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C. DAVIDSONS BOKTRYCKERI AB, VÄXJÖ

ABSTRACT

A great number of igneous dikes occur along the Swedish Skagerrak coast. They belong to the Permian rift zone of the Oslo region. The rocks treated in this study are dolerites, porphyritic dolerites, and rocks of the rhomb porphyry dikes. Some dikes of porphyritic dolerite have non-porphyritic margins, which seem to have been intruded shortly before the intrusion of the central, porphyritic parts of the dikes. A few rhomb-shaped feldspar xenocrysts have been observed in the border zone between the non-porphyritic and porphyritic parts of the dikes.

The rhomb porphyry dikes are made up of three different rocks, viz. marginal dolerite (Dm), marginal rhomb porphyry (RPm), and central rhomb porphyry (RPc). Dm is non-porphyritic while RPm and RPc carry 20–30 vol. % rhomb feldspar phenocrysts. In addition RPm and RPc contain xenocrysts of labradorite-bytownite composition. It is suggested that the rocks of the Swedish rhomb porphyry dikes have been formed by the mixing of one basaltic magma and one more acid, rhomb feldspar carrying magma. The individual rocks of the dikes represent different stages of magma mixing or intrusions from different levels of the magma reservoir. They came to their present positions as results of three close events of intrusion giving the sequence Dm, RPm, and RPc.

CONTENTS

1. INTRODUCTION

Dike rocks belonging to the Permian igneous rock complex of the Oslo region are known from outside the graben zone both to the northwest, southwest, and southeast (see Oftedahl 1952, p. 47). A great number of these dikes occur along the Swedish Skagerrak coast, and most of them strike north–south. They have previously been investigated by Olbers (1870), Törnebohm (1876), De Geer (1902), Lindström (1902), Swedmark (1902), Ljungner (1927), Brögger (1933 a and b), and Asklund (1947, 1948, 1950). The most detailed descriptions have been given by Ljungner. In his paper the dike rocks are named madeirite, limburgite, dolerite, and rhomb porphyry. They all belong to the Permian period of eruption (Ljungner 1927, p. 71). In Ljungner's opinion the most mafic dike rocks are the oldest, and he regards them as basic derivatives of the Oslo essexite (op. cit., pp. 31, 45, and 142). Asklund (1948, p. 28), however, states that the most mafic dike rocks are the youngest. In the map (Asklund 1947, p. 76) he also makes a distinction between ultramafic and alnöitic dikes. Regarding the relationship between the Swedish rhomb porphyry and the Permian rhomb porphyries of the Oslo region, Ljungner (1927, p. 71) writes: "Die Übereinstimmung der Gesteine darf also als festgestellt angesehen werden."

Ljungner (1927, p. 69) writes: "Diabasgängen geringer bis mässiger Breite sind als Begleiter der Rhombenporphyrgänge nicht selten. Sie sind nicht nur geographisch und geologisch sondern auch petrographisch mit dem Rhombenporphyr so nahe verknüpft, dass sie ohne Zweifel aus derselben Eruption stammen" . . . "Sporadisch können auch Rhombenfeldspateinsprenglinge in typisch diabasischen Gänge auftreten." Ljungner also suggests a variation of the grain size and the composition between the marginal and the central parts of the rhomb porphyry dikes (op. cit., p. 56). Asklund (1947, p. 77) pointed out the doleritic character of the rhomb porphyry, but he also reported that in the vicinity of Hamburgön the dike rock is more similar to the typical rhomb porphyry of southern Norway. A relationship between the dolerite and the rhomb porphyry has been thus suggested and will also be the subject of this investigation. Some observations of the Swedish rhomb porphyry dikes have previously been published (Samuelsson 1967). These observations are included in the present descriptions, and no further references to my preliminary paper will be made.

2. METHODS

Using the descriptions and maps by Ljungner (1927) and Asklund (1947) I have choosen and visited some well-exposed parts of the dikes. Some new dikes have been observed, and some distant outcrops have been connected by means of magnetometric measurements. The latter have been carried out by G. Lind and B. L. Ramachandra from the laboratory of Applied Geophysics, University of Aaarhus. Field observations from the different dike localities are collected in Table 1.

During the microscopic work, the following manuals have been used: Deer-Howie-Zussman (1963, vols. II and IV), Tröger (1959), and Winchell (1961). The microscopic analyses of plagioclase and pyroxene have been carried out on a Leitz' 4-axis universal stage. The compositions of the plagioclases will be found in Table 5. The optical data of the rhomb-shaped feldspars are collected in Table 6. The refractive indices have been determined for sodium light by means of the immersion method and a refractometer according to Abbe.

The volumetrical analyses have been carried out with the aid of a Swift's automatic point counter. 1 000 points were counted in each analysis. A number of chemical analyses of rocks (sample weights = 1–2 kg.) are presented in Table 2. Partial analyses of 45 samples have been made at the Department of Geology, Chalmers University of Technology, Gothenburg, with the aid of a Perkin-Elmer atomic absorption spectrophotometer, model 303. The samples have been prepared according to Shapiro and Brannock (1956). The instrumental settings have been made in accordance with "Analytical methods for atomic absorption spectrophotometry" (Perkin-Elmer, Nov. 1966). The estimated accuracy of this analytical method will be found in Table 4.

The petrochemical calculations of the rock analyses (Tables 2 c and d) are according to Burri (1959) and Johannsen (1950).

3. GEOLOGICAL AND PETROGRAPHIC DESCRIPTIONS

3.1. Doleritic dike rocks

The doleritic rocks occur in dikes with a north–south strike (Fig. 1). The dip is mostly vertical. In the map two types of dolerites are shown, the one being porphyritic and the other not. Generally, the latter dikes are rather narrow, one or two meters in width, while the porphyritic dikes may attain a width of ten meters.

3.1.1. Descriptions of individual dikes (Tables 1 and 3: Fig. 1)

a) Dolerite from Hasselösund (Table 3, no. 5)

The dike is situated about 100 m. east of the road from Hasselösund to Smögen. The maximum width is about 1 m. It strikes N 10°E, with vertical dip. Specimens for microscopic and chemical investigations were taken 300 m. south of the fishing harbour of Hasselösund.

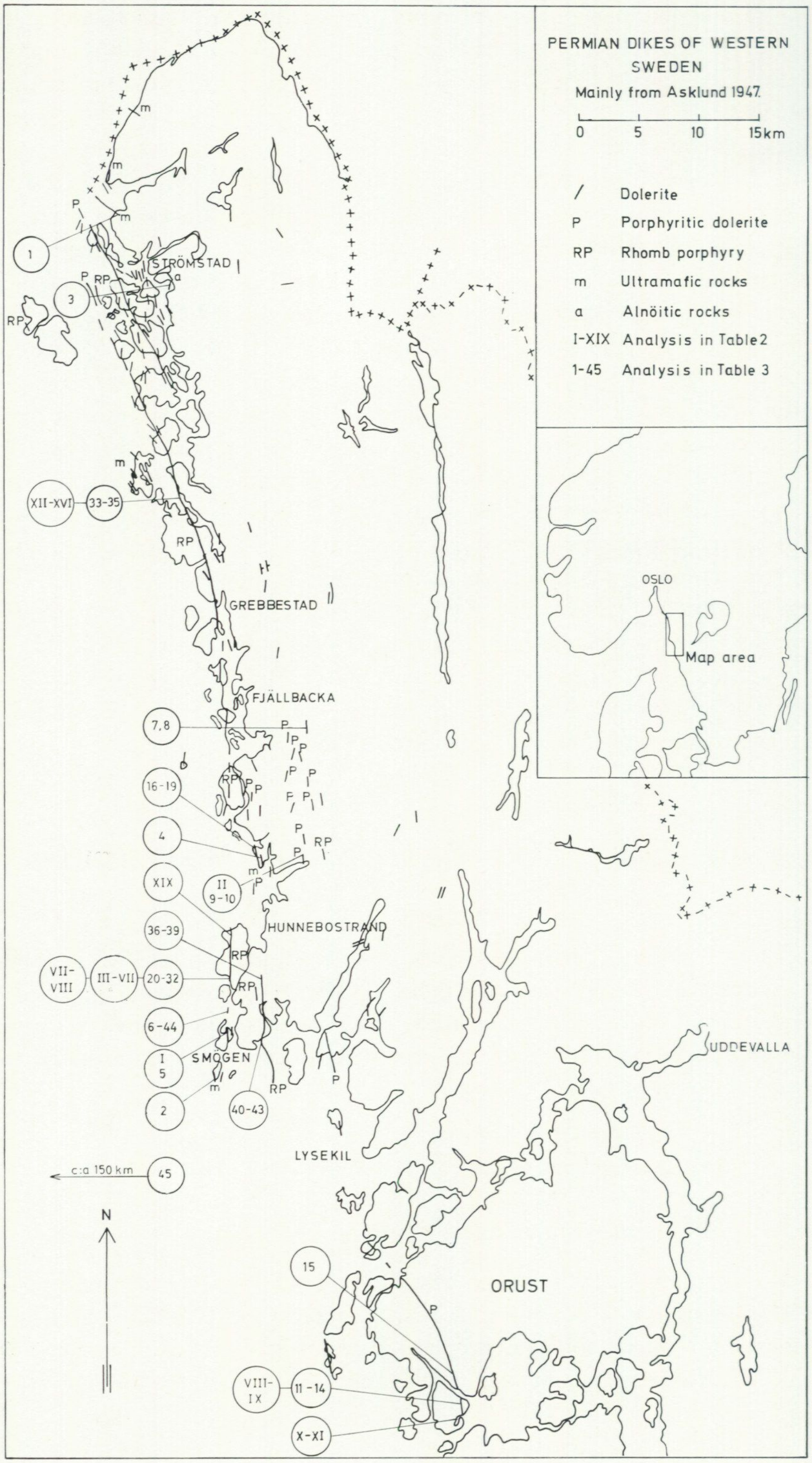
PERMIAN DIKES OF WESTERN SWEDEN
Mainly from Asklund 1947.
0 5 10 15km
/ Dolerite
P Porphyritic dolerite
RP Rhomb porphyry
m Ultramafic rocks
a Alnöitic rocks
I-XIX Analysis in Table 2
1-45 Analysis in Table 3
OSLO
Map area
STRÖMSTAD
GREBBESTAD
FJÄLLBACKA
HUNNEBOSTRAND
SMÖGEN
LYSEKIL
UDDEVALLA
ORUST
c:a 150 km
N

Fig. 1. The map.

The rock is fine-grained, even in the central part of the dike. No macroscopically visible feldspar phenocrysts have been observed. The plagioclase obviously consists of two morphologically different types. In thin sections the one is about 1.5×0.4 mm. and the other 0.5×0.1 mm. The larger crystals often display a combination of Carlsbad and albite twins and correspond to An_{58-64} (Table 5). The plagioclase grains have an anorthite content of 45–47 % (Table 5). The pyroxene forms granules and elongated aggregates (γ/c about 44°). Chlorite, calcite, and yellow-brown leucoxene also occur in the dense groundmass, which was very difficult to investigate in detail. Further there are many vesicles, a few mm. in diameter. These contain marginal chlorite and central calcite.

