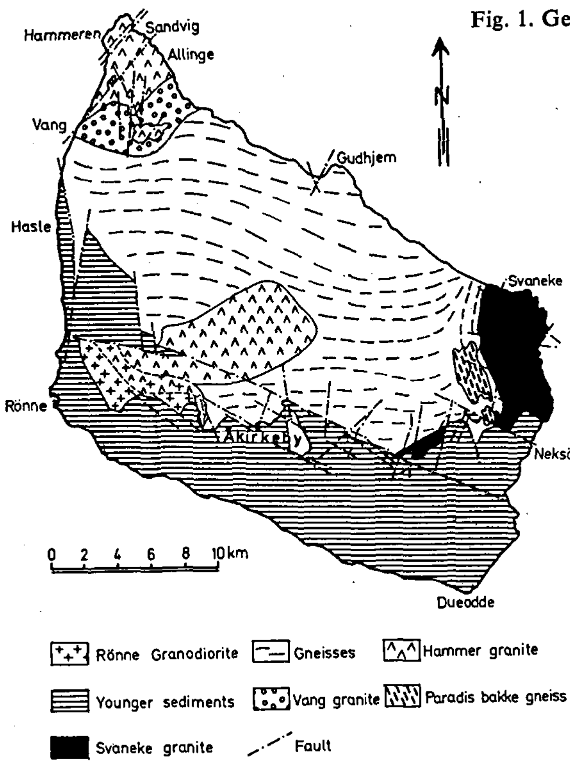

Fig. 1. Geological map of Bornholm.

gneiss, Hammer granite, Vang granite, and Rønne granite, while the area east of the line consists of gneisses, Svaneke granite and Hallegård granite.

The gneisses in both areas are granitic to granodioritic, generally rather well foliated rocks which in the western part are more or less granitised in connection with the formation of the Hammer granites. Recrystallization in connection with the formation of the Hammer granites has not been observed in the eastern part, where granitisation in the gneisses only is recorded close to the Svaneke granite complex.

In the western part occurs a non foliated granodioritic massif, the Rønne granodiorite which is the most homogeneous type of the major Precambrian rocks found on Bornholm. Another similar, but more granitic rock is the Vang granite found on northern Bornholm. The Rønne granite and especially the Vang granite have been influenced by recrystallization in connection with the formations of the Hammer granites.

The Hammer granites occur in two large areas, one on northern Bornholm and one in the Almindingen area in central Bornholm. Furthermore a number of small bodies of Hammer granite occurs in the gneisses. Two types of

Hammer granite can be distinguished, one weakly foliated and the other one homogeneous. The foliated type is dominating in the Almindingen area and it occurs in the eastern part of the area on North Bornholm. The homogeneous Hammer granite occurs in the western part of the area on North Bornholm. A small body of hypersthene bearing granodiorite is found west of Hasle; this rock is practically without foliation and has sharp boundaries to the surrounding well foliated gneiss. The relations between this hypersthene granodiorite and the other rocks on Bornholm are unknown.

In the area east of the line Gudhjem–Åkirkeby the Svaneke granite complex and the Hallegård granite occur.

The following evolution of the Precambrian of Bornholm can be proposed: The rocks now found as gneisses were deformed and metamorphosed in almandine-amphibolite facies. The first traceable deformation was accompanied by some pegmatite formations. Later further deformation took place accompanied by new pegmatite formations and often intense migmatization. After this deformation the Vang granite and the Rønne granodiorite were emplaced, probably as intrusive bodies.

In connection with a third deformation and recrystallization the Hammer granites and the Svaneke granite complex were formed. It is unknown whether the third deformation observed on East Bornholm in connection with the formation of the Svaneke granites is of the same age as the deformation observed in connection with the formation of the Hammer granites.

After the consolidation of the gneisses and granites basaltic rocks were intruded as dykes mainly trending north–south. Dykes with an east–west trend are also observed.

The present distribution of the different rock types is strongly controlled by numerous faults. The faulting took place from Precambrian time and up to Tertiary time.

The Precambrian of East Bornholm

The Precambrian of East Bornholm can be divided into four main components: 1) The gneisses west of the Svaneke granite complex, 2) Gneisses inside the Svaneke granite complex, 3) The Svaneke granite complex, 4) The Hallegård granite. The localities mentioned in the text are found on the map, fig. 2.

The gneisses west of the Svaneke granite complex

The gneisses investigated occur in the area from the western boundary of the Svaneke granite complex until 4–5 km west of this boundary (see fig. 6). In this area the following gneiss types occur: a) grey biotite gneiss, b) granitised

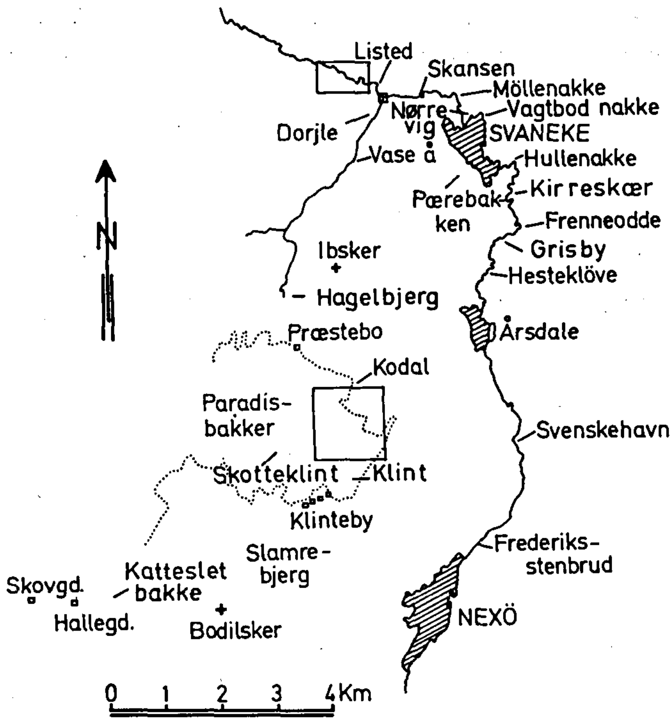

Fig. 2. Map showing the localities mentioned in the text. The frames indicate areas covered by detailed maps. The punctured line indicates the boundary for Paradisbakkerne.

grey biotite gneiss, c) Paradisbakke gneiss, d) quartz rich gneiss, e) skarn bearing grey biotite gneiss, f) quartzite. The area is mainly composed of grey biotite gneiss in which the other gneiss types are irregularly distributed.

Grey biotite gneiss.

The grey biotite gneisses (striated granite by Callisen, 1934) occur in many different varieties. The most common one is a grey weakly foliated biotite gneiss, in which some of the plagioclase grains are porphyroblasts (see fig. 4). Other types are rather well foliated and occasionally with a banding of alternating dark and light bands. The average composition of the gneisses is found in table I.

Granitised gneisses

The granitised gneisses are grey biotite gneisses which have been enriched in microcline. Accompanying the increase in the content of microcline the content of all the other minerals has decreased. The average modal composition of the granitised biotite gneisses is found in table I, from which it appears that the microcline content is ten volume per cent higher than in the grey biotite gneisses.

In the field can be observed a gradual transition from main gneisses over more and more granitised gneisses to a leucogranitic almost homogeneous rock with only weak foliation. The latter occurs in the central parts of the granitised gneiss areas.

The granitization of the gneisses is discordant to the structures developed during the first and second recognizable period of deformation of the gneisses.

Paradisbakke gneiss

The Paradisbakke gneiss (Paradisbakke migmatite by Micheelsen, 1961 and Paradisbakke granite by Callisen, 1934) occurs in rather restricted areas mainly in Paradisbakkerne (see fig. 6). The rock generally has a stronger migmatitic appearance than the other gneisses on East Bornholm because of dark colour of the matrix.

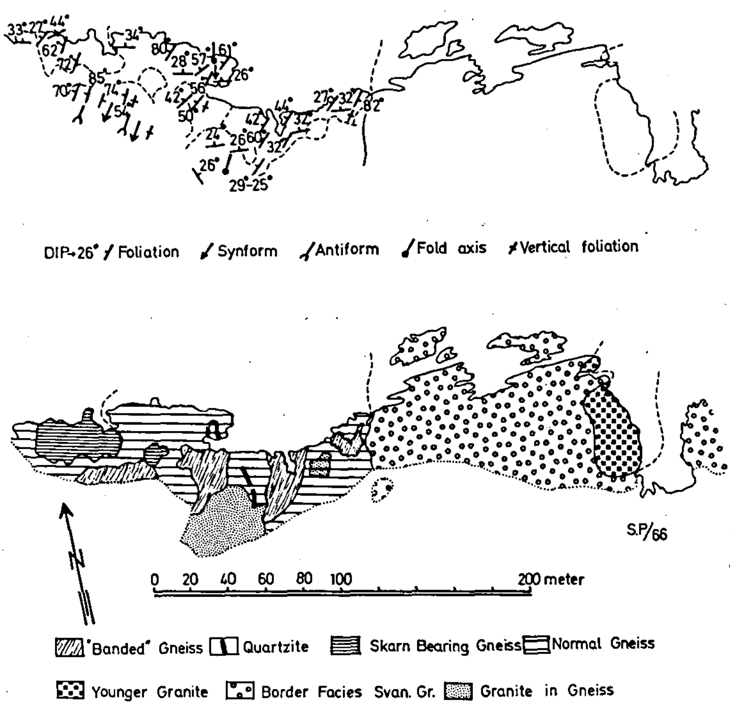

Fig. 3. Geological map of the coast west of Listed harbour. The folds indicated are F2 folds deforming the S1 surfaces. The S3 foliations strike ca. east-west and dip towards north. The S1 surfaces strike ca. northwest-southeast. The banded gneisses are mainly quartz rich gneisses.

The Paradisbakke gneiss is only weakly foliated in the central parts. Towards the boundaries the foliation becomes more pronounced and a narrow transitional zone to the other gneiss types can be observed in the comparatively well exposed Paradisbakke area.

Quartz rich gneisses

Gneisses with a high content of quartz are rather common. The main occurrences (see fig. 6) are west of Kodals Huse in Paradisbakkerne, at Hagelbjerg west of Ibs Kirke, and at the coast west of Listed (see fig. 3). These gneisses have a banded appearance with quartz dominated layers alternating with layers more rich in feldspars and dark minerals. The quartzrich gneisses at Hagelbjerg and west of Kodals Huse contain primary muscovite, i. e. muscovite which is not a result of plagioclase alteration, a feature which previously has not been recorded from the Precambrian of Bornholm.

The quartz rich gneiss at Hagelbjerg contains locally one to two per cent of pyrrhotite.

Skarn bearing gneisses

A special variety of the grey biotite gneisses is a gneiss which contains elliptic lenses of garnet-epidote rock in the cm scale. These skarn lenses are composed of strongly intergrown garnet and epidote together with an unidentified alteration product. These skarn lenses were only observed at the coast west of Listed (see fig. 3), but Callisen (1956) reports wollastonite-garnet-diopside skarns from a locality ca. 0.5 km south-west of Listed.

Quartzite

An almost pure quartz rock occurs as a concordant layer in grey biotite gneiss (see fig. 4) west of Listed (see fig. 3). The quartzite is weakly banded, 5–10 cm thick, and occurs as boudins in a synform structure in the gneisses.

Larger gneiss areas inside the Svaneke granite complex

At four localities larger areas with gneiss occur inside the Svaneke granite complex: a) at Vagtbod Nakke (Svaneke), b) At the Vaseå estuary (Listed), c) At Skansen (east of Listed), d) At Kirreskær (south of Svaneke). Besides these gneiss areas numerous small inclusions, partly of gneisses, are observed in the Svaneke granite complex; these inclusions are described on pp. 108–109.

Vagtbod Nakke

At the head of Vagtbod Nakke occurs gneiss, which because of its relationship to the later described zoning in the Svaneke granite complex is considered to be

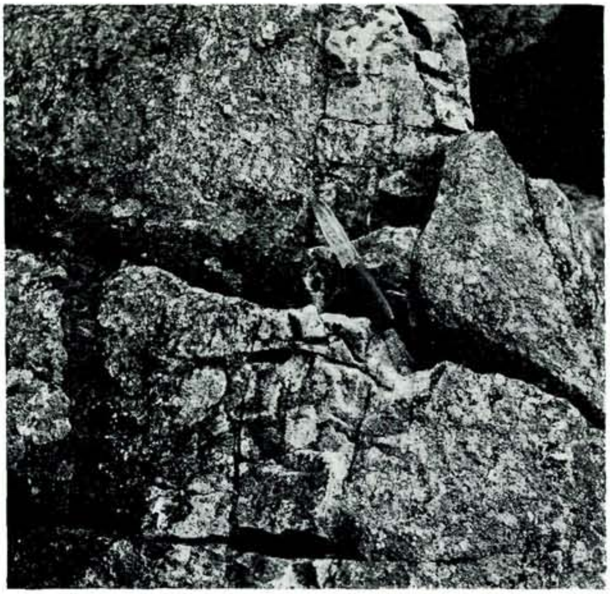

Fig. 4. Layer of quartzitic rock ca. 10 cm thick at the coast west of Listed. The surrounding grey biotite gneiss shows porphyroblastic plagioclase.

part of the gneisses outside the Svaneke granite complex. The gneiss at Vagtbod Nakke is a reddish-grey rock with abundant microcline porphyroblasts and a content of small lenses of fine grained mafic gneiss. Further some rootless lenses of Svaneke granite occur in the gneiss. In a thin section of the gneiss a few small garnets were observed.

Vaseå estuary

The gneiss at the Vaseå estuary (see fig. 5) is completely enclosed in Svaneke granite which here partly has intrusive relation to the gneiss.

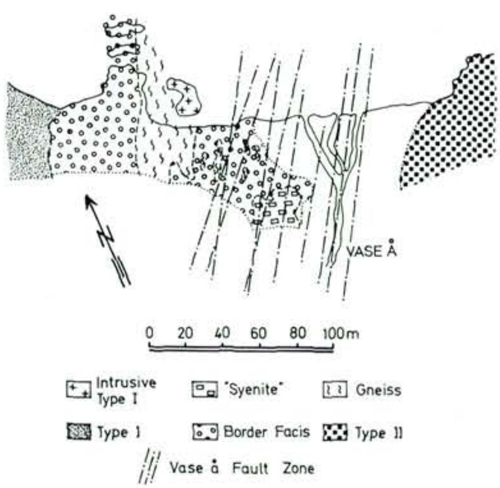

Fig. 5. Geological map of the area around the Vaseå estuary at Listed. Type I, Type II, and Border Facies are the normal Svaneke granite types. The syenite is a microcline dominated rock without quartz (see Callisen, 1934).

The gneiss is a rather fine grained homogeneous grey rock with green plagioclase porphyroblasts similar to the grey biotite gneiss. Close to the boundary toward the Svaneke granite the gneiss is well foliated and the foliation is subparallel to the boundary (see fig. 14).

Skansen

The gneiss at Skansen is a small (10–20 m long) flatlying lens strongly granitised along the borders. Only a small portion of unaltered gneiss is left. The latter is quartz rich and well foliated.

Kirreskær

The gneiss at Kirreskær is below sea level. The gneiss is well foliated and comparatively mafic.

The Svaneke granite complex

During the field work it was found possible to divide the Svaneke granite into a number of subtypes. It is therefore preferred here to describe the »Svaneke granite« (in the sense of Callisen (1934) and Micheelsen (1961)) as the Svaneke granite complex. Besides the subtypes of Svaneke granite, the complex contains rocks which are penecontemporary with the formation of the Svaneke granites. These rocks are pegmatites, aplites, bodies or dykes of granite and composite dykes of aplite-leucogranite-pegmatite. These rocks will be treated separately.

The Svaneke granite subtypes occur in a zoned arrangement with the following types recorded from the boundary in the west towards the central parts of the complex: 1) Border Facies Svaneke granite, 2) Svaneke granite Type I, 3) Svaneke granite Type II, 4) Svaneke granite Type III. Together with Svaneke granite Type III occurs: 5) Svaneke granite Type IV. Fig. 7 shows the quantitative differences between the Svaneke granite types.

Border Facies Svaneke granite

The border facies of the Svaneke granite complex occur as two different varieties. One type is a non-lineated rock and is found at the coast west of Listed and in Paradisbakkerne. The other type is an often strongly lineated rock (Lineated Border Facies) which occurs at Frennenakke south of Svaneke and at the coast just north of Årsdale. The non-lineated type is a light

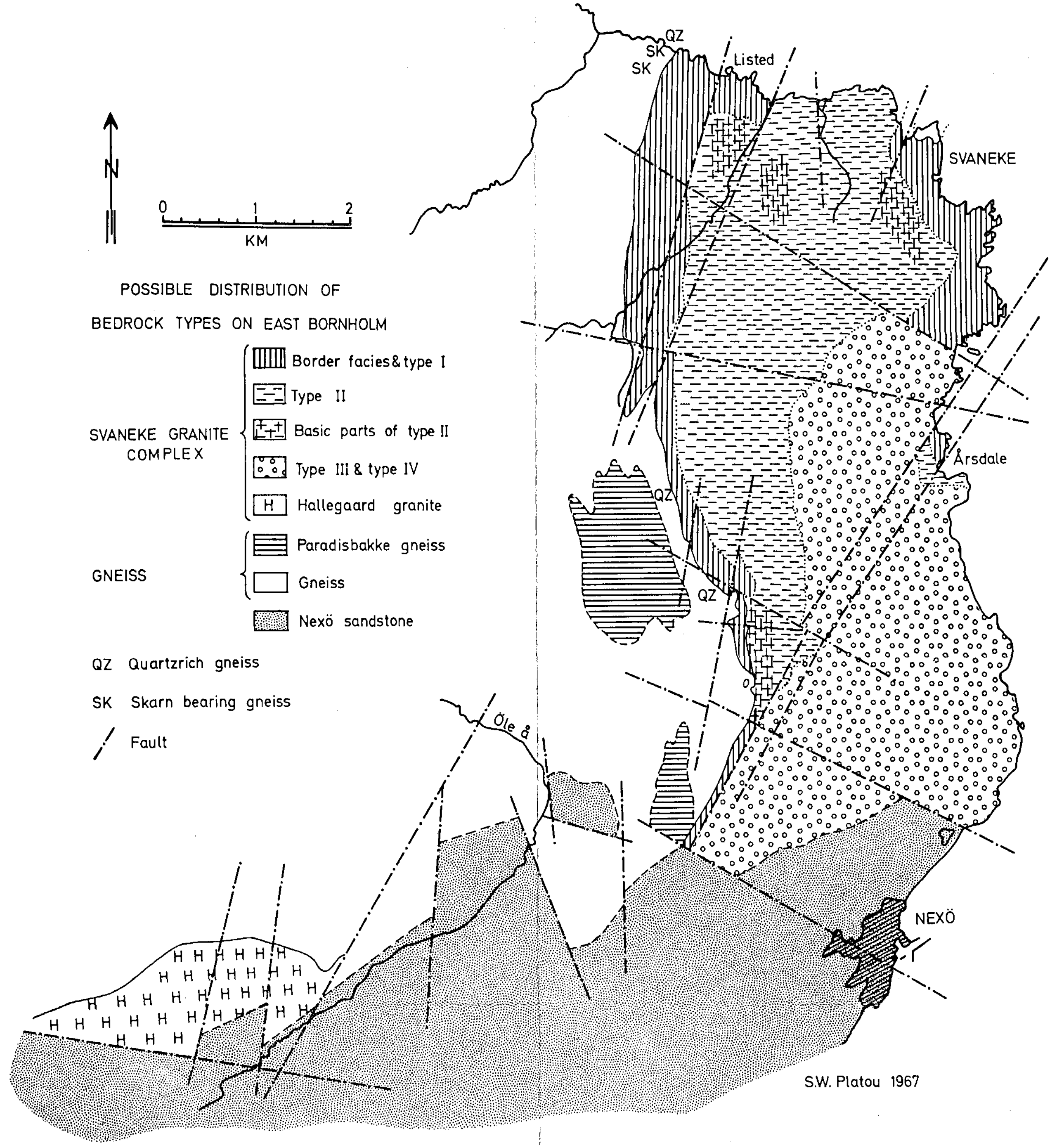

Fig. 6. Distribution of bedrock types on East Bornholm. The map is a result of combined interpretation of the geology of the outcrops and the magnetic anomaly map. No distinction has been made between Border Facies rocks and Type I as Type I only occupies small areas.