The ore minerals have only been investigated briefly. Both magnetite and pyrite occur. The high titanium content of the chemical analyses (cf. Table 2 a, no. I) in combination with the presence of leucoxene in the thin slide indicates a primary titanium content of the ore minerals.

b) Dolerite from Kålen (Table 3, no. 6)

The width of the dike is 1.3 m. The dike runs north–south with vertical dip and parallel to a rhomb porphyry dike 200 m. to the east. The dolerite is fine grained. It has only been examined by chemical methods.

c) Dolerite ESE Fjällbacka (Table 3, nos. 7 and 8)

This dike occurs at the crossroad, 4.3 km. ESE Fjällbacka church. The width of the dike is 10 m. The strike is north–south and the dip vertical. The rock is fine- to medium-grained. The colour is green with red stains. No macroscopic phenocrysts can be observed. In thin slides, however, can be seen a few rectangular plagioclase phenocrysts showing strong alteration. Some chemical data will be found in Table 3, nos. 7 and 8.

The rock shows strong alteration and contains much sericite, epidote, and chlorite. This allows only a rough estimation of the modal composition: plagioclase contaminated with epidote, sericite, and chlorite = 50–60 %, pyroxene = 15–20 %, opaque minerals = 8–10 %, leucoxene = 2 %, quartz = 1 %, undetermined = 10 %. The texture is sub-ophitic (Krokström 1932, p. 199).

The plagioclase of the matrix is even-grained and rectangular in section, with a maximum crystal size of 1.0×0.5 mm. It shows strong alteration. Epidote has been found mostly in the centre of the grains, and sericite in the margins. Chlorite occurs as rare grains often associated with small amounts of quartz. Owing to the strong alteration the determination of the anorthite content is difficult. The refringence is lower than that of Canada balsam, and the extinction in the symmetric zone has given An_{16}. The abundant occurrence of epidote in the central parts of the plagioclase grains may indicate a primary zoning.

Most of the pyroxene is monoclinic, with $\gamma/c = 42–45°$. $2V\gamma$ is 60–70° (estimated), $v > r$, and the birefringence 0.03. The interference colours are anomalous in brown and blue-violet, forming an hourglass pattern. These characteristics point to titanaugite. A few grains of orthorhombic pyroxene, probably hypersthene, have been found. Epidote appears as scattered grains, most frequently in the plagioclase. Leucoxene occurs in small aggregates, often in connection with ore minerals. The latter are rather uniformly distributed all through the rock. Both magnetite and pyrite have been observed. A blue-green chlorite with anomalous interference colours is found everywhere in the rock, whereas quartz occurs only interstitially. Traces of carbonate can be seen. Apatite and small, blue-green hornblende needles also belong to the accessories. Further some small, isotropic grains with high refringence have been discovered. These seem to be garnet crystallized in a late stage.

d) Porphyritic dolerite, Gerlesborg (Table 3, nos. 9 and 10)

Asklund (1947, p. 76) has noted a porphyritic dolerite at the inner part of Bottnafjorden. The total width is 11 m. From the margins and about 0.6 m inwards the rock lacks phenocrysts, whereas it becomes gradually more rich in phenocrysts from there and towards the centre. The mineral content of the central part of the dike is: phenocrysts of plagioclase = 42 %, plagioclase of the matrix = 23 %, pyroxene = 14 %, epidote and serpentine = 12 %, opaque minerals = 7 %, and biotite = 2 %. The plagioclase phenocrysts have a maximum size of about 10×5 mm. The average size is about 4×3 mm. They are usually idiomorphic. Several twin laws are represented. In one grain different crystallographic orientations have been observed. The anorthite content in the grain center is 72–74 % (Table 5). The margins of the phenocrysts have normal zoning towards the same anorthite content as the plagioclase of the groundmass (Fig. 2). The groundmass is doleritic (Krokström 1932, p. 199).

The plagioclase of the groundmass is idiomorphic, with a maximum crystal size of 1.0×0.1 mm. The average size is about one half of these dimensions. The An content is 58–62 %, with indications of a final crystallization at 45 %. Pyroxene is present in the groundmass. It shows $\gamma/c = 44°$, birefringence about 0.025, $2V\gamma = 50–60°$, and an hourglass zoning. This is an augite which is frequently twinned. There are also a few larger pyroxene grains with $\gamma/c = 47°$, a distinct hourglass zoning, and anomalous interference colours. No pleochroism has been observed.

The main part of the serpentine is found in aggregates which seem to be pseudomorphs after olivine. Leucoxene can be seen in small quantities around some irregular opaque grains. There is also some interstitial quartz.

Fig. 2. Phenocrysts of plagioclase in porphyritic dolerite. Gerlesborg (Table 3:9). 2 nic.

e) Porphyritic dolerite, V. Orust and Lyrön

The old geological map, Tjörn and Orust (Olbers 1866), records dolerite at Lyrön. The geological map-sheet Uddevalla (Lindström 1902) shows a few scattered occurrences of dolerite in the mentioned area. With the aid of a magnetometer it was possible to connect the earlier known occurrences to a continuous dike from Ellös in the north to Lyrön in the south, interrupted only at one point. Ljungner (1927, Tafel 1) has connected the occurrence at Ellös with a rhomb porphyry dike at Nävekärr. Asklund (1947, p. 76), however, identified the latter dike as a porphyritic dolerite, which is correct. With the exception of some occurrences of dike rocks on small islands, the dike area is covered by sea. The Orust dike has its best exposures 300 m south of Ellös, at Lyrön, and on the northern shore of Lyrösund. At Ellös the central part of the dike is rather fractured. Here and at Lyrön the central part of the dike also shows rapid weathering, whereas the margins do not weather much. The margins have been fractured at right angles to the contact. This fracturing has sometimes the character of columnar jointing. On the northern shore of Lyrösund, the border zone between the non-porphyritic margins and the porphyritic central part of the dike contains a lot of xenoliths. These consist mostly of small fragments from the wall rock. However, there have also been found some rhomb-shaped feldspar xenocrysts (Fig. 3).

Four thin sections have been studied from the southern part of the dike at Lyrön. They have been taken 0.1, 0.2, 2.5, and 3.0 m. from the western contact. The modal composition at 3.0 m is: phenocrysts of plagioclase = 17 %, plagioclase of the matrix = 42 %, pyroxene = 16 %, serpentine, chlorite, and other secondary minerals = 15 %, opaque minerals = 10 %. At 0.1 and 0.5 m. the rock is very fine-grained, with altered plagioclase. This alteration is also seen at 2.5 m. At 3.0 m. the rock is fresh.

Fig. 3. Xenolith-rich zone between non-porphyritic margins and porphyritic central part of dolerite dike. Some rhomb-shaped xenocrysts can be observed. Lyrösund, Orust.

The plagioclase phenocrysts measure about 5×1 mm. They have an oscillatory zoning near the margins. The cores consist of An_{70} (Table 5).

The groundmass is ophitic (Krokström 1932, p. 199). Its plagioclase is strongly zoned, ranging from andesine to oligoclase (Table 5). Two pyroxene varieties are present. Predominant is an augite with $\gamma/c = 40–45°$ and 2 $V\gamma = 55–60°$. In thin sections the colour is pale green with no visible pleochroism. Hourglass zoning and anomalous interference colours can be seen in some crystals. The other pyroxene is a hypersthene with 2 $V\alpha = 55–60°$, pale pink colour in thin sections, and no visible pleochroism.

The groundmass also contains some secondary minerals. A yellowish brown serpentine predominates in a thin section from the central part of the dike. This serpentine has occasionally been developed as regular aggregates associated with ore minerals. The aggregates seem to be pseudomorphs after olivine or pyroxene altered during the intrusion. The slides from 2.5, 0.2, and 0.1 m. contain abundant blue-green chlorite. Very small flakes of brown biotite are always present.

f) Porphyritic dolerite from Åbyfjorden

Ljungner (1927, pp. 70, 147, and Fig. 39 c) mentions two small dikes with interesting features. The dikes are vertical and strike N35°W. The larger one has been laterally faulted along planes stretching NNE. The smaller dike is only about 3 dm. in width and branching. The central part of this dike is porphyritic. However, in a short distance the magma of the porphyritic core-rock has broken through the non-porphyritic margins and appears close to the wall rock. Some rhomb-shaped feldspars occur in the porphyritic rock.

3.1.2. Chemical studies on the doleritic rocks

Six chemical analyses have been made on the dolerites and two on the doleritic margins of a rhomb porphyry dike (Table 2). Partial analyses will be found in Table 3 and Fig. 4. It can be observed that the dikes with non-porphyritic margins and porphyritic cores show a general trend in the distribution of some main elements. The margins have been enriched in sodium and potassium as compared with the cores. The non-porphyritic dikes seem to be rather basic in composition, except no. 7, the altered dike rock SE of Fjällbacka.

The difference between the analyses of the non-porphyritic margins and the porphyritic central parts of the doleritic dikes are rather clearly displayed by the Niggli values (Table 2 d). Most of the differences seems to be due to the occurrence of An-rich phenocrysts in the central parts of the dike. In analyses VIII and IX (Table 2 d), viz. margin and kernel of porphyritic dolerite from

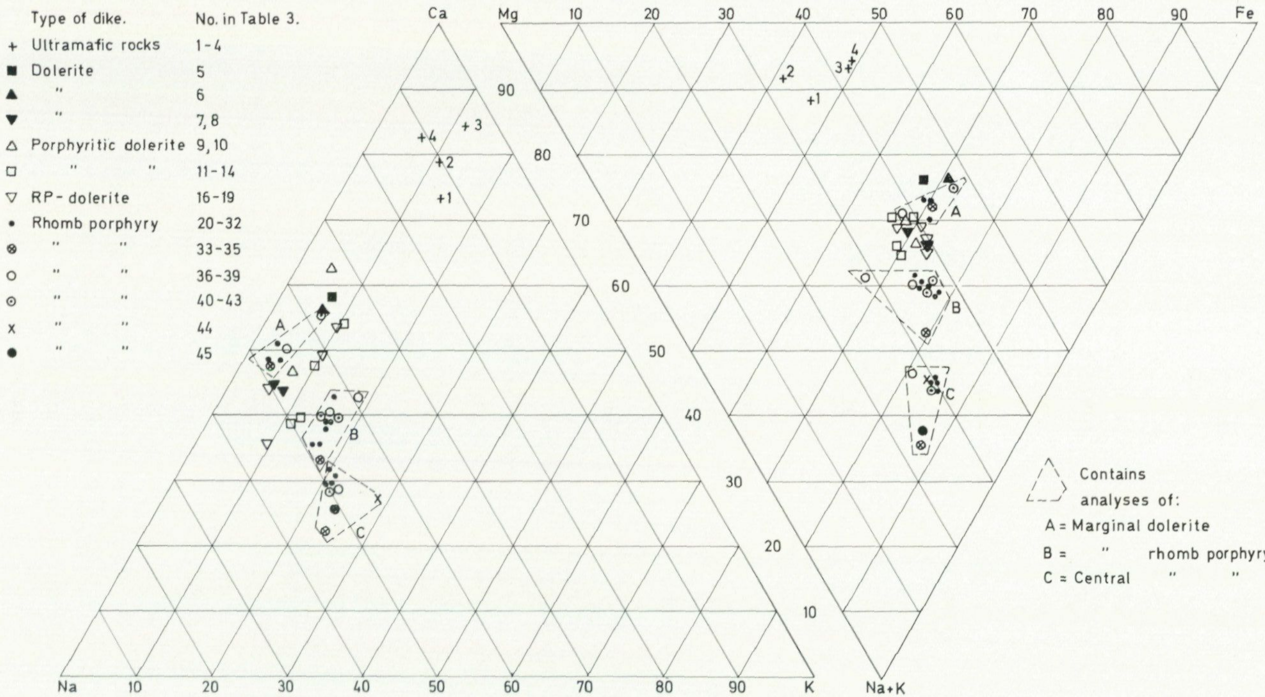

Fig. 4. Ca-Na-K and Fe-Mg-(Na+K) diagrams (atomic proportions). Analyses used for plotting are taken from Table 3.

the central part of Lyrön, the mg values are identical. Analyses X and XI are from the same dike, 300 m. to the south of the above-mentioned locality. No. X, the marginal part of the dike, is slightly lower in mg.