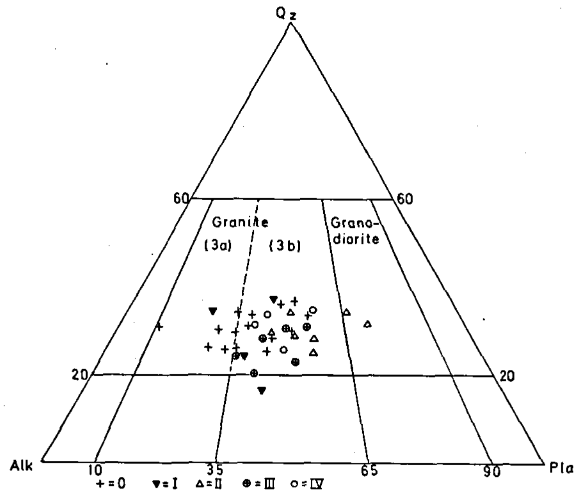

Fig. 7. Distribution of the Svaneke granite types in a quartz-feldspar diagram.

yellow-red rock with a comparatively small content of dark minerals which occur concentrated in clusters. These clusters have a tendency to be concentrated in flat lying planes. The microcline grains are often somewhat larger than the other grains.

The Lineated Border Facies type is rich in dark minerals, and the rock is often very strongly lineated. All transitions between the non-lineated and the lineated Border Facies occur and the two types are often found intermixed with each other, which can be observed north of Kirreskær. Here also numerous small bodies of leucogranite occur in the Border Facies rocks. In thin sections of the Border Facies granites are observed that they often show a bicomponental structure. One component is quartz and often strongly myrmekitic plagioclase and the other component is quartz, perthite and non-myrmekitic plagioclase. The biotite is weakly altered to chlorite. Flourite is observed in a few thin sections. The non-lineated type is a granite (3a), while the lineated type is a granite (3b). There exists a very large variation in the quantitative composition of the Border Facies rocks, as expressed in the standard deviations in table II and on fig. 7. In the leucogranitic rocks, found together with the Border Facies rocks, e. g. north of Kirreskær, the content of microcline is somewhat larger than in the surrounding granite.

Svaneke granite Type I

Svaneke granite Type I occurs in a zone between Border Facies Svaneke granite and Svaneke granite Type II. In Paradisbakkerne the zone is less than 100 m broad, but along the coast south of Svaneke the zone is at least 300 m wide. These difference in the width of the areas covered by Type I are dependent on the steepness of the boundary between Svaneke granite Type I and the other types.

Svaneke granite Type I is a light yellow rock with irregular grain size distribution, i.e. a relatively fine grained matrix of quartz, perthite, and plagioclase in which larger grains of the same minerals occur. The dark minerals appear as irregular patches without preferred orientation. A typical locality with Type I is the outcrops at the coast just west of Listed harbour.

In thin sections are observed that the matrix plagioclase often occurs in grain groups composed of ten to fifteen single grains which all is strongly myrmekitic in opposition to the larger plagioclase grains which practically do not show myrmekite texture. The microcline is perthitic and replaces plagioclase and the rim of the biotite grains. The microcline grains often have inclusions of plagioclase. The biotite is normally weakly altered to chlorite.

Svaneke granite Type I is a granite (3b) and the content of dark minerals is often so low that the rock is a leucogranite. .The modal composition of Type I is found in table II.

Svaneke granite Type II

Svaneke granite Type II occupies large areas in the Svaneke granite complex. Type II appears in three main varieties between which all transitions occur. One type has an almost granodioritic composition and occurs at Dorjle Klippe, Pærebakken, Møllenakke, and along the east boundary of Paradisbakkerne. Another type is more granitic in composition and occurs on the coast east of the Vaseå estuary and in some outcrops inland. The third type is the most granitic of the three variants of Svaneke granite Type II. The latter variant is found in a few outcrops west of Ibs Kirke.

In hand specimens the three variants are medium to coarse grained and has a homogeneous grain size distribution. The content of dark minerals is highest in the granodioritic type and smallest in the granitic type. The dark minerals appear as irregular patches equally distributed in the rock. Hornblende, biotite, and sphene are visible to the naked eye. The colour of Svaneke granite Type II varies much; the granitic type is yellow-red, the intermediate type is dark grey, and the granodioritic type is partly light grey and partly red-grey. The red colour is caused by red microcline.

Thin sections show that the plagioclase normally is zoned with a core of somewhat altered plagioclase surrounded by a rim of unaltered plagioclase with an albite content a few per cent lower than in the core. The plagioclase grains have often developed complex twins i. e. Carlsbad twins, Albite twins, and sometimes also Pericline twins. This twinning of the plagioclase separates Type II from the other Svaneke granite types, in which practically only Albite twins occur. Hornblende and biotite are normally unaltered, although the biotite in some cases can be somewhat altered to chlorite in connection with the occurrence of flourite along the cleavage planes in the biotite.

Svaneke granite Type II shows rather large differences in composition. In average Type II is a granite (3b). Type II is the most granodioritic variant of the Svaneke granites (see table II). Some of the samples investigated have a granodioritic composition (see fig. 7).

Svaneke granite Type III

Svaneke granite Type III occupies the central area of the exposed part of the Svaneke granite complex. It is well exposed along the coast from Grisby to Hestekløve and from Årsdale to Nexø, and it also occurs in many inland outcrops. In hand specimens a variation from a light yellow rock with abundant microcline porphyroblasts to a homogeneous yellow-red granite can be seen. The porphyroblastic type occurs mainly at Hestekløve, but is also observed south of Årsdale. A third variant occurs locally just north of Nexø; this granite is grey. The colour seems to be a result of alterations in connection with the faulting here, which is accompained by a very weak sulphide-flourite mineralization (Bøgvad, 1940).

In thin sections it is seen that Svaneke granite Type III consists of a matrix of quartz surrounding the feldspar grains. The plagioclase and microcline grains are of approximately the same size also in the porphyroblastic variant. The microcline is strongly perthitic and replaces plagioclase. Biotite is generally altered to chlorite and ore, but also only partly altered and completely unaltered biotite grains occur. Hornblende appears in some thin sections in the core of an undeterminable aggregate of alteration products; but in most cases only the alteration product is observed. Ore occurs as independent grains, often surrounded by a rim of sphene. Apatite occurs as isolated prismatic grains, which is unusual as apatite in the other Svaneke granite types occurs together with the other dark minerals. Flourite is rather common in Type III, either in altered hornblende or along cleavage planes in altered biotite.

The average composition of Svaneke granite Type III is granite (3b). The porphyroblastic type is normally a leucogranitic rock.

Svaneke granite Type IV

Svaneke granite Type IV is observed in the coastal outcrops south of Årsdale as lenses in Svaneke granite Type III. Type IV does not occur everywhere in Type III; in some areas the rock is very common, separated by areas where it does not occur. Because of the few inland outcrops the description is based on observations along the coast. The dimensions of the lenses of Type IV vary from some tenths of m^2 up to several hundreds of m^2.

In hand specimens and in the field the rock is dark red in colour, and its grain size varies much; rather coarse grained types are common. Thin sections show that the plagioclase and the dark minerals are strongly altered. Biotite is nearly completely altered to chlorite which often is the only dark mineral found in the sections. Besides chlorite also ore and quartz occur as alteration products of the biotite. Ore (magnetite) seems to be more or less altered to hematite. Flourite occurs as in Svaneke granite Type III. In average Svaneke granite Type IV is a granite (3b).

Intrusive Svaneke granites

At two localities Svaneke granites have acted intrusively towards the surrounding rocks. One locality is at the Vaseå estuary at Listed, where the Svaneke granite north of the gneiss inclusion has an intrusive boundary to-

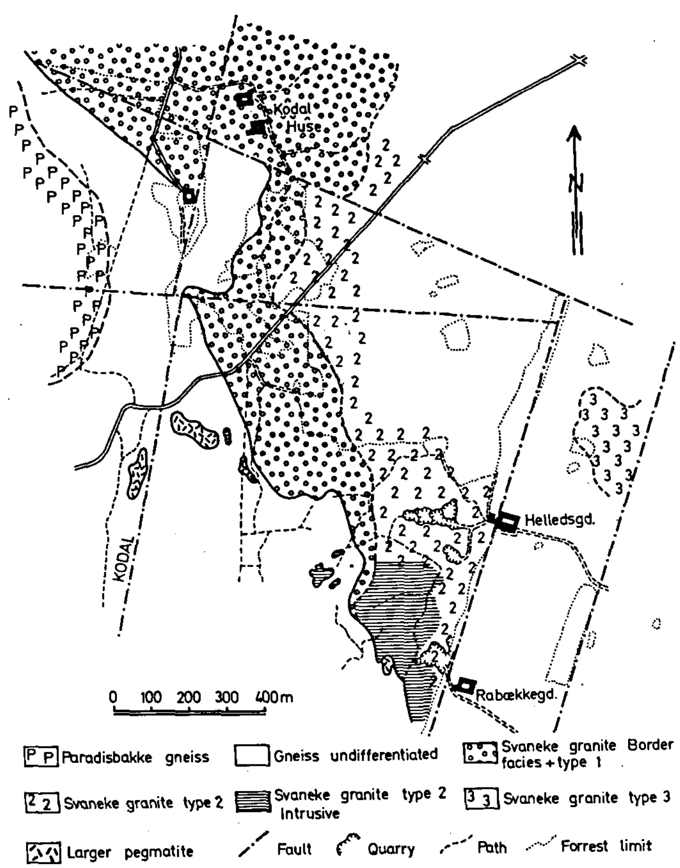

Fig. 8. Geological map of the north-east corner of Paradisbakkerne. The map is partly based on geological mapping and partly on magnetic measurements.

wards the gneiss. The intrusive Svaneke granite is a Svaneke granite Type I which has an aplitic border zone towards the gneiss. From the granite small apophyses are sent into the gneiss. These apophyses have a normal Type I grain size at the start, but the grain size becomes more and more aplitic inwards in the gneiss. The largest apophysis is several metres long and 5–10 cm wide.

The other locality is in Paradisbakkerne west of the quarry at Rabækkegård. Here a Svaneke granite Type II occurs with discordant relations to the otherwise normally developed zoning in the Svaneke granite complex here (see fig. 8).

Svaneke granite Type II is here in direct contact with the gneisses, and in the gneisses up to 100 m west of the boundary occur small bodies of Svaneke granite Type II which can be interpreted as apophyses from a larger mass close to the surface.

Boundary relation between the Svaneke granite types

The boundary between Border Facies Svaneke granite and Svaneke granite Type I can be observed at several localities, e. g. at the coast just west of Listed harbour where the boundary is flat lying with Type I below Border Facies granite. Between the two rocks a transitional zone ca. 0.5–1 m thick occurs in which the faintly lineated Border Facies granite gradually becomes more homogeneous, and together with the homogenisation a decrease in grain size can be observed.

The boundary between Svaneke granite Type I and Svaneke granite Type II is a transitional zone several metres broad. In the zone the irregular grain size distribution in Type I disappears and the more homogeneous Type II appears. Coincident with the change in texture the content of the dark coloured minerals increases. The boundary between Type I and Type II is well exposed at several localities, e. g. at Møllenakke and in Paradisbakkerne.

The boundary between Svaneke granite Type II and Svaneke granite Type III has not been identified with certainty. At one locality, the north-eastern corner of the Årsdale peninsula, this boundary may be present. In a transitional zone ca. 25 m broad the two rock types are intermixed in each other. From Type II towards Type III small lenses of Type III in Type II are first observed; the number of these lenses increases resulting in Type III becoming the dominant part of the mixture with Type II as relict patches which finally disappears.

In the area around Grisby occurs Svaneke granite Type III which south of Frennenakke is in contact with Svaneke granite Type I, but this boundary relationship may be caused by faulting.

The boundary between Svaneke granite Type III and Svaneke granite Type

IV is transitional over 10–20 cm. The red colour of Type IV is not strictly connected with Type IV, as all steps from red coloured Type III over red coloured somewhat recrystallised Type III to typical Type IV occur.

Small inclusions in the Svaneke granites

Inclusions of rocks with a composition different from that of the Svaneke granites are rather common. These inclusions vary in size from a few cm^2 up to about 0.5 m^2. The inclusions are normally comparatively rich in dark coloured minerals. They are more fine grained than the surrounding granite, and they are partly completely homogeneous in texture and partly foliated.

In Border Facies Svaneke granite inclusions are common in the Lineated Border Facies type, especially around some of the larger gneiss inclusions, e. g. at the Vaseå estuary and at Kirreskær. Inclusions are also common in Lineated Border Facies north of Årsdale and at Frennenakke. At these localities a correlation between the intensity of the lineation and the number of inclusions seems to exist, i. e. the number is biggest in the most pronounced lineated rocks. In non-lineated Border Facies practically no inclusions are observed.

Inclusions are not common in Svaneke granite Type I, but they occur in

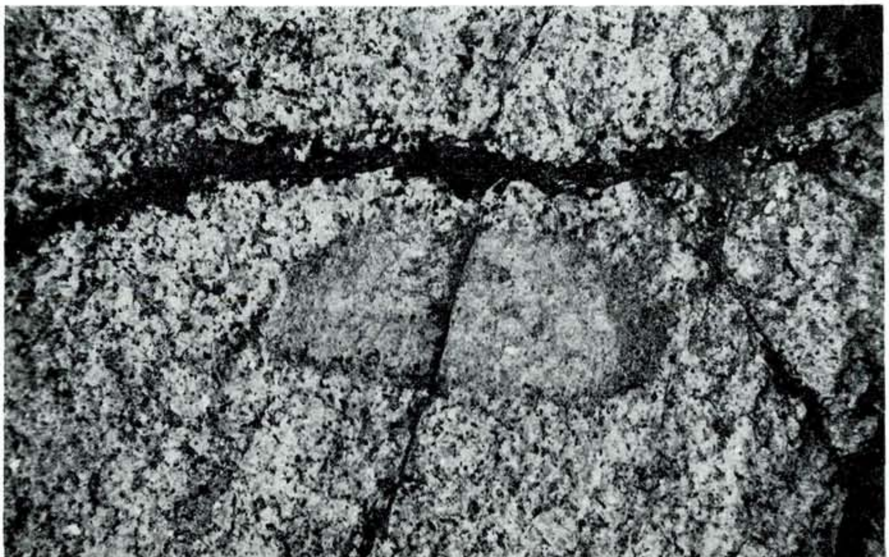

Fig. 9. Homogeneous inclusion, with mafic rim, in Svaneke granite Type II at Møllenakke.

all the areas with Type I; they are especially common at Møllenakke. The inclusions are normally of well foliated biotite gneiss.

Inclusions are not very common in Svaneke granite Type II, although they are not difficult to find. The inclusions are all completely homogeneous, i. e. without foliation and they are sometimes surrounded by a rim rich in mafic minerals (see fig. 9). In some of the larger quarries a weakly developed preferred orientation in the long axes of the dark mineral clusters can be observed in Type II and in the inclusions.

In Svaneke granite Type II a total of about 10 inclusions were observed; all completely homogeneous. Some of these inclusions have rather strange shapes, e. g. triangular in opposition to the inclusions in the other Svaneke granite types which all have a semispheric or elliptic shape.

Hallegård granite

The Hallegård granite is situated some km west of the Svaneke granite complex (see fig. 6). The relations between the Hallegård granite and the other rocks in the Precambrian of Bornholm have been subject to many discussions. Callisen (1934) regarded it as a Rønne granodiorite based on petrological investigations, and this interpretation was adopted by Micheelsen (1961). Von Bubnoff & Kaufmann (1933) described the Hallegård granite as a Svaneke granite type. The opinion of the present author is that the Hallegård granite is to be regarded as a separate rock unit which on the other hand has many similarities with the Svaneke granites, especially Svaneke granite Type II.

In the area occupied by the Hallegård granite only few outcrops are present, and most of the outcrops show granophyric pegmatite; at present the best outcrop is the road cut at Skovgårde, at the road between Nexø and Åkirkeby.

In hand specimens the Hallegård granite resembles Svaneke granite Type II, i. e. it is a rather coarse grained rock with a high content of dark minerals and a homogeneous habit, but in opposition to Svaneke granite Type II the Hallegård granite is easily decomposed to gravel similar to the Årsdale gravel which is the weathering product of Border Facies Svaneke granite. In thin sections the light and dark coloured minerals are seen to be strongly intergrown in each other. The microcline is strongly perthitic and replaces plagioclase which on the other hand also sometimes seems to replace the microcline.

The modal composition of two thin sections of Hallegård granite is found in Table II. The rock is a granite (3b) with a content of hornblende higher than found in the Svaneke granite types.

Tectonic evolution of East Bornholm

The tectonical evolution of East Bornholm described here is based on only few observations because of the lack of good outcrops and the absence of marker horizons. Two types of tectonics are important in the area, i. e. folding (accompanied by formation of foliations) and fault tectonics.

Fold tectonics

In the area it seems possible to distinguish between the following tectonic elements:

Planary structures:

- S1 surfaces: Foliations formed as a result of the first recognizable recrystallization of the rocks.
- S2 surfaces: Foliations formed as a result of the second recrystallization of the rocks. The S2 surfaces are parallel with the axial surfaces of the F2 folds.
- S3 surfaces: Foliations formed as a result of the third recrystallization of the rocks.

Linear structures:

- F2 fold axes: Fold axes for the folds formed synchronously with the second recrystallization of the rocks.
- L2 lineations: Mineral lineation formed during the second recrystallization of the rocks.
- L3 lineations: Mineral lineation formed during the third recrystallization of the rocks.

The S1 surfaces are the foliation dominating the gneisses. West of Listed the S1 surfaces are subparallel to the original bedding in the rocks as e. g. expressed in the relations between the quartzite here and the foliation in the gneiss (see fig. 4). The banding in the quartz rich gneisses can be remnants of an original layering.

The S2 surfaces are only faintly developed and are seldom observed. They are discordant to the S1 surfaces and parallel with the axial surfaces in the F2 folds. This can be observed at the coast west of Listed. The S2 surfaces strike approximately north-south and dip towards west.

The S3 surfaces are well developed locally, but the occurrence of this foliation is restricted to the areas with granitised gneisses (see fig. 3) and in some parts of the Border Facies Svaneke granite, e. g. at Vagtbod Nakke at Svaneke (see fig. 10). The strike of the S3 surfaces are approximately east-west with a northern dip of 20–30 degrees.

Fig. 10. The boundary between gneiss and Svaneke granite at the west coast of Vagtbod Nakke. The boundary runs approximately vertically at the compass with gneiss to the right. The flat lying foliation is the S3 foliation.

F2 folds are common in the area investigated, both in the gneiss inclusions in the Svaneke granite and in the gneiss west of the Svaneke granites. It is only possible to recognize folds with an amplitude of 10–40 m. On the

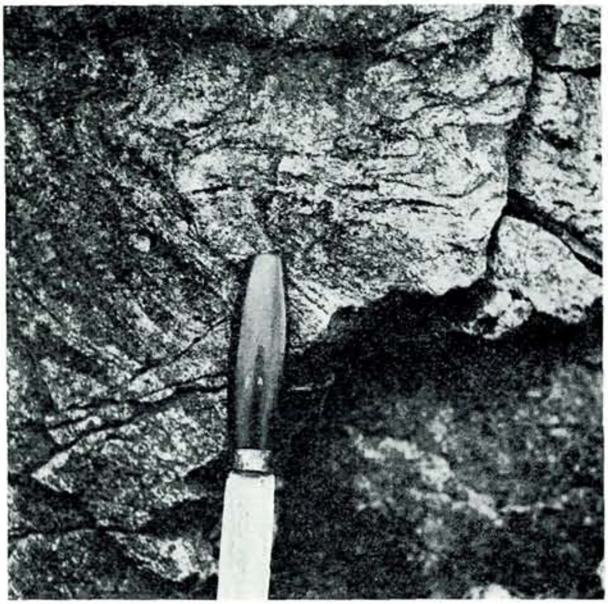

Fig. 11. F2 parasite folds in banded quartz rich gneiss at the coast west of Listed.