As the Mg and Fe contents of the plagioclase are low (see Deer-Howie-Zussman 1963: Vol. IV pp. 112) and plagioclase phenocrysts only make up less than 20 % of the rock (see p. 10), and as the Mg/Fe ratio in the range bytownite-andesine does not show any considerable variation, it seems reasonable to state that the mg value is independent of the frequency of plagioclase phenocrysts.

In connection with this observation it is interesting to note that the mg values of the marginal part (VIII) is the same as of the porphyritic part (IX) at central Lyrön as mentioned above. This means that the matrix of the porphyritic rock and the non-porphyritic rock have the same mg value. Samples nos. X and XI show a slightly lower mg value in the marginal part of the dike, which might be due to a higher content of olivine and/or pyroxene pseudomorphs in the central part of the dike (see p. 11). This very weak indication of fractionation gains some support by the fact that the k and si values are also slightly higher in the marginal part at this locality. The k values of analyses VIII and IX are identical and the si values very similar.

The w values of the two sample pairs differ more in samples X and XI than in VIII and IX. Ghose, Mueller and Berner (1970, 26-E-1) state: "The variation in Fe^{2+}/Fe^{3+} is not nearly as systematic among igneous rocks as that of $Mg^{2+}/(Mg^{2+}+Fe^{2+})$ . . . However, if Table 12-E-2 is examined, it will be seen that there is a marked decrease in this ratio in volcanic calc-alkali sequence (basalt to rhyolite) and that it is considerably lower than in the corresponding plutonic member of the sequence (gabbro to granite)." Regarding this it might be suggested that the w values indicate a differentiation trend in both sample pairs and that the differentiation is more marked in sample pair X and XI. It is important to note that this trend runs from the porphyritic rock to the non-porphyritic.

3.1.3. The mode of the dolerite intrusion

The non-porphyritic margins of the porphyritic dikes have chilled contacts with the wallrock, whereas there is no chilled contact between the non-porphyritic margins (0.5–1.0 m.) and the central porphyritic part of the dike. However, at localities nos. 11–14 (Table 3) this contact zone often contains xenoliths. According to Bhattacharji and Smith (1964) the related fact indicates that the magma of the marginal dolerite has intruded as a narrow dike, in which flow differentiation caused the xenoliths to concentrate in a central zone. Before this central zone had been wholly crystallized the dike opened again and the magma of the porphyritic dolerite intruded. According to a rapid field examination of the dike, flow differentiation does not seem to have caused any extreme concentration of plagioclase phenocrysts in the porphyritic dolerite. However, about one meter inwards from the xenolith zone the dike is not so rich in phenocrysts as in the central part (see also Laitakari 1969, p. 58).

The chemical differences between the central and the marginal parts of the dikes are in part explained by the occurrence of phenocrysts of bytownite in the former. The non-porphyritic margins represent the liquid phase, which has been squeezed away from the magma chamber after the crystallization of the plagioclase phenocrysts accompanied by some olivine and/or pyroxene grains.

The non-porphyritic dolerites are more or less ordinary basaltic rocks, with the exception of the dike SE of Fjällbacka. This rock has a rather high sodium content, mineralogically expressed in a low An content of the plagioclase (oligoclase). The central part of the dike is more sodic than the marginal zones. There are no traces of internal contacts within the dike. It seems possible to regard this rock as a differentiation product of a basaltic magma.

The doleritic rocks occurring in the rhomb porphyry dikes will be discussed below.

3.2. The rocks of the rhomb porphyry dikes

Previous petrographic works of the Swedish rhomb porphyries show that these mostly appear as dikes of considerable size (De Geer 1902, Swedmark 1902, Lindström 1902, Ljungner 1927, Asklund 1947). The maximum width is about 50 m. The greatest length of one single rhomb porphyry dike stretching from Rossö to Otterön seems to be about 22 km., but as this dike is situated in an archipelago it seems probable that it continues some km. both to the north and the south of its visible endpoints (Fig. 1).

The total extension of the area with rhomb porphyry dikes is about 80 km., from Syd-Hälsö in the north to the small skerries Trillingarna, south of Sotenäset, in the south. As far as 35 km. to the south of this area single rhomb-shaped feldspar xenocrysts are found in the dolerites. Accordingly, the north-south extension of the area with Permian rocks is 115 km. and its greatest width 19 km. Actually the east–west extension of the dike province is not very well known. Asklund's (1947) survey is restricted to the area of the Bohus granite. The region to the east of the granite has not been investigated after the extensive mapping in the first years of this century (De Geer 1902, Swedmark 1902, Lindström 1902).

3.2.1. Field observations of the rhomb porphyry dikes

A summary of the field observations of the rhomb porphyry dikes is given in Table 1 and Fig. 5. The following text will give a description of some typical and interesting localities.

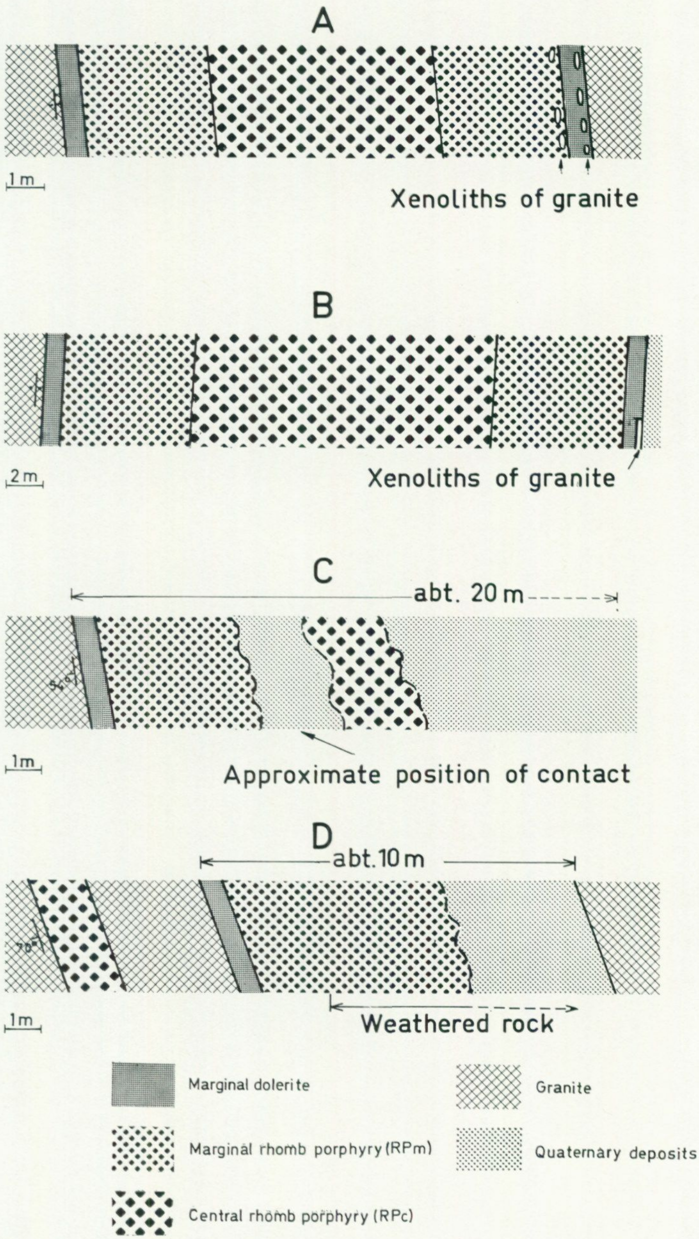

Fig. 5. Sketch map across different composite dikes of dolerite and rhomb porphyry. A = Rhomb porphyry dike, Raftötången (Table 3:33). B = Rhomb porphyry dike 5 km. south-west Hunnebostrand (Table 3:20). C = Rhomb porphyry dike, Skogen (Table 3:36). D = 300 m. north of C.

Fig. 6. The contact between marginal rhomb porphyry (left) and central rhomb porphyry, Raftötången (Table 3:33).

An excellent exposure of a rhomb porphyry dike has been found at Raftötången (Table 3, nos. 33–35). This dike has a width of 13 m. The strike is N6°W and the dip vertical. The wall rock consists of a coarse-grained granite with some pegmatite. Parallel to the contacts the dike is composed of three different rock types (Fig. 5):

a) Along both contacts there is a zone (width 0.5–0.7 m.) consisting of dark-grey, fine-grained rock of doleritic appearance and lacking rhomb-shaped phenocrysts. Some xenoliths of granite showing signs of assimilation have been observed. The contact with the wallrock is chilled. This contact rock has been called "marginal dolerite", abbreviated Dm.

b) The intermediate zone of rhomb porphyry has a width of 3 m. on each side of the dike. The transition from Dm appears as a zone, 0.3 m. in width, where the first rhomb-shaped feldspars are found and soon reach a frequency, which remains constant into the next rock-type. In this internal contact zone towards Dm numerous small pits occur, which constitute weathered remnants of formerly chlorite-filled cavities. The contact zone also contains some xenoliths of partly assimilated granite. The groundmass of the intermediate zone is coarser than that of the central zone (see p. 21). The rocks is named "marginal rhomb porphyry" and abbreviated RPm.

c) The central part of the dike has a width of 6 m. and consists of a grey rock with numerous rhomb-shaped feldspar phenocrysts. The matrix is more fine-grained than that of the RPm (see p. 25). The rock has been called "central rhomb porphyry", abbreviated RPc. The transition from RPm to RPc is indicated by a zone, 2–3 cm. in width and almost free from feldspar phenocrysts. The groundmass of the RPc is slightly chilled towards RPm (Fig. 6).