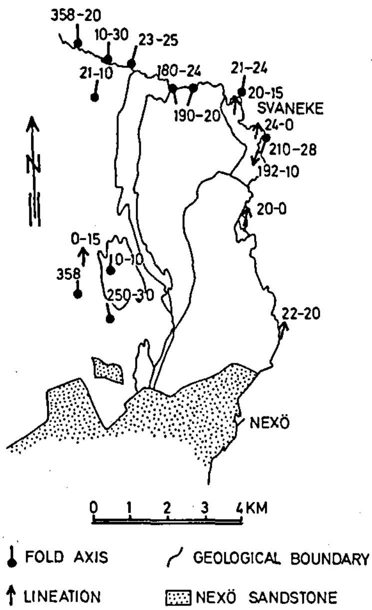

Fig. 12. Map showing the orientation of the F2 fold axis and L2 and L3 lineation. The fold axis is partly constructed and partly measured.

north coast the fold style is rather open (see fig. 11), but in Paradisbakkerne the folds are tight similar in style, which e. g. is the case in the Skotteklint area.

As the folds become more tight the amplitude becomes smaller. All the folds are overturned with an eastern vergenz. At the north coast the plunge directions of the fold axes are between north-east and north-north-east; in Paradisbakkerne the plunge directions are approximately north-south (see fig. 12). Fine examples of F2 folds can be observed in the quarry in Paradisbakke gneiss at Præstebo (see fig. 13).

The L2 lineation is a mineral lineation formed as the intersection lines between the S1 surfaces and the S2 surfaces. The L2 lineation is generally only weakly developed, corresponding to the weak development of the S2 surfaces. The orientation of the L2 lineation corresponds to the orientation of the F2 fold axis, i. e. they strike more or less north-south.

The L3 lineation is much more strongly developed than the L2 lineation. L3 is only observed in restricted areas, i. e. in the lineated Border Facies Svaneke granite and locally in the gneisses close to the Border Facies Svaneke granite, but as the L3 lineation has the same orientation as the L2 lineation it may have a much more widespread occurrence. The L3 lineation was formed as the intersection lines between the S3 surfaces and the older planary surfaces, as these two groups of planary surfaces strike approximately perpendicular to each other.

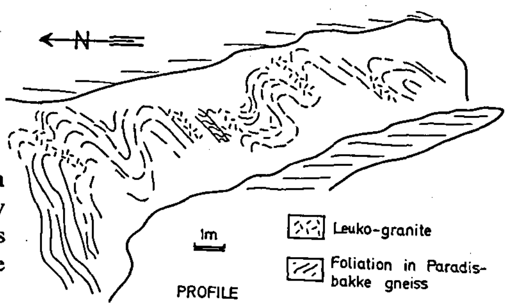

Fig. 13. F2 folds and migmatization in Paradisbakke gneiss in the quarry at Præstebo. The leucogranite veins are mainly found in the axial surface zones.

Fault tectonics

Faults play an important role in controlling the distribution of the bedrocks on East Bornholm (see figs. 6 and 15). Faults are observed everywhere, and in average the distance between two faults is approximately 100–200 m. The faults are normally associated with breccia zones which may be up to several tenth of m wide.

The faults, which have had sufficiently large horizontal displacements to exert an influence upon the distribution of the rock types on the geological map are shown on fig. 6. The three main directions of the faults are north-east to south-west, north-south, and west-north-west to east-south-east, but a few have other directions. The largest faults are probably the Vaseå-Døvredal fault and the faults running along the eastern border of Paradisbakkerne; these faults are accompanied by 25–100 m wide breccia zones.

The boundary between the Svaneke granite complex and the gneiss

The description of the field relations around the boundary between the Svaneke granite complex and the gneisses falls in two parts, one concerns the main western boundary and the other concerns the boundary relations between the Svaneke granite and the larger gneiss inclusions.

Three main types of boundaries are observed: 1) Discordant boundaries with a rather sharp contact, 2) Breccia type boundaries, and 3) Concordant boundaries. Between these main types many transitional types can be observed. The breccia type seems to be the most common type.

Main western boundary

This boundary is only exposed in two areas, at the coast west of Listed and in Paradisbakkerne. Further, the course of the boundary can be deduced from some outcrops at Hagelbjerg west of Ibs Kirke, where outcrops of gneiss and Svaneke granite occur seperated by a 50 m wide area without exposures. As mentioned the boundary can be traced on the magnetic map, part of which is shown on fig. 15.

At the coast west of Listed the boundary is exposed over a length of ca. 50 m. The boundary cuts the F2 structures in the gneisses. The boundary is sharp although somewhat obscured by the occurrence of small veins of leucogranite, partly in the boundary surface itself and partly crossing the boundary. The Svaneke granite east of the boundary is homogeneous showing a very weak lineation. The gneisses west of the boundary are rather inhomogeneous and partly granitised (see fig. 3).

The boundary is well exposed at several localities in Paradisbakkerne, where several boundary types occur. The main type seems to be a breccia type with a width varying from 10–20 cm up to several metres. In many outcrops an evolution from leucogranite to Svaneke granite can be observed. Several metres from the boundary a leucogranite – brecciated gneiss may occur, often containing sharp rectangular gneiss fragments. Approaching the boundary Svaneke granite can be observed in the central parts of the leucogranite veins, and at the boundary the veins are completely composed of Svaneke granite.

These observations could be interpreted as the Svaneke granite having sent

Fig. 14. The west boundary between Svaneke granite and the gneiss inclusion at the Vaseå estuary. The gneiss is the massive rock to the right.

apophyses into the gneiss, but the field observations seem to indicate that the Svaneke granite in the leucogranite veins was formed in situ. Unfortunately, it was not possible to collect samples of the veins.

Other boundaries

At Vagtbod Nakke two boundary types are present. On the west side occurs a boundary type similar to the boundary west of Listed, i. e. a sharp apparently discordant boundary. Although the boundary is discordant to the foliation in the rocks, both the gneiss and the Svaneke granite around the boundary express this foliation, which probably is a S3 foliation (see fig. 10) and in the gneiss are observed rootless bodies of Svaneke granite, also weakly foliated. The boundary on the east side of Vagtbod Nakke is apparently a breccia type boundary, but as the outcrops here are rather bad and as there is not much difference in colour between the gneiss and the Svaneke granite the nature of this boundary cannot be further described.

At Kirreskær the boundary seems to be of the breccia type.

At the gneiss inclusion at Skansen is observed a concordant boundary type. The boundary is parallel to the foliation in the gneiss and Svaneke granite. The gneiss is strongly migmatised close to the border, as described in detail below.

The boundary between the gneiss and the Svaneke granite at the Vaseå estuary is concordant on the west side of the gneiss (see fig. 14), and of the breccia type on the east side. Here numerous inclusions of gneiss in the Svaneke granite are found. Gneiss inclusions in the Svaneke granite are also common west of the gneiss; these inclusions are all well foliated, and the foliation is orientated subparallel to the boundary.

The rocks are strongly foliated close to the western boundary. In the Svaneke granite the foliation has disappeared ca. 10 m from the boundary. In the gneiss only a few cm wide zone is strongly foliated, then the gneiss has its normal appearance as a homogeneous weakly foliated rock.

Petrological variations across the boundaries

The variations in the proportions between the different minerals in the Svaneke granite Border Facies and in the gneisses up to the boundary are similar from locality to locality, although the intensity of these variations varies much. Two typical examples of the quantitative mineralogical variations across the boundary are shown on fig. 16. From the Svaneke granite towards the gneiss is observed an increase in the content of microcline accompanied by a simultaneous decrease in the content of dark minerals and plagioclase. Approximately 5–10 m before the boundary a microcline maximum is recorded

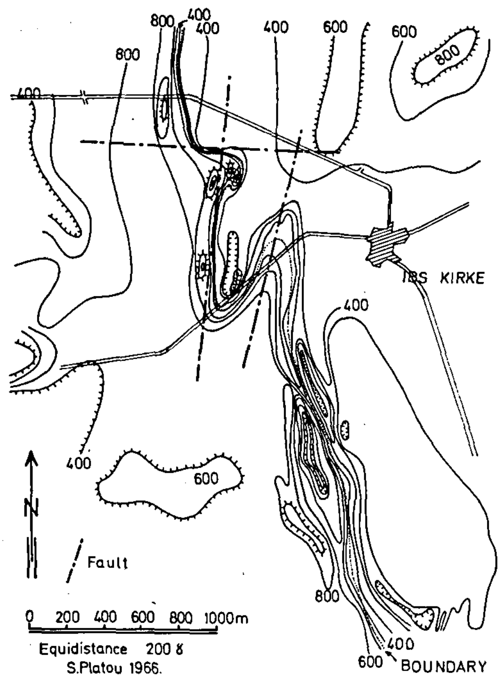

Fig. 15. Magnetic anomalies (vertical intensity) in the area west of Ibs kirke. The Svaneke granite-gneiss boundary is marked by a minimum trench of ca. 400 gamma.

in the Svaneke granite; this maximum is succeeded by a relative microcline minimum, which again is succeeded by an often extremely high content of microcline just at the boundary surface. In this zone, which is ca. 10 cm wide, the dark minerals practically disappear and the plagioclase content is very low. In the gneiss just beyond the boundary a microcline minimum is then observed, but some tenths of cm into the gneiss this rock has its normal composition. The above described development is most extreme at the western boundary of the Vaseå estuary gneiss inclusion. The most common development in Paradisbakkerne corresponds to the development at Skansen as shown in fig. 16. At Listed and at the western boundary at Vagtbod Nakke the development corresponds to the relations at Vaseå, although not so pronounced developed.

The microtextural variations across the boundary are in some cases not gradual, i. e. in the gneiss up to the border a normal gneiss texture is observed, and some dm into the Svaneke granite a normal Svaneke granite texture occurs. But in most cases a transitional zone exists in which the gradual recrystallization of gneiss to Svaneke granite can be observed.