The sub-division of the rhomb porphyry dikes into three different types as described above has been shown to be a common development, though with some interesting variations (Table 1).

4 km. WSW of Hunnebostrand church (Table 1, Fig. 7) lies an outcrop where only the western part of the dike is visible. Nearby Dm here occurs in some small dikes separated from each other and RPm by laminae of granite. The contact between the granite laminae and Dm is sharp, and Dm is chilled. The contact between the same laminae and RPm is not so distinct, and a considerable remelting of the granite has taken place. The RPm groundmass shows no considerable decrease of grain size at this contact.

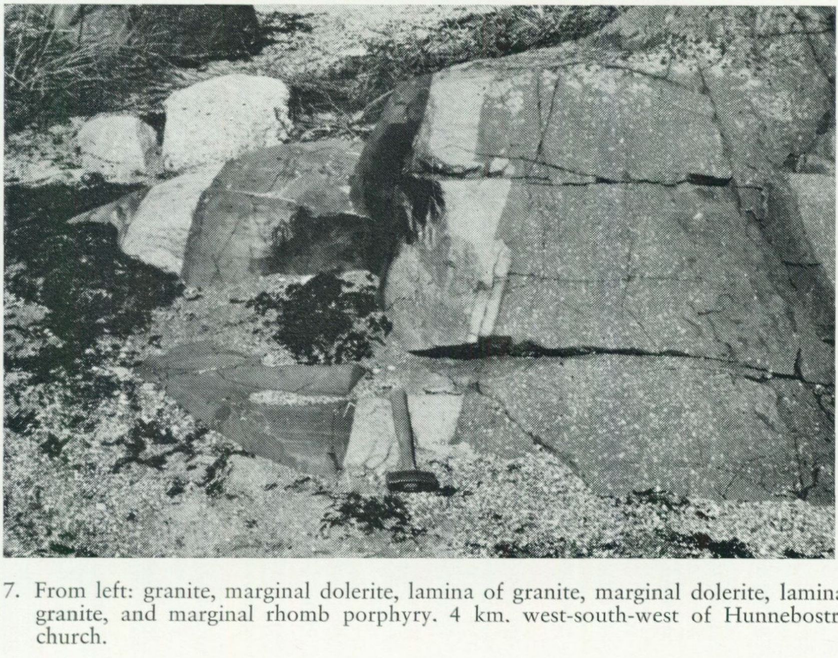

Fig. 7. From left: granite, marginal dolerite, lamina of granite, marginal dolerite, lamina of granite, and marginal rhomb porphyry. 4 km. west-south-west of Hunnebostrand church.

Fig. 8. The contact between marginal dolerite (left) and marginal rhomb phorphyry. 4 km. west-south-west of Hunnebostrand church. 2 nic.

About 50 m to the north of the outcrop now described is another where Dm borders directly and rather distinctly on RPm. The contact is not chilled and the small plagioclase laths of Dm are arranged parallel to the contact plane within one millimeter of the latter (Fig. 8). This arrangement indicates that there was a plane of friction between Dm and RPm and that the small plagioclase crystalls of Dm existed when RPm intruded.

At this locality it is evident that Dm has been intruded shortly before RPm. At other localities this sequence is not so obvious. However, there are no signs of the reversal.

Locality no. 36 (Table 3) shows another variation of the dike rock distribution. At C in Fig. 5 RPc occupies the central part of the dike, 300 m. to the north of this locality RPc is found in a dike 1.5 m. in width 3 m. to the west of the main dike (Fig. 5 D). Here RPc is very fine-grained but of the same composition as RPc in general (Table 3, no. 39). Rhomb-shaped feldspars of ordinary size are found all through the dike. The place where RPc cuts RPm and Dm is covered by Quaternary deposits, and so is the area where the separate RPc dike terminates. However, along the section where the main dike runs parallel to the RPc dike, the rocks of the main dike are fractured and rapidly weathering, whereas the RPc dike rock has remained fresh and unfractured. This is best understood if RPc intruded after Dm and RPm, just as indicated by the chilling of the RPc contact against RPm at Raftötången (see p. 17). Another example of RPc in a separate dike is found at locality no. 44 (Table 3). This dike is only 1.5 m. wide. It is found on a small island, and the main dike probably runs on the bottom of the sea quite close to RPc, as seen from the topography.

At locality no. 16 (Table 3) is a small exposure of a porphyritic dike which seems to contain a mixture of doleritic and rhomb porphyry material. The dike is only exposed from its western contact and 8 m. inwards. The non-porphyritic margin grades into the more porphyritic central part. The groundmass corresponds to that of the dolerites. It contains the same plagioclase phenocrysts as the porphyritic dolerites. There are also some big crystals of pyroxene. A good deal of rhomb-shaped feldspars are distributed through the rock together with partly assimilated xenoliths of granite.

3.2.2. Petrography of the rhomb porphyry dikes

The following description refers to locality no. 20 (Table 3). When other localities are treated this is announced. The dike is 32 m. wide, with Dm = 1 m., RPm = 7 m. and RPc = 16 m. From the western margin to the central part of the dike, rock samples were taken along an almost straight line. A few samples have also been taken from the opposite side of the dike. The modal analyses of the matrix are given in Fig. 9.

A rough estimation of the volume occupied by the rhomb-shaped feldspars has been obtained by placing a square lattice on the rock surface. The sides of the squares were 10 cm. The points occupied by phenocrysts were counted at locality no. 20 (Table 3) and 1.5 km. further north in the same dike. Countings were made at a distance of 5 and 15 m. from the western margin of the dike (viz. in RPm resp. RPc). The results are given below:

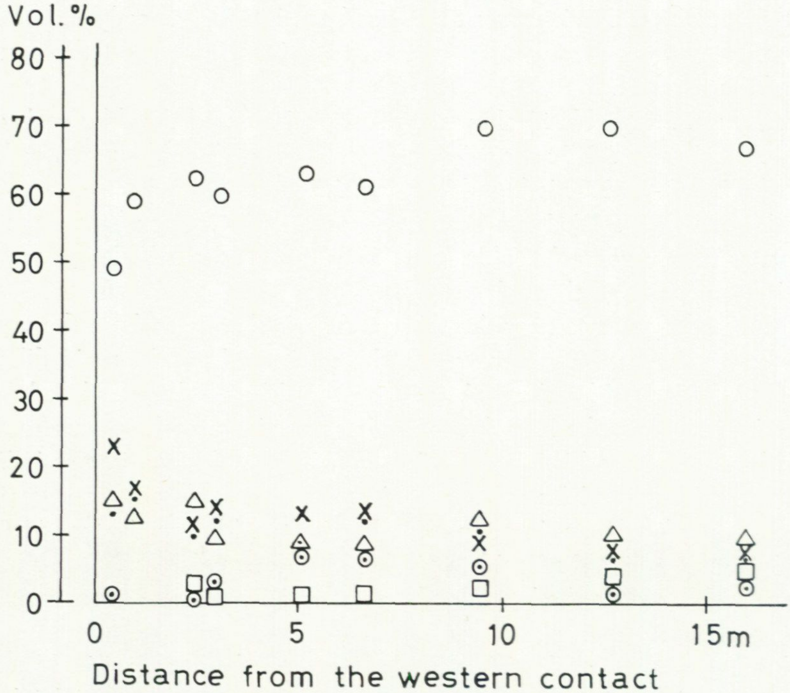

Fig. 9. Volumetrical analyses of the groundmass from the western half of the rhomb porphyry dike at locality no. 20 (Table 3). ○ = feldspar, × = pyroxene, ⊙ = biotite and amphibole, • = opaque, □ = quartz, △ = rest, mostly chlorite.

Locality	Points counted at each distance	Rhomb-shaped feldspars RPm (5 m.)	RPc (15 m.)
No. 20 (Table 3)	220	22 %	30 %
1.5 km. north of no. 20	110	28 %	30 %

1. The western marginal dolerite has been studied in thin slides from 0.1 m. and 0.5 m. At 0.1 m. the rock is strongly altered. At 0.5 m. the rock is fine-grained, holocrystalline, and subophitic. The plagioclase (average size 0.6×0.2 mm.) is an andesine (Table 5). It has been altered and contains sericite as well as epidote. The pyroxene grains are hypidiomorphic, with an average size of 0.5×0.3 mm. Only monoclinic pyroxene has been observed. Determinations of γ/c gave, in five instances, figures between 43° and 45°, and in three instances 30°. 2 $V\gamma$ has been determined as 44°, 46°, and 84° respectively. The colour in both cases is pale green and there is no visible pleochroism. The pyroxene with the greatest extinction angle is a common augite. The other values correspond to an aegirine-augite. Opaque minerals are magnetite and pyrite. The former is most frequent.

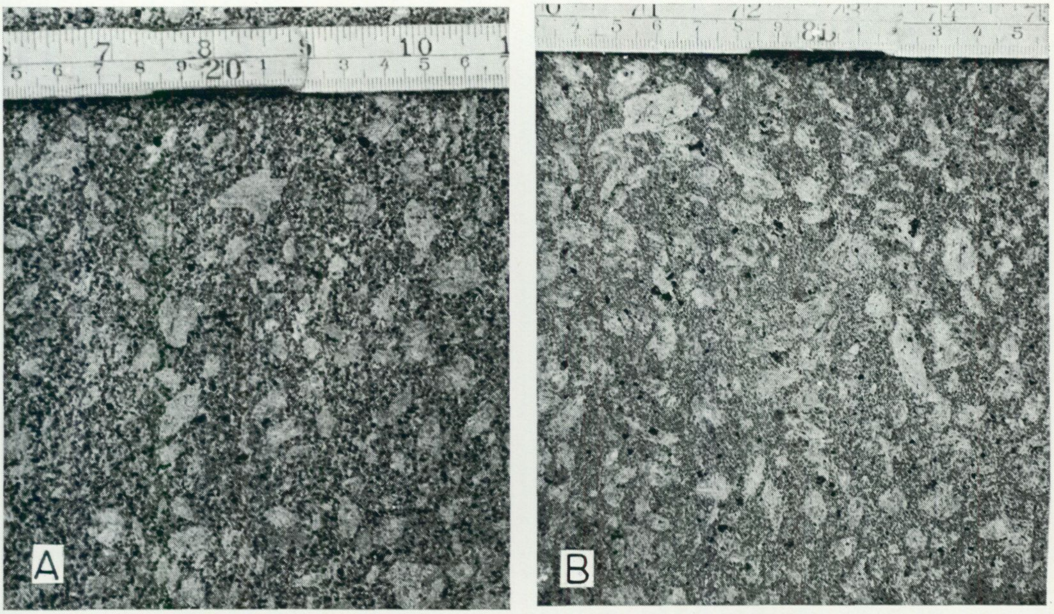

Fig. 10. Weathered surface of marginal rhomb porphyry (A) and central rhomb porphyry (B).

Among the remaining minerals a blue green chlorite has a dominant position. Serpentine and epidote also occur.

2. The marginal rhomb porphyry (RPm) consists of rhomb-shaped feldspar phenocrysts in a dark grey matrix (Figs. 10 and 11). As these phenocrysts are essentially of the same type in RPm and RPc, some notes of their characteristics will be given after the description of RPc. The matrix of RPm is dominated by elongated plagioclase feldspars twinned according to the albite and Carlsbad laws. Some pericline twins have also been found. The plagioclase has an average size of 0.7×0.2 mm. The crystals are often surrounded by a pink-coloured feldspar with α' and γ' on (001) = 1.523 and 1.536 ±0.002 respectively, viz. an alkali feldspar (Ljungner's anorthoclase). 1.5 km. to the north of locality no. 20 (Table 3) one megacryst (6×2.5 cm.) of broadly twinned plagioclase was found in RPm a few cm. from the boundary towards RPc (Fig. 12). The crystal is rather fractured and in part completely sericitized. It shows oscillatory zoning, with a central part of calcic labradorite. The crystal contains some inclusions of serpentine which are probably pseudomorphs after both olivine and pyroxene. An analysis is given in Table 2: no. XIX. A similar megacryst, also occurring in RPm, has been observed at locality no. 41 (Table 3).

Optical studies of the plagioclase (Table 5) indicate that the RPm magma at the moment of intrusion seems to have contained a labradorite-bytownite plagioclase of early formation together with rhomb-shaped feldspar crystals. In

Fig. 11. Marginal rhomb porphyry. A rhomb feldspar is seen in the upper right corner. Below the center is an augite partly enclosing a plagioclase crystal, which has an alkali feldspar rim outside the augite crystal. 2 nic.

the dike the earliest crystallized plagioclase crystals have a composition approximately corresponding to $Ab_{43}An_{57}$. A study of the well-developed zones of the plagioclase individuals has revealed that the crystallization continued to $Ab_{74}An_{26}$. Of latest formation is an alkali feldspar, which now constitutes the outermost zone of the plagioclase.

Fig. 12. Megacryst of plagioclase (6×2.5 cm.) in the border between marginal and central rhomb porphyry. 4 km. WSW of Hunnebostrand church.

Polished slabs of RPm have been tested with colouring agents sensitive to potassium feldspar (Bailey and Stevens 1960). This operation has revealed that about 1/3 of the matrix feldspar is rich in potassium. According to thin sections there seems, however, to be some variations of the proportions between potassium-rich and potassium-poor feldspar within the matrix of RPm. The pyroxene individuals are mostly hypidiomorphic, about 0.3 mm. in length and 0.1 mm. across basis. The optical data ($\gamma/c = 44°$ and $2\ V\gamma = 50°$) point to a titanium augite. The estimated birefringence is 0.024. The crystals sometimes show hourglass zoning. Opaque minerals are magnetite and pyrite. Magnetite has a still more dominant position than in Dm. Among other minerals are biotite with brown-yellow to red-brown pleochroism as well as amphiboles with an uralitic appearance and $\gamma/c = 10–12°$. Apatite, chlorite, and serpentine are also present. In the chlorite aggregates a few grains of an isotropic mineral (n = 1.88) have been observed. This mineral is probably melanite.

3. The central rhomb porphyry (RPc) is grey with a purple tint (Figs. 10 and 13). The rhomb-shaped feldspar occupies about 30 % of the rock (see p. 19).

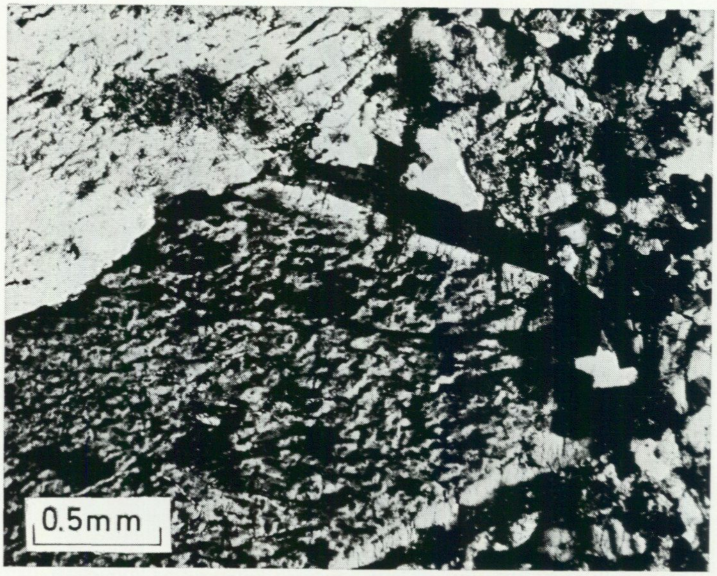

Fig. 13. Central rhomb porphyry. The plagioclase (light) and alkali feldspar (dark) rims are absent between the different crystals in the aggregates of rhomb-shaped feldspars. For locality, see Table 3:20. 2 nic.

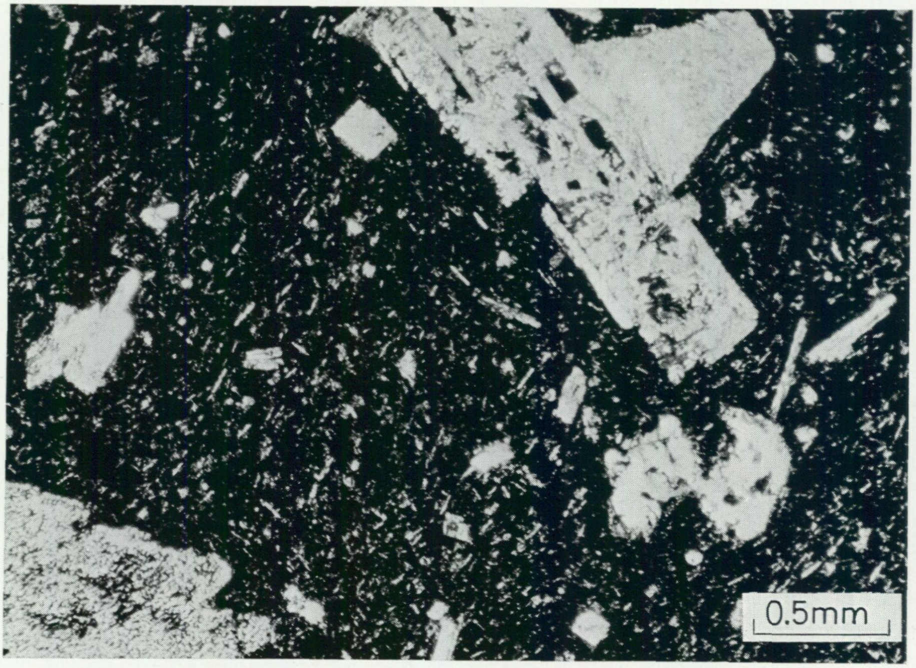

Fig. 14. Central rhomb porphyry in a narrow (1.6 m.) dike. A rhomb-shaped feldspar and a fragment of plagioclase (An_{68-74}) are fixed in a fine-grained matrix. For locality, see Table 3:39.

The matrix is more fine-grained than in RPm, due to the smaller size of the feldspar grains, 0.4×0.2 mm. The structure of the matrix is hypidiomorphic. Two kinds of feldspar are found in the groundmass. The central parts of the grains consist of a plagioclase with Carlsbad and albite twins containing 30–52 % An (Table 5). The central parts grade into marginal zones of alkali feldspar with α' on (001) = 1.523 ±0.002. This alkali feldspar also occupies interstitial areas in the groundmass. (See also Ljungner 1927, p. 57, Oftedahl 1946, p. 40, and 1948, p. 17.)

The proportions between plagioclase and alkali feldspar in the groundmass have been determined in the same way as in RPm. (See p. 23.) The alkali feldspar amounts to about one half of the total feldspar content of the matrix, with a lesser degree of variability than in RPm.

In addition to the plagioclase in the kernels of the groundmass feldspar some bigger xenolithic plagioclase individuals are found. In the small dikes, containing only RPc, the xenocrystic character of these plagioclase individuals in the fine-grained matrix is very obvious (Fig. 14). The xenocrysts are of labradorite-bytownite composition (Table 5, no. 39).

The pyroxene shows $\gamma/c = 45°$, $2\,V\gamma = 45–52°$. The birefringence is 0.025. The pleochroism is weak in green colours sometimes with a purple tint. The optical properties correspond to an augite which seems to contain less titanium than the pyroxene of RPm. Some thin sections contain small crystals of an orthorhombic pyroxene with a lower birefringence than that of augite.

The opaque minerals present are magnetite and pyrite. The former predominates. The latter is often associated with aggregates of chlorite and serpentine. Other minerals are quartz occupying interstices, biotite, amphiboles, chlorite, and serpentine. Apatite displays rather big crystals (diameter 0.8 mm.) in the matrix as well as in the phenocrysts. Apatite has also been observed within the pyroxenes.

When it arrived at its final position, the RPc magma seems to have contained some plagioclase of labradorite-bytownite composition in addition to the rhomb-shaped feldspar crystals. In the dike the crystallization has produced plagioclase showing distinct zoning from sodic labradorite (kernels) to oligoclase. Finally an alkali feldspar crystallized.

3.2.3. The rhomb-shaped feldspars

3.2.3.1. PREVIOUS DESCRIPTIONS

Rhomb-shaped feldspars, characteristic of volcanic rocks from the Oslo region, have been subject to many studies. Some of the papers considered to be of interest in connection with the actual study are cited below.

Ljungner's (1927, p. 55) investigation of rhomb-shaped feldspars from the Norwegian and Swedish rocks shows, "1) Dass die Kristalle einen antiperthiti-

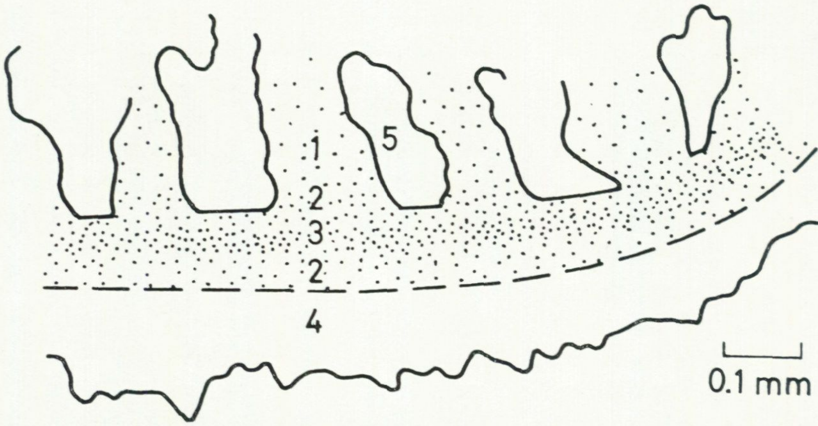

Fig. 15. Marginal part of rhomb-shaped feldspar. Sketch from description by Ljungner (1927, p. 52). Ljungner's designations are followed by the results from the present study within parentheses (cf. Table 6).
1. Main feldspar, oligoclase-andesine (An_{30}).
2. Andesine } (Andesine-labradorite)
3. Labradorite }
4. K-feldspar in growth-zone ($Or_{60}Ab+An_{40}$).
5. Second feldspar ($Or_{70}Ab+An_{30}$).

schen Bau besitzen, dessen kleineren Teil von einem pertitisch zuweilen zerfallenen Kali-Natronfeldspat (Natron-Ortoklas), dessen grösserer Teil hingegen von Oligoklas-Andesin (mit einem gewissen, noch nicht bestimmbaren Kalieinteil) bestehen:

2) dass die Rhombenfeldspateinsprenglinge der bohusländischen und Olso-Vorkommen identisch sind."