At Skansen this recrystallisation process is well exposed. Furthest away from the Svaneke granite centimetre thick veins of almost pure microcline occur in the gneiss, but further towards the Svaneke granite small quartz-microcline pegmatites as a gradual development of the microcline veins are

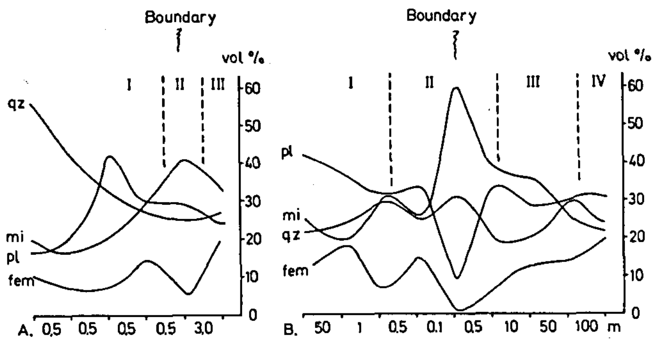

Fig. 16. Mineralogical variations across the boundary between gneiss and Svaneke granite at: A) Skansen and B) The Vaseå estuary. The values on the abscissa indicate the distance in m between the investigated samples. I: Gneiss, II: Boundary zone, III: Svaneke granite Border Facies and Type I, IV: Svaneke granite Type II, qz: quartz, mi: microcline, pl: plagioclase, fem: dark minerals.

observed. These small pegmatites have foliation parallel boundaries. At this stage half of the rock volume consists of neosome, and the paleosome at this stage consists of rather small grains of quartz, plagioclase, dark minerals, and small amounts of microcline.

Further towards the boundary the rock gradually consists of more and more neosome and at the same time the grain size in the neosome decreases from pegmatitic to normal granitic (ca. 5 mm). As this happens the small microcline grains in the paleosome become larger and the dark minerals gradually disappear from the paleosome, but simultaneously they grow in the neosome.

At the boundary the paleosome only consists of plagioclase and minor amounts of dark minerals. As the plagioclase becomes the only relict of the paleosome the plagioclase grains become more and more myrmekitic in texture and somewhat altered in opposition to the newly formed plagioclase grains which do not show myrmekitic texture and which are unaltered. Some tenths of cm into the Svaneke granite the last remnants of the paleosome are groups of about 10–15 grains of strongly myrmekitic plagioclase; these grain groups finally disappears some metres into the Svaneke granite. At Skansen the above described relations are found over a distance of 2–3 m, but at other localities, e. g. where a breccia type border occurs, the transitional zone is several metres wide.

Pegmatites, aplites, composite dykes, and younger granites

Pegmatites

The classification problems of pegmatites have been dealt with by several authors so that several classification systems exist (see Ramberg (1956), Micheelsen (1960), Reitan (1965), and Edelman (1968)). The present author uses a threefold system to describe the pegmatites: 1) Classification according to genesis of the pegmatites, 2) According to the internal structures, and 3) According to the boundary relations. A description of a single pegmatite can imply terms from all three classification systems.

Pegmatites are genetically formed as a combination of two modes of formation, i. e. growth strictly in situ, and by growing under dilation. Pegmatites are formed by growth in situ when the pre-pegmatite material on the spot grows. The growth is often selective which means that especially minerals as microcline and quartz grow. At the same time the dark minerals as biotite and hornblende can be altered or totally dissolved or eventually recrystallised into larger grains in the pegmatite. Pegmatites formed during dilation (i. e. a »crack« opens in the country rock and is filled with pegmatite material) are formed practically independently of the previous material on the spot. But in many cases the pegmatite minerals along the boundaries are developed by selective growth of the minerals in the host rock up to the pegmatite.

The internal structures of the pegmatites depend partly on the physical conditions in the mother rock i. e. which of the components were mobile, and partly on how fast the deposition of the minerals took place. Zoning expresses which minerals were mobile during the formation of the different zones in the pegmatites. Complications occur when the pegmatite formation is seperated by periods without pegmatite formation.

The mobility in the mother rock also has a bearing on the distance from which the pegmatite material was supplied, therefore the pegmatites genetically can be formed in four different ways which normally occur in combination.

1. Pegmatites formed by growth in situ
   - a: The material in the pegmatite originates from the place where the pegmatite now occurs. Material has been added from the nearest vicinity of the pegmatite, often resulting in the formation of a rim rich in dark minerals along the pegmatite boundaries.
   - b: The pegmatite material is partly from the place where the pegmatite now is situated, and partly supplied from a greater vicinity around the pegmatite.

2. Pegmatites formed under dilation
   a: Pegmatites formed by filling under dilation. The pegmatite material is supplied from the nearest vicinity of the pegmatite.
   b: Pegmatites formed under dilation; the material originates from a greater vicinity of the pegmatite.

The only genetic difference between in situ pegmatites and dilation pegmatites is then the physical conditions present in the host rock at the time of the formation of the pegmatite. When dilation pegmatites are formed the host rock must have been sufficiently rigid to allow »cracks« to open up. The formation of in situ pegmatites then implies physical conditions which allowed the crystals to grow directly independent of the possibility of dilation during the growth. The two ways of pegmatite formation are so similar that most of the pegmatites observed are formed as a combination of these two modes of formation. Especially common is the case where the pegmatite starts to grow as an in situ pegmatite and finishes its growth as a dilation pegmatite.

In close relation to the physical condition in the rock is the tectonical conditions in the area of pegmatite formation as most pegmatites are formed in structurally controlled zones, e. g. axial surface zones.

The internal structures of pegmatites can shortly be described as the combination of two cases, i. e. completely homogeneous bodies which differs from the surrounding rocks by its grain size and the other type, pegmatites composed of a zonary arrangement of mineral groups. On East Bornholm the following types of internal structures are observed:

Simple pegmatites. These are homogeneous bodies composed of quartz, plagioclase and microcline with only small amounts of biotite and ore. A maximal grain size is normally seen in the central parts of the veins, and often a continuously increasing grain size can be observed from the host rock towards the centrals parts of the pegmatite. In other cases the pegmatite has a homogeneous grain size from border to border. The sizes of these pegmatites are not large, some metres long and up to 0.5 m wide. The simple-vein structure may be present in both pegmatites formed in situ and in dilation pegmatites.

Zoned pegmatites. The zoning in these pegmatites is more or less well developed. The maximum number of zones observed was four, with the following mineral paragenesis:

Border zone:	quartz-plagioclase-microcline-(biotite)
Transitional zone I:	microcline-quartz-plagioclase-(biotite)
Transitional zone II:	quartz-microcline-(plagioclase)-(biotite)
Core zone:	quartz-(microcline)

The core zone is normally found asymmetrical in the pegmatites and always in the highest parts of the pegmatite body. A special development of zonary pegmatites occurs, i.e. almost pure quartz veins with small amounts of microcline and eventually plagioclase along the boundaries. The zoned pegmatites are mainly formed by dilation.

Combinations of simple veins and zonary veins. This type is the most common type of pegmatite in the area. Normally it is the border zone and transitional zone I which have been replaced by the simple vein structure.

Pegmatites composed of granophyric intergrown quartz and feldspar. These pegmatite dykes occur as a separate type as they are entirely composed of granophyric intergrown quartz and feldspar (both plagioclase and microcline).

The shape of the pegmatites and the boundary relations between the pegmatites and the host rock show great variance; the following four main types can be separated, but many transitional types occur:

Regular pegmatites. Long veins with sharp subparallel boundaries. These pegmatites are mainly formed by dilation. They can show either simple vein structures, zoned structures, or a combination.

Irregular pegmatites with diffuse boundaries. Small irregular pegmatite veins with transitional boundaries with an irregular course. These pegmatites are mainly formed by growth in situ.

Irregular pegmatites with sharp boundaries. The shape and course are irregular, but the boundaries are sharp. These pegmatites are often formed as a combination of growth in situ and dilation.

Breccia pegmatites. Pegmatites which occur as an irregular net in the host rock. These pegmatites are mainly formed by dilation.

Distribution of the pegmatite types in the Svaneke granites

Pegmatites are rare in the Svaneke granite Border Facies; a few simple veins with irregular and diffuse boundaries occur and also a few more regular veins were observed.

In Svaneke granite Type I occurs all the pegmatite types. The long rectilinear type is only represented by a few dykes at Møllenakke. The most common type is a simple vein with irregular boundaries both sharp and diffuse, but also quartz veins with small amounts of feldspar are common especially west of Svaneke.

Svaneke granite Type II is the Svaneke granite type which contains the largest amount of pegmatite. The main pegmatite type is long rectilinear partly zonary pegmatites, but in most cases with a simple vein structure. These peg-

Fig. 17. Rectilinear pegmatites in Svaneke granite Type II in the quarry at Rabækkegård (see fig. 8).

matites are mainly found in the granodioritic variant of Svaneke granite Type II, as in the quarries at Pærebakken, Rabækkegård, and Helledsgård, but not at Dorjle Klippe, where pegmatites are practically absent. In the above mentioned quarries the pegmatites occur with a frequency of one pegmatite for each 5 to 10 m (see fig. 17). In Rabækkegård's quarry it can be observed that the pegmatites were formed in zones with relatively upward movements on the northern side (the dykes strike about east-west). The direction of movement is indicated by the displacement of an older pegmatite by the long straight dykes. Irregular pegmatites are practically absent in Svaneke granite Type II.

Granophyric pegmatites occur at two localities, one at Møllenakke, where a dyke more than 75 m long and 5–6 m wide occurs, the other dyke occurs south of Rabækkegård in Paradisbakkerne; this dyke is more than 80 m long and 5 m wide. The Rabækkegård dyke is composed entirely of quartz and microcline. The Møllenakke dyke contains large amounts of plagioclase. Breccia type pegmatites do also occur in Svaneke granite Type II, as for instance at Møllenakke and in Helledsgård's quarry, where a small pegmatite of this type contains garnet.

In Svaneke granite Type III is observed a few rectilinear dykes with sharp boundaries; they have often developed a partial zoning. The core zone can be absent.

Pegmatites were not observed in Svaneke granite Type IV.

In the Hallegård granite pegmatites are very common; the area probably consists of 20–30 per cent of pegmatite material. These pegmatites are all of the granophyric type and they partly occur as straight dykes and partly as more irregular bodies which can cover several thousands m². The grain size in the pegmatites varies much, but it is generally coarse, although fine grained aplitic types also occur. Both types have granophyric texture. The Hallegård granite up to the pegmatite is generally altered in a zone up to 1 m wide, but where the gneiss is in contact with pegmatite no alteration was observed. The pegmatite occurrence seems to be restricted to the Hallegård granite area, although they cut the boundary between the Hallegård granite and the gneiss. The boundary between gneiss and pegmatite is sharp and discordant to the gneiss foliation as it can be observed at the large pegmatite at Katteslet Bakke.