Ljungner's studies are condensed in Fig. 15, which also contains results obtained during the present study.

Oftedahl (1948, p. 9) discusses the earlier nomenclature of the rhomb porphyry feldspars: "The rhomb porphyries contain antiperthitic plagioclase phenocrysts, which are often selvaged by an alkali feldspar zone. The predominant crystal faces are (110), (201), and (101) by which the crystals obtain a nearly rhombic outline in sections parallel to (010) and vertical to the c axis. In rocks transitional to the rectangle porphyries the faces (001) and (010) also occur."

Oftedahl (1944, p. 75) has shown that phenocrysts of the rhomb porphyry and the akerite porphyry have high temperature optics. This is also the case of some subvolcanic plutons in the Oslo area (Barth and Oftedahl 1947, p. 102). Dons (1952, p. 14) describes akerite porphyry with antiperthitic phenocrysts showing one or two marginal zones of alkali feldspar.

In the general description of the rhomb porphyries Oftedahl (1946, p. 37) reports anorthite contents of the rhomb-shaped feldspars ranging from 30 to

40 % in the more acid rhomb porphyries and from 40 to 42 % in the the rectangle porphyries and the kjelsåsite porphyry. The dike at Tyveholmen is said to be a typical rhomb porphyry dike. Its phenocrysts are antiperthitic, with 30 to 50 % alkali feldspar in irregular spots or strings. The plagioclase contains 30–40 % An (op. cit., p. 40). The origin of the various feldspars in the phenocrysts of the Tyveholmen dike and the larvikites has been discussed by Muir and Smith (1956), Smith and Muir (1958), and Laves (1956). The general conclusion was that the various feldspars represent "stages in the unmixing of an originally homogeneous ternary feldspar" (Barth 1969, p. 45). Smith and Muir (1958, p. 20) also state "The present assemblages are described as antiperthites of oligoclase and orthoclase (or microcline)".

A very important paper on the anorthoclases of the rhomb porphyries of the Oslo region was published after the accomplishment of the main part of this study (Harnik 1969). Four rhomb porphyry lavas, one rectangle porphyry lava, and one rhomb porphyry dike (Tyveholmen, Oslo) have been studied. Harnik found that the phenocrysts were composed of kernel and rim, which were studied separately.

"The results can be summarized as follows: 1. The cores of the phenocrysts are micro- to crypto-antiperthitically unmixed. The antiperthitic host commonly makes up more than 90 % of the total volume. Its composition varies depending on RP-type between approximately $Or_{15}Ab_{75}An_{10}$ and $Or_{10}Ab_{45}An_{45}$. The concentration of potassium in solid solution in the plagioclase host on one hand appears to be dependent on the crystallization temperature and yet on the other, proportional to the degree of disorder of the host. The structural state of the host can be designated as disordered to intermediate. – The alkali feldspar guest has an An-content that is in most cases between An_5 and An_{15}. These alkali feldspars are occasionally in their turn unmixed again; they can, depending on their composition, form antiperthite as well as perthite. The members of this second unmixing-generation are sometimes almost pure K- and Na-feldspars with small An-content. The structural state of the guest, in view of the observed symmetry, high An-contents and small measured $\triangle$-values (about 0.40), is considered to be disordered to intermediate, which corresponds to the structural state of the host.

2. The rims of the phenocrysts differ in the following way from the cores: Host and guest are more An-poor and more (Ab+Or)-rich than those that occur in the cores. The total volume of the exsolved domains is nearly twice as large as in the cores; yet the chemical differentiation between host and guest has not progressed as far. The tendency for formation of crypto-perthite is stronger in the rims than in the cores.

Especially striking differences between core and rim of the phenocrysts were observed in the Tyveholmen-RP. Precession photographs of feldspars in the cores as well as in the rims show strong reflections of the triclinic plagioclase host twinned according to the albite law. However, photographs of feldspars of the rims in addition show distinct, wide streaks between these reflections; one can also recognize weak reflections from exsolved alkali feldspar. These observations appear to corraborate the views of Laves (1956) concerning the appearence of feldspar phases in rhomb porphyries.

3. The Ca-poor alkali feldspars of the groundmass are strongly unmixed. The Na-feldspars are structurally intermediate to ordered. Also the structural state of the K-feldspars is regarded as intermediate to ordered in view of their symmetry and the measured relatively high $\triangle$-values (about 0.83). The feldspars of the groundmass are thus structurally significantly more ordered than feldspars of the same chemical composition making up the phenocrysts." (Harnik 1969, Abstract.)

3.2.3.2. PRESENT OBSERVATIONS

The appearance and distribution of the phenocrysts are illustrated in Fig. 10 and on p. 20. Optical values are given in Table 6. Chemical analyses of handpicked fragments of phenocrysts are given in Table 2.

The phenocrysts mostly occur as discrete crystals. Aggregates of several crystals are also common. The crystals are more or less idiomorphic. The crystal faces against the groundmass are usually rounded (corroded). The main part of the crystals is usually antiperthitic, with a plagioclase containing 30 % An and an alkali feldspar with the approximate composition $Or_{70}An+Ab_{30}$ (Table 6). The antiperthitic texture is cut by a rim of plagioclase which reaches the labradorite composition (cf. Ljungner 1927, p. 52). This plagioclase has often the same otpical orientation as the antiperthitic host plagioclase. The rim of plagioclase is mantled by alkali feldspar ($Or_{60}An+Ab_{40}$). The border between plagioclase and alkali feldspar is sharp (Fig. 13). The alkali feldspar has sutured contours towards the matrix. These rim-zones are always present in the contact between the solitary phenocrysts and the matrix, and between the outer margin of the phenocryst aggregates and the matrix. They are never found along the crystal borders within an aggregate. This is true for ordinary RPc. In RPm the plagioclase rim is always present as above. The alkali feldspar rim, however, might be absent. When present it is generally thinner than in RPc.

The observations described show that the formation of the antiperthite as well as the aggregates of phenocrysts is prior to the development of the rims. They also evidence that the rim of alkali feldspar is formed after the intrusion (cf. Lundqvist 1968, p. 99).

A possibility to study the formation of the rims of the phenocrysts is offered by the narrow RPc dikes. In these dikes large crystals or rhomb-shaped feldspars occur even in the aphanitic margins, and the formation of the rims can be studied in early, "frozen" stages. Fig. 16 comes from a thin section taken 0.1

m. from the contact of RPc at locality no. 39, Table 3. It is observed that the dark matrix has a corroding effect on the phenocrysts and that it fills some cavities in the phenocrysts.

Fig. 16. Detail of rhomb-shaped feldspar, strongly heated and corroded by the matrix magma, which has also penetrated into the feldspar crystal. For locality, see Table 3:39. 1 nic.

The matrix is microscopically inseparable, but it has an even distribution of minute opaque minerals, which facilitates its tracing. It is also seen that the phenocrysts have melted in part at the contacts with the matrix. The fused zone is broader along the crystal faces than along the borders of the cavities. The minute opaque minerals occuring in the partly fused zones indicate exchange of material between the phenocryst and the matrix. Bridgwater (Bridgwater and Harry 1968, p. 128) describes dike rocks from South Greenland containing plagioclase megacrysts and alkali feldspar rhombs. The latter show many similarities with the present rhomb feldspars. Inter alia they frequently display a hollow center filled with basic groundmass material.

Thin sections from the central part of the same dike (Table 3:39) show that the plagioclase rims have developed twin lamellae and that a thin alkali feldspar rim occasionally has come to existence outside. When RPc occurs in broad dikes the plagioclase rim has as a rule been twinned.

Characteristic of the phenocrysts of the RP dikes is frequently also the occurrence of small strings and patches of pyroxene in a more or less regular intergrowth with the feldspars (Fig. 17). Ljungner (1927, pp. 48 and 52) noted this pyroxene and also observed its occurrence within the alkali feldspar patches, there partly acting as its substitute. From Fig. 17 it can be seen that this pyroxene, an augite, has grown continuosly from a pyroxene grain situated in the matrix. The pyroxene grains outside and inside the phenocryst have the same optical orientations. Occasionally it can be observed that they are linked together by a thin channel. Consequently, both have crystallized simultaneously and at the same time as the rest of the matrix. This kind of pyroxene has no clear genetic connection with the comparatively large grains of augite found within the rhomb-shaped crystals and between the crystals in the aggregates (Fig. 18).

The texture of the rock suggests that the development of the plagioclase rims and the pyroxene strings is due to the contact between the phenocrysts and the magma, the latter now constituting the matrix.

When studied microscopically, some rhomb-shaped crystals have proved to be not entirely antiperthitic. Instead, their central parts are occupied by feldspars which show no visible perthitic or antiperthitic texture. Only sporadic optical investigations have been made on these central parts, however, indicating that they are built up in more than one way. A rather common development is displayed by albite twins occasionally becoming invisible in the microscope (cf. Oftedahl 1948, Fig. 3). This feldspar is a plagioclase, which seems to have the same An content as the plagioclase of the antiperthitic domains, viz. 30 % and high temperature optics (Table 6). Another kind of development in the kernels involves a central area of clear plagioclase with 49–53 % An and high temperature optics. Around the kernel-plagioclase described is seen a zone of unevenly distributed clouded alkali feldspar rich in minute, secondary

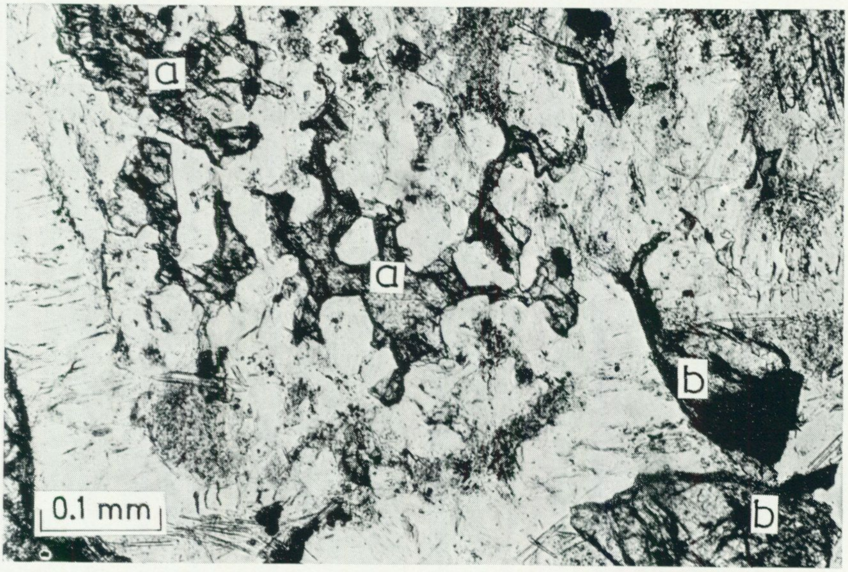

Fig. 17. Pyroxene of the same crystallographic orientation both inside (a) and outside (b) a rhomb-shaped feldspar. Marginal rhomb porphyry, Raftötången (Table 3:33). 1 nic.