Composite dykes

The dykes termed composite dykes were observed around the boundary between gneiss and Svaneke granite in Paradisbakkerne. The dykes are characterised by an aplitic grain size in their east end (they strike more or less east-west) and a gradually increasing grain size towards west and upwards (see fig. 18).

The structure of these dykes is rather complicated. Besides the continuous change in grain size it is also observed that the relatively fine grained types occur as fragments in the more coarse grained parts, e. g. granite fragments in the pegmatitic part. The most illustrative example of a composite dyke occurs on the western edge of Kodalen (see figs. 8 and 18). This dyke is more than 100 m long and 20 m wide. The lower boundary is sharp and shearing movements have taken place along the boundary. The upper boundary is irregular but rather sharp without signs of movement. Other dykes of this type occur north of Klint, one of them cutting the boundary between gneiss and Svaneke granite. A somewhat different type of composite dykes occurs south of Årsdale, near Svenskehavn. Here apparently original 6 subparallel aplite dykes were present. The largest of these dykes is 20 m long and 1.5 m wide. These aplites are now more or less brecciated and replaced by zonary dilation pegmatites which have a border zone of granophyrical intergrown

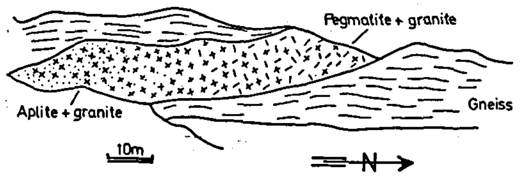

Fig. 18. Sketch of the Kodalen composite dyke.

quartz and microcline, a transitional zone with quartz and microcline, and a quartz core.

Besides the above mentioned aplites, aplitic rocks are practically absent on East Bornholm.

Younger granites

Rocks with granitic composition and texture, but somewhat younger than the Svaneke granites, occur as nearly vertical dykes and larger round bodies. These younger granites have only been observed inside the Svaneke granite complex.

Granite bodies

Three examples of this type were observed, one in Svaneke granite Border Facies just west of Listed, the other in Svaneke granite Type II east of the Vaseå estuary, and the third in Svaneke granite Type III south of Årsdale.

Fig. 19. The younger granite west of Listed harbour (homogeneously looking rock behind the small bay). Border Facies Svaneke granite surrounds the intrusion.

The Listed intrusion is round although somewhat irregular in shape (see map, fig. 3). Its diameter is about 75 m. The rock in the body is a homogeneous granite (see fig. 19) and the boundary to the surrounding Border Facies Svaneke granite is sharp but irregular in detail; small apophyses occur in the Svaneke granite.

In thin sections the minerals are somewhat intergrown in each other, and two generations of plagioclase occur. The biotite is only sporadically altered to chlorite and many biotite grains are completely unaltered. Other minerals are sphene, epidote, and ore. The epidote grains have often idiomorphic shapes.

The intrusion east of Vaseå is an irregular elliptic body about 50 m long and 25 m across. The intrusion is zoned with a fine grained boundary zone towards the Svaneke granite and with continuously increasing grain size towards the central parts of the body. Here a rather coarse grained granite with microcline porphyroblasts occurs. The boundary between the body and the Svaneke granite is very sharp, but it has an irregular course, and many apophyses are sent into the Svaneke granite.

The third younger granite body is completely round with a diameter of 1.5 m. It consists of two parts, a 20–30 cm broad aplitic border zone and a central medium to coarse grained part (see fig. 20).

Granite dykes

Dykes of granitic rocks have practically only been observed in Svaneke granite Type III. They occur either as single dykes or as swarms. The two largest dykes occur north of Hestekløve and at Grisby. These dykes are more than 75 m long and 5–6 m wide. The boundary towards the Svaneke granite is sharp, but with a somewhat irregular course. The granite in the dykes is slightly more fine grained than the surrounding Svaneke granite, and it has a very low content of dark minerals.

A swarm of leucogranite dykes occurs south of Årsdale. The largest dyke in this swarm is 60 m long and 1–2 m wide, and the smallest dyke about 15 m long and 0.5 m wide. The seven dykes in this swarm have the same appearance in hand specimens. The rock is somewhat more fine grained than the surrounding Svaneke granite and is more red in colour.

Besides the above mentioned dykes several small dykes occur, some with a relatively fine grained border zone and others completely homogeneous.

In thin sections of the dykes the light minerals occur as irregular aggregates. The plagioclase is commonly brecciated, with the cracks filled out with ore and a fine grained unidentified mineral. This brecciation only affects some of the plagioclase grains, while others are completely fresh, and some-

Fig. 20. Small circular instrusion of aplite and granite in Svaneke granite Type III at the coast south of Årsdale.

times the brecciated plagioclase is surrounded by a rim of nonbrecciated unaltered plagioclase. The dark minerals are strongly altered to chlorite and ore so that chlorite is the most common dark mineral.

Quantitative petrography

Modal analyses of younger granite bodies, dyke granites, and composite dykes are listed in table 3. The composition of the granite bodies is at the boundary between granite (3a) and granite (3b), while the two other groups are granite (3b).

Discussion

Petrogenesis of the Svaneke granite

The opinion concerning the petrogenesis of the Svaneke granite complex has changed much since the first description of the complex. Callisen (1934) regarded the Svaneke granite as a homogeneous intrusive body and this point of view was shared by von Bubnoff and Kaufmann (1933, 1942). Later Micheelsen (1961) interpreted the Svaneke granite as a result of in situ recrystallization of the preexisting rocks without much metasomatism.

Many circumstances make it difficult to describe the petrogenesis of the Svaneke granites. The outcrops are scarce, only part of the Svaneke granite complex is exposed above sealevel, and further it is not possible to study the Svaneke granite complex in regional geological connections.

It can be suggested that the Svaneke granite Border Facies and Svaneke granite Type I may have been formed by in situ recrystallization of the gneisses (accompanied by metasomatism) because these two rocks contain orientated inclusions with structures corresponding to the structures in the gneisses outside the Svaneke granite complex.

The relations between the Border Facies granites and Svaneke granite Type I require some further comments. The non-lineated Border Facies granite is practically without gneiss inclusions, while the lineated Border Facies granite normally contains many inclusions of gneiss. In thin sections, of the two types of Border Facies, can be observed that a paleosome component normally is present in the lineated type, but this is not always the case in the non-lineated Border Facies granite. The paleosome component is practically always present in Svaneke granite Type I, and here gneiss inclusions are also rather common. These relations can be interpreted in such a way that the mobility, and therefore the intensity of recrystallization, has been large in parts of the Border Facies granite area now occupied by non-lineated Border Facies granite, in contrast to a relatively lower mobility in the areas with lineated Border Facies granites and Type I.

The granitization in connection with the formation of these granites cannot have moved through the rocks as a granitization front (see Micheelsen, 1961) as the formation seems to indicate rather stationary conditions during the formation of the granites. The intensity of granitization was then mainly dependent on the degree of mobility in the rocks which guided the amount of metasomatic supplied material.

The formation of the rocks then took place partly with the preexisting material which was reorganised, and partly with additional material supplied by metasomatism.

The question is then whether the formation of the Border Facies granites and Type I could be called an anatectic process (see Mehnert, 1968 and Winkler, 1967). The answer to the question depends on what is understood by anatexis, what it means that a rock has been partially or totally melted.

A problem is the source of the material which was supported to Border Facies and Type I. The material cannot have been supplied from the gneisses outside the Svaneke granite complex, and therefore the material must have been supplied from inside the Svaneke granite complex. Regarding the relatively small areas granitized it should be possible, leading to a degranitization of some other parts of the complex, as the areas now occupied by the granodioritic variant of Svaneke granite Type II. It can be deduced from the great amount of pegmatite in this rock that much material has moved through Type II.

Svaneke granite Type II corresponds in composition to the composition of the gneisses. Therefore it can be suggested that this rock was formed by in situ recrystallization without significant metasomatism except eventually the subtraction of material from the granodioritic variant. The intrusive Type II in Paradisbakkerne (see fig. 8) was probably emplaced as a coherent body after the recrystallization as it does not differ in composition and appearance from the surrounding Type II.

The relations between Svaneke granite Type III and the other Svaneke granites are unknown, therefore it is difficult to say much about the petrogenesis of this granite. It can be suggested from the widespread alteration of the dark minerals and the common occurrence of flourite that the granite in later stages of its formation has been rich in volatiles. It is not possible to deduce whether Type III was formed in situ, or if it has moved upwards in the central parts of the complex. The occurrence of many granite dykes in Type III seems to indicate that a certain mobility has been present.

Svaneke granite Type IV seems to be a result of recrystallization of Type III, probably rather late in the evolution of the complex in areas with high mobility, as indicated by the recrystallization of the light minerals and the complete alteration of the dark minerals and the occurrence of flourite.

It can be suggested that the Hallegård granite is an intrusive body in which the material has been highly mobile to judge from the numerous pegmatites and the special texture of this rock; which may be interpreted as a result of crystallization of a granitic magma.

The relation between the Svaneke granites and the tectonical evolution

Von Bubnoff & Kaufmann (1933) were the first to make tectonical investigations in the area. They interpreted the F2 folds (in the terminology of this paper) as a result of magma pressure effect from the intruding Svaneke granite. Micheelsen (1961) described a great fold structure on East Bornholm named the »East Bornholm Fold« with a fold axis dipping about 15° towards north-west.

From the preceeding description of the tectonical relations on East Bornholm it is clear that the East Bornholm Fold does not exist, which again means that the Svaneke granite was not formed postkinematic in relation to this fold as suggested by Micheelsen (1961).

As previously mentioned it is not possible to look at the Svaneke granite in a regional tectonical setting, but the observations around the boundaries between the gneiss and the Svaneke granite make it possible to suggest that at least the Border Facies Svaneke granite and Svaneke granite Type I were formed in close connection with the recrystallization accompanying the third period of recognizable deformation, i. e. the formation of the S3 planary surfaces and the L3 lineation. It is not possible to relate the other Svaneke granite types to the tectonical evolution.

The relations between pegmatites, composite dykes, younger granites, and the Svaneke granite complex

The pegmatites in the Svaneke granite have been discussed by Micheelsen (1961). He suggested that all the pegmatites observed on East Bornholm were formed in connection with the formation of the Hammer granites. During the Svaneke granite formation, these pegmatites were partly preserved and partly dissolved in the Svaneke granite.