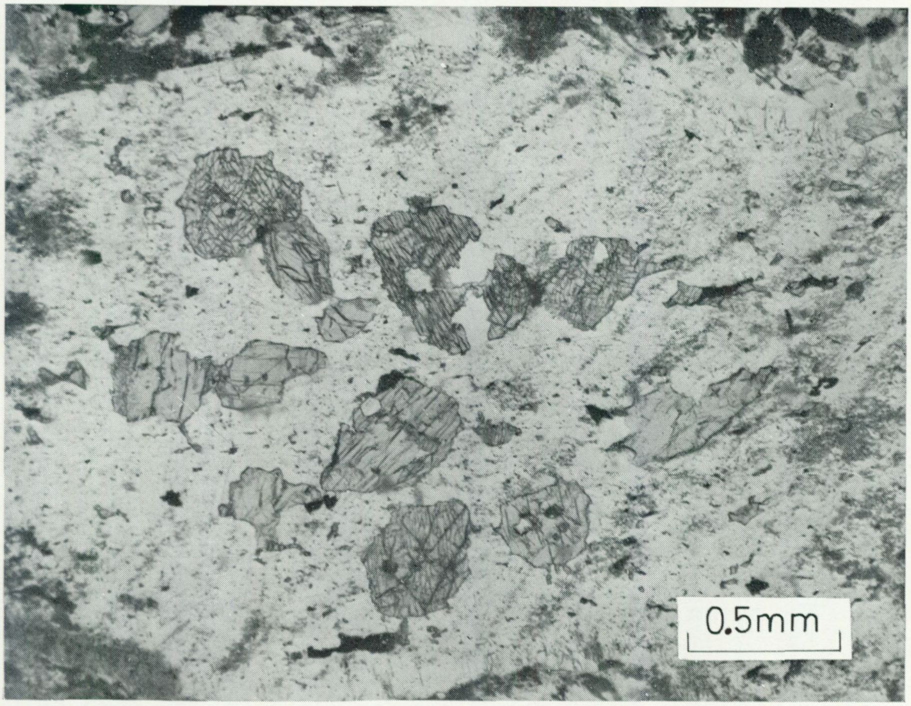

Fig. 18. Augite in rhomb-shaped feldspar of central rhomb porphyry. For locality, see Table 3:29. 1 nic.

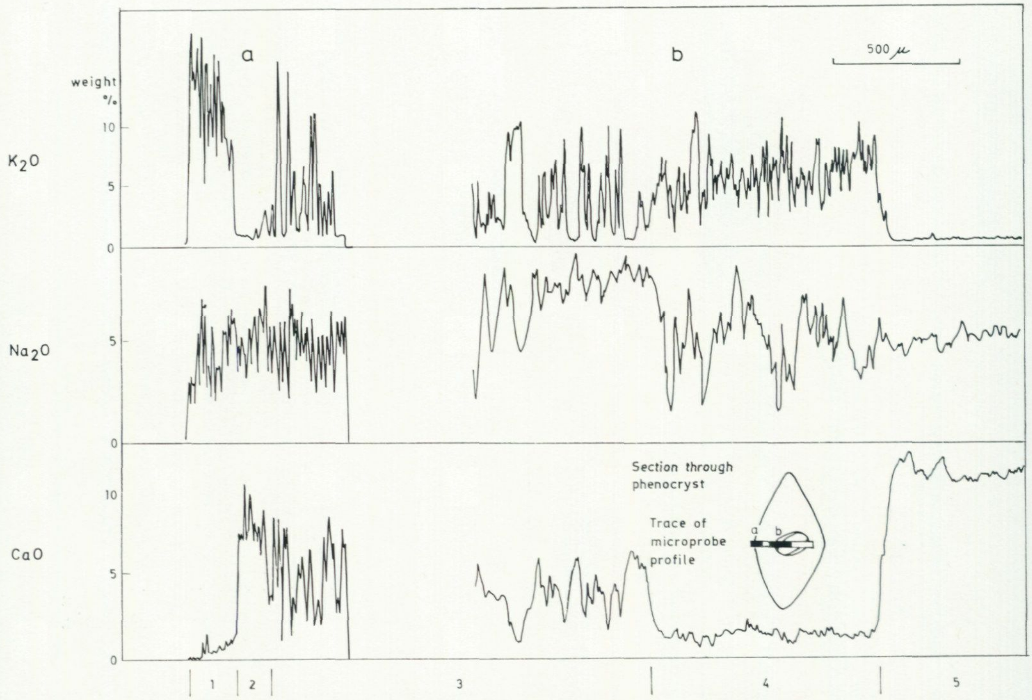

Fig. 19. Microprobe profiles of rhomb-shaped feldspars from RPc. The black parts of the profile in the inset sketch have been reproduced here. The profiles can give only the approximate compositions. Parts (a) and (b) of the profile unfortunately had to be taken from different phenocrysts of the same sample. The curves have been redrawn so they can be mutually compard. However, the crystallographic orientation is not the same in (a) and (b). In spite of many shortcomings, this preliminary test verifies the optically found existence of an alkali feldspar rim (1) and a plagioclase rim (2) more An-rich than the plagioclase of the antiperthitic part of the core (3). It also demonstrates that the central core of this particular phenocryst is composed of an alkali feldspar-rich, clouded part (4) and an An-rich plagioclase (5). The antiperthitic part (3) commonly occupies the whole core of the phenocrysts. The scanning speed was 190 μ/min.

minerals. One phenocryst of this composition has been traversed by a microprobe profile. The results are recorded below. However, it should be noted here that the alkali feldspar zone seems to contain submicroscopic domains of plagioclase.

It should be pointed out that the optical investigation of the rhomb-shaped phenocrysts can give only tentative results (Table 6). As demonstrated by Harnik (1969) there exist submicroscopic domains of different feldspar phases in the phenocrysts from the Oslo district. He also shows that the determination of the different feldspars is a severe work. For the Swedish RP dikes this work on the whole still remains. According to the complicated geology of the Swedish RP dikes it might be expected that the early history of their phenocrysts is very difficult to trace. However, for the present investigation there are some features of their latest history which are of the greatest interest, viz. the development of the rims.

In order to verify the results of the microscopic work, some microprobe profiles have been made by Mr. H. Nairis at the laboratories of the Geological Survey of Sweden. The contents of CaO, Na_2O, and K_2O have been determined (Fig. 19). The core consists of a central part, which does not show the usual antiperthitic pattern. This central part is made up by two different domains. One is clear, free of inclusions and shows c. $An_{51}Ab_{47}Or_2$. The other is clouded, very rich in inclusions and seems to contain a potassium feldspar with some sodium. According to the parallelism of the CaO and Na_2O curves, it seems possible that an An-poor plagioclase is also present. The rest of the core consists of a plagioclase host (c. An_{30}) and an alkali feldspar guest (c. $Or_{66}Ab_{30}An_4$). The inner rim consists of a plagioclase (c. $An_{47}Ab_{51}Or_2$) and the outer rim of heterogeneous alkali feldspar.

4. GENETIC DISCUSSION

Regarding the age relations between the doleritic dikes and the rocks of the rhomb porphyry dikes, it should be stressed that the dikes have never been observed to cross each other. Direct evidence of age relations are so far not available. As to the age relations between the different rocks within the rhomb porphyry dikes, there is clear evidence of the sequence: Dm, RPm, and RPc (cf. pp. 16–19). The interpretation of the age relations between the doleritic dikes and the rocks of the rhomb porphyry dikes has obviously to be based on petrographic facts, and in connection with this the whole problem of the genesis of the different rocks in the rhomb porphyry dikes should be discussed.

From the previous description (p. 28) it is obvious that the antiperthitic texture of the kernels of the rhomb-shaped phenocrysts had been developed before the plagioclase rims. However, structural rearrangements might have taken place within each unmixed unit simultaneously with the formation of the rims. The development of the plagioclase rim (and its abscence within the feldspar aggregates) indicates a drastic change in the environments. Ljungner (1927, p. 49) regards the plagioclase rim to have been formed by fusion and recrystallization, and the outer alkali feldspar zone to have been formed by oriented growth (cf. Walker and Skelhorn 1966, p. 101). Investigations of the rhomb porphyries in the Precambrian rocks of the Kiruna district led to the following general suggestion by Quensel (1918, p. 14): ”Das immer noch seltene Auftreten von Feldspäten in Rhombenform erfodert auch mehr oder weniger exceptionelle Bildungsbedingungen, die gerade in einer plötzlichen chemischen Veränderung des Magmas zu suchen sein könnten, wobei ein schon in Auskristallisation begriffene Feldspatgeneration nicht mehr stabil bleibt, sondern einer Auflösung preisgegeben würde."

In his investigation of the RP lavas and the Tyveholmen dike, Harnik (1969, p. 509) found that the rim around the phenocrysts differed "in the following way from the cores: Host and guest are more An-poor and more (Ab+Or)-rich than those that occur in the cores". He suggested that pressure and temperature ought to have been comparatively stable during a long period in order to be able to produce crystals of homogeneous composition: the futural kernels of the phenocrysts. This long primary period of crystal growth was stopped by a change of the PT-conditions. Decreasing pressure was probably the ultimate cause. Consequently monoclinic feldspar lower in Or and higher in sodium was developed as a rim around the cores of the phenocrysts. The crystallization of the rims was soon interrupted by new changes of the PT-conditions caused by the processes leading to the effusion of the RP-lavas (op. cit., p. 553).

For the interpretation of the genesis of the rocks in the present study it is very important to note that the composition of he rims as seen from p. 33 and Table 6 is on the whole not in agreement with Harnik's observations.