The relations between pegmatites and the Svaneke granites cannot be as simple as that. On East Bornholm pegmatites both older and younger than the Svaneke granite are observed. This can be illustrated by two examples. At Vagtbod Nakke pegmatite ca. 0.5 m wide in the gneiss is running towards the boundary between gneiss and Svaneke granite, beyond the boundary it has been decomposed into the Svaneke granite, but a remnant can be observed about 20 cm into the Svaneke granite. In Paradisbakkerne pegmatites are observed cutting the boundary between intrusive Svaneke granite Type II and the gneiss, and as the intrusive Type II here cuts Type I and Border Facies granite these pegmatites are clearly younger than the formation of the main parts of the Svaneke granite complex.

Further, it seems unlikely that the numerous straight pegmatites observed in Svaneke granite Type II could have survived a complete recrystallization from original rock to Svaneke granite.

The present author's point of view is that the pegmatites in the Svaneke granite complex are relatively younger than the Svaneke granites, but formed in connection with the formation of this complex. Some pegmatites observed in the gneiss close to the boundary between gneiss and Svaneke granite were also formed in connection with the formation of the Svaneke granite complex.

The relations between the pegmatites and the Svaneke granite types show that the Svaneke granite types formed with the largest amount of metasomatic supplied material (Border Facies and Type III and IV) contain the smallest amount of pegmatite. This seems to indicate that mobility is not sufficient, although necessary, for the formation of pegmatites. The possibility of formation of structural traps for the mobile material should also be present, i. e. a certain rigidity should be present.

The composite dykes are also relatively younger than the formation of the Svaneke granites as they cut the boundary between gneiss and Svaneke granite. The formation of these pegmatites is on the other hand a problem in itself, which it is outside the scope of this paper to discuss.

The younger granite intrusions and dykes are also relatively younger than the Svaneke granites; as they mainly occur in connection with Svaneke granite Type III it can be suggested that they originated as a result of mobilization of parts of this granite.

Inclusions in the Svaneke granite complex

The inclusions of rocks different from the Svaneke granites have been discussed by Callisen (1956) who concluded that inclusions of all the other types of granites and gneisses observed on Bornholm are present in the Svaneke granite.

From the previous description in this paper it appears that the inclusions in the Svaneke granites are either clearly gneissic or they consist of a homogeneous rock resembling the gneisses, but without foliation. In Svaneke granite Border Facies and in Type I the inclusions are normally well foliated, and the foliation is either the S2 foliation or the S3 foliation. When the inclusions in Type I are compared with the inclusions in Type II it is seen that the foliation in the inclusions disappears, when the boundary between Type I and Type II is crossed. The inclusions in Type II are therefore interpreted as gneiss inclusions which have been homogenetised during the recrystallization resulting in the formation of Svaneke granite Type II.

Callisen (1956) mentions inclusions of Hammer granite in the Svaneke granite. As Hammer granite apparently does not occur on East Bornholm these inclusions probably correspond to some of the younger granites which may resemble Hammer granite.

Dansk sammendrag

Artiklen beskriver Svaneke graniten på Øst-Bornholm og gnejserne vest for denne Svaneke graniten kan opdeles i fire hoveddele, nemlig Grænse-Facies Svaneke granit, Svaneke granit Type I, Svaneke granit Type II og Svaneke granit Type III; der optræder yderligere en femte type – Svaneke granit Type IV – i små mængder i Svaneke granit Type III. Svaneke graniten Grænse-Facies findes i kontakt med gnejsen, derefter følger indad i komplekset: Svaneke granit Type I, Svaneke granit Type II og i den centrale del af komplekset findes Type III (se det geologiske kort fig. 6).

Alle Svaneke graniterne har granitisk sammensætning undtagen dele af Type II, der er granodioritisk i sammensætning. Type II er således den mest basiske af Svaneke graniterne.

Gnejserne vest for Svaneke graniten består overvejende af en grå biotit gnejs med svag migmatisering; desuden er kvartsrige gnejser almindelige, enkelte kvartsiter (se fig. 4) og gnejs med små linser af granat og epidot, dvs. skarnførende gnejser (se fig. 3), findes også. I Paradisbakkerne findes en speciel mørk gnejstype (tidligere benævnt Paradisbakke migmatit), hvor migmatiseringen træder tydeligt frem på baggrund af gnejsens mørke farve.

I gnejserne kan iagttages tre perioder med rekrystallisering. Den første rekrystallisering, der kan spores, resulterede i dannelsen af den foliation, der nu dominerer gnejserne. Den anden periode resulterede i dannelsen af en ny svagt udviklet aksialplansfoliation samtidig med at den først dannede foliation foldedes intenst. Folder ses f. eks. ved Listed og i Paradisbakkerne. Den tredie rekrystalliseringsperiode resulterede i dannelsen af en foliation samtidig med, at gnejserne partielt granitiseredes, og Svaneke granitens ydre zoner dannedes. I forbindelse med anden periodes rekrystallisation dannedes en svag lineation, og i forbindelse med tredie periode en mere kraftig lineation, der specielt er kraftigt udviklet i dele af Svaneke granitens Grænse-Facies (lineret Grænse-Facies).

Pegmatiter er ret almindelige i gnejserne og i Svaneke granit Type II, medens de er sjældne i de andre typer af Svaneke granit undtagen dog i Svaneke granit Type I ved Møllenakke vest for Svaneke. En speciel pegmatittype er de skriftgranitiske pegmatiter, der udelukkende består af skriftgranitisk sammenvokset kvarts og feldspat. Disse gange er især almindelige i forbindelse med Hallegård graniten vest for Bodilsker. Hallegård graniten svarer i udseende til Svaneke graniten, men optræder som en selvstændig, muligvis intrusiv granit.

Forkastninger er meget almindelige i området, og de spiller en stor rolle i fordelingen af bjergarterne på det geologiske kort. Desuden medfører den dårlige blotningsgrad i området, at kortlægning er meget vanskelig at udføre, og derfor anvendtes magnetiske målinger for at kunne følge bjergartsgrænserne (se fig. 15). Det geologiske kort er således et resultat af geologisk feltarbejde og geofysiske målinger.

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Table 1. Modal composition of gneisses from East Bornholm

Mineral/Rock	8395	2s	291	2s	15	2s	I	2s	II	2s
Quartz	53	6.4	72	8.0	45	6.8	25	4.2	29	4.4
Plagioclase	22	2.6	12	1.4	28	4.2	27	4.4	31	4.6
Phertite	19	2.4	11	1.2	13	2.0	38	4.8	28	3.4
Biotite	2		1		8		5	2.8	8	3.6
Hornblende ...	1		–		4		tr.		1	
Ore	1		1		–		tr.		tr.	
Sphene	tr.		1		2		1		1	
Epidote	tr.		tr.		tr.		tr.		tr.	
Chlorite	–		–		–		1		tr.	
Muscovite	2		1		–		–		-	
Total	99		99		100		99		100	
An. in pla.	31	6.2	32	5.6	28	3.1	26	3.4	27	3.4
n	1		1		1		5		12	

8395: Quartz rich gneiss west of Kodals huse.
291: Quartz rich gneiss from Hagelbjerg.
15: Quartz rich gneiss, coast west of Listed.
I: Granitised gneisses.
II: Grey biotite gneisses.
tr. = Less than one per cent.
– = not present.
2s = Double standarddeviation.
An. in pla. = anorthite content in plagioclase.
n = number of samples investigated.

Table 2. Modal Composition of the Svaneke granit types and the Hallegård granite

Mineral/Rock	Oa	2s	Ob	2s	I	2s	II	2s	III	2s	IV	2s	5428	2s	5402	2s
Quartz ...	28	4.8	30	2.0	26	6.4	28	2.3	27	3.6	29	3.8	23	9.6	30	4.2
Plagioclase	24	5.0	32	4.4	29	6.5	34	4.7	32	4.7	27	4.2	34	11.2	25	3.4
Phertite ...	42	5.2	27	3.0	38	7.5	25	6.4	34	7.2	30	6.7	27	11.4	32	4.4
Biotite ...	3	2.6	8	4.2	4	2.2	8	3.5	3	1.8	6	4.4	6		4	
Hornblende	1		1		2	1.3	3	1.6	tr.		–		9		5	
Ore	1		1		tr.		tr.		1		1		1		1	
Epidote ...	–		tr.		tr.		tr.		tr.		–		–		tr.	
Sphene ...	tr.		tr.		1		1	0.4	tr.		tr.		1		tr.	
Chlorite ...	tr.		tr.		tr.		tr.		2		6	3.2	1		1	
Total	99		99		100		99		99		99		102		98	
An. in pla.	25	3.4	24	2.6	26	2.8	27	3.0	24	3.0	24	2.4	28	4.0	25	2.0
n	9		4		5		7		6		4		1		1	

Values in volume per cent.

Tr. = less than one per cent.
An. in pla. = Anorthite content of plagioclase.
2s = double standarddeviation.
n = number of samples.
– = not present.
Oa: Border Facies non-lineated.
Ob: Lineated Border Facies.
I: Svaneke granite Type I.
II: Svaneke granite Type II.
III: Svaneke granite Type III.
IV: Svaneke granite Type IV.
5428: Hallegård granite 0.5 km west of Skovgårde.
5402: Hallegård granite, roadcut at Skovgårde.

Table 3. Modal analyses of younger granites and composite dykes

Mineral/Rock	I	2s	II	2s	III	2s
Quartz	31	4.4	34	5.0	33	3.6
Plagioclase	24	4.4	29	4.8	34	6.4
Microcline	43	4.6	32	4.6	30	6.8
Biotite	1	2.0	1	2.0	2	3.8
Hornblende	–		tr.		tr.	
Ore	tr.		tr.		tr.	
Epidote	tr.		–		tr.	
Sphene	tr.		tr.		–	
Chlorite	1	0.4	1	0.4	tr.	
Total	100		97		99	
An. in pla.	22	4.8	21	4.0	20	4.4
n	6		7		5	

I: Younger granite bodies.
II: Composite dykes.
III: Younger granite dykes.
– = not present.
tr. = less than one per cent.
2s = double standarddeviation.
n = number of thin sections investigated.