The innermost rims of the Swedish phenocrysts are higher in An and lower in Or than the cores. The sodium content is also slightly lower in the rims. Following Harnik's model of interpretation, it seems possible to suggest that the inner rims of the Swedish phenocrysts have crystallized at a higher pressure and temperature than the cores. However, there is very little Or in the plagioclase rims. If these rims have been developed by a continuous crystallization from the same magma as the primary ternary cores, the rims should also have crystallized as a ternary feldspar and contain more Or than the cores (cf. Harnik 1969, p. 539). A momentary rise in temperature could have occurred, if the magma where the rhomb feldspars crystallized was intruded by another magma. If this magma have had a very low potassium content, this would of course lead to a low potassium concentration in the plagioclase rims. An intrusion of a more basic magma should have brought the rhomb feldspar phenocrysts out of equilibrium with their surroundings and should have caused their resorbtion. However, as observed in the microscope, this resorbtion has for the most part been confined to a partial fusion of a thin marginal zone (thickness 0.1 mm.). This rather restricted thermal action on the phenocrysts could be explained if the intruding magma has been very close to its liquidity or if pressure has increased simultaneously with the invasion of the magma. Such a pressure increase should have been helpful in preventing the phenocrysts from total resorbtion (Lindsley 1967, Fig. 1). When pressure released, probably when the dike fissure reached the surface of the crust, the plagioclase rims were formed by remelting and recrystallization of the outer parts of the phenocrysts. The close connection between the "maturity" of the plagioclase rim and the grain size of the

RP matrix (see p. 30) indicates a contemporaneous formation of the rims and intrusion–crystallization of the dike rock.

According to the field relations in the rhomb porphyry dikes, the composition of the matrix of RPm and RPc as compared with the rhomb-shaped feldspars, and the textural relations between the matrix and the rhomb feldspars, an invasion of a basaltic magma into an acid, rhomb-feldspar-carrying magma actually seems to have occurred.

The constant appearance of three different rock types in the great rhomb porphyry dikes indicates that sudden openings of dikes or fissures have made possible three intrusions of magma, and that the area involved was very large. It seems probable that these extensive, momentary tectonic episodes should have been to some extent connected with major subsidences in the central rift zone further westwards.

Macdonald and Katsura (1965, p. 475) describe plagioclase phenocrysts with an outer rim of a more calcic plagioclase. These phenocrysts are found in both the dacitic lava and the banded pumice of the Lassen Peak eruption 1915. The banded pumice is interpreted as an example of incomplete mixing of two magmas. The special zoning of the plagioclase phenocrysts is due to a disturbance of the feldspar equilibrium in the crystallizing dacitic magma. The cause of this disturbance is not conclusively stated. However, different possibilities are discussed: "uneven basification of silicic magma by admixture of a small proportion of mafic magma, but alternatively it may have resulted from assimilation of sialic material by rising of basic magma. A shift of equilibrium within the magmatic system, due to increase of pressure on a hydrous magma or to sudden decrease of pressure on an anhydrous magma and an increase in the temperature of the magma . . . possibly by rising gases in a shallow chamber just before eruption or in the volcanic conduit during the rise of the magma to the surface" (op. cit., p. 497).

Larsen et al. (1936, 1937, 1938) mentioned an andesite containing uniform crystals of labradorite (An_{62}) side by side with crystals showing reversed zoning in which a kernel of oligoclase (An_{28}), with evidence of partial fusion and resorbtion, is enclosed in andesine (An_{41}). Also in other andesites and in some of the basalts are found not only phenocrysts of olivine and calcic plagioclase but also strongly corroded crystals of quartz and sanidine. Their conclusion is that very large masses of two porphyritic magmas have been thoroughly mixed (cf. Walker and Skelhorn 1966, p. 103).

Composite dikes of the Oslo region were early described i. a. by Keilhau 1823, Lyell 1841, and Voght 1891 (Dons 1952, p. 54). They have also been studied more recently (Dons, op. cit., Oftedahl 1957, Antun 1964). Somewhat differing genetic interpretations have been presented in this connection. Antun (1964) describes an example of a composite dike from Oslo. Starting with a critical review of the older literature on the subject, he states that all composite dikes of the Oslo region are built up by successive intrusions of different magmas. He (op. cit., p. 58) improves some of Harker's (1904) ideas concerning two different modes of occurrence of xenocrysts in composite dikes. The dikes in question are composed of doleritic margins and central porphyry. In the doleritic margins the phenocrysts of the porphyry appear as xenocrysts, either uniformly distributed all through the dolerite or scattered just along the dolerite border on the porphyry. The first kind of distribution is due to an early and deep-seated meeting and mixing of two magmas (viz. dolerite and porphyry). The second kind of distribution of xenocrysts has been developed in the dike by interaction between partly congealed dolerite and porphyry magma in the border zone. In this case the two magmas have occupied different chambers, and no mixing occurred at depth. Antun (loc. cit.) also points to the restricted size of this kind of intrusion.

5. SUMMARY

Below is given a summary of observations, which seem to be important in the genetic discussion of the relationship between the actual dikes of dolerite and rhomb porphyry.

1. The appearance of dolerite and rhomb porphyry in dikes with uniform orientation and obviously belonging to the same period of intrusion.
2. The localization of the rhomb porphyry dikes to the western part of the dike area.
3. Flow differentiation in a primary intrusion pulse from a basaltic magma chamber as shown by the non-porphyritic margins and the xenolith zone of some porphyritic dolerites.
4. The appearance of three rock types in the rhomb porphyry dikes and the compositional homogeneity of each rock.
5. The close time relationship between the intrusions of Dm, RPm, and RPc.
6. The occurrence of xenocrysts of plagioclase An_{68-72} in RPm+RPc and the same plagioclase forming phenocrysts in the porphyritic dolerite.
7. The occurrence of rare xenocrysts of rhomb-shaped feldspars in some dikes of dolerite.
8. The rhomb-shaped feldspar crystals in RPm and RPc not being in equilibrium with their present matrix magma.
9. The dolerite character of the matrix in RPm and to some extent also in RPc.

The observations suggest the following conditions and sequence of events:

1. Rhomb-shaped feldspar and pyroxene existed in aggregates in a cooling magma, at least of the size now seen in the rhomb porphyry dikes. The cooling had proceeded far enough to produce antiperthitic unmixing of the phenocrysts. The absence of large xenoliths and rafts of this magma in the rhomb porphyry dikes indicates that the crystallization had not been completed (cf. Bridgwater and Harry 1968).
2. Beneath this rhomb-feldspar-carrying magma was a basaltic magma containing phenocrysts of labradorite-bytownite composition.
3. The basic magma intruded the cooling rhomb-feldspar-carrying acid magma and a mixing of magmas occurred.
4. Some of the basaltic magma intruded as separate narrow non-porphyritic dikes and as marginal dolerite in the rhomb porphyry dikes.
5. The basaltic intrusion was soon followed by two intrusion pulses with marginal and central rhomb porphyry respectively, which represent different stages of magma mixing or different levels in the magma reservoir. A second intrusion pulse can also be observed in some dikes of dolerite, viz. the porphyritic parts of these dikes.

This sequence of events implies the presence of vast areas of Oslo plutons (kjelsåsite-larvikite) beneath the granite of northwestern Bohuslän. Gravimetric and magnetic measurements made by G. Lind, Laboratory of Applied Geophysics, Aarhus University, along an E–W profile across the Kosteröarna islands indicate a probable eastward extension of the Oslo plutonic rocks to the area between Koster and Strömstad (Lind: personal communication).

Oftedahl (1952, p. 62) concludes that magmas of monzonitic, nepheline-monzonitic, and syenitic compositions have existed in the Oslo region at the same time. Regarding the alternating intrusions of basalt and rhomb porphyry Oftedahl (loc. cit.) says: "Another problem of magmas is suggested by the alternation of basalt and rhomb porphyry lava flows: The co-existence of monzonitic and basaltic magma in the upper crust . . . The monzonitic magmas formed in the crust, in connection with rejuvenation of fault movements on old continental fracture lines. Large masses of monzonitic magma worked its way towards the surface. Simultaneously the fractures opened up through the sialic crust to permit ascent of basaltic magma.

These "basaltic fractures" seem to be situated along the sides of the fractured graben zone. Then magma from the basaltic fissures and from the central, monzonitic magma chamber reached the surface alternatively to form the complexely built lava plateau. It is still possible that a mixing of the two magmas gave origin to the andesitic lava RP 13 (the recangle porphyry)."

The formation of the rocks in the Swedish rhomb porphyry dikes as interpreted by the writer is not in accordance with Harnik's (1969, p. 552) conceptions regarding the RP-lavas and the Tyveholmen dike. Therefore it does not seem possible to use the present model for general statements concerning the formation of the vast areas of RP-lavas in the Oslo district (cf. Saether 1962, p. 37–46). Saether (op. cit., p. 154) here makes an important statement: "On the whole it is certain that most of the rhomb porphyry dikes, which occur in the investigated area (and perhaps all of them), have been formed at a far later stage in the igneous history of the Oslo region than the lava series. They cannot have been feeders of rhomb porphyry flows in the known lava series. They must have been formed by re-melting processes (as shown by the above mentioned dyke 8) in connection with the evolution of the younger deep-seated rocks in the area concerned.

This result does not contradict the existence, in other parts of the Oslo region, of rhombporphyry dikes which have really been feeders of lava flows (cp. p. 44)."

It is interesting to note Oftedahl's (1946, p. 40 and Fig. 25) observation that the rhomb-shaped phenocrysts of the Tyveholmen dike, Oslo, have both a plagioclase and an alkali feldspar rim.

The writer has visited the Oslo district only during two short excursions. On the second one the large rhomb porphyry dikes were examined at some localities. In a few cases they seem to consist of more than one type of rock. One sample was taken from the large dike at the sea shore south of Grimstad. Only one type of rock here occupies the whole width of the somewhat irregular dike. This rock was partly analysed together with the samples from the Swedish dikes (Table 3, no. 45). The results are in agreement with RPc from locality no. 35 (Table 3), which is the most alkalirich of the investigated dike rocks. In connection with this observation the differences in composition between the RP rocks of localities no. 35 and nos. 20–31 should be noted. The former locality is the northernmost RP-dike investigated, and the latter belongs to the southernmost RP-dikes investigated. In spite of the differences in composition, the genesis of the rocks is the same.

Another indication that the observations now recorded may have general applications to problems concerning the Oslo graben is displayed by the large RP-dikes, which to the north, southwest, and southeast of the subsided area in their terminal parts have a continuation of dolerite dikes (Oftedahl 1952, p. 47).

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Table 1 Width of the dolerite and rhomb porphyry dikes and their different components. The numbers in the first column refer to the map and Table 3. Da = non-porphyritic margins of dolerite dike, Dp = porphyritic central part of dolerite dike, Dm = doleritic margins of rhomb porphyry dike, RPm = marginal rhomb porphyry, RPc = central rhomb porphyry

No in Table 3	Locality	Width in m. Total	Da	Dp	Dm	RPm	RPc	Remarks on the contacts and page of description
5	Dolerite, 200 m. S of the fishing harbour of Hasselösund, Smögen	1						Non-porphyritic dike (p. 5)
6	Dolerite, 1.2 km. S of the triangulation point on Tryggö, Sotenäset peninsula	1.3						Non-porphyritic dike (p. 7)
7, 8	Dolerite, 4.3 km. ESE of Fjällbacka church	10						Altered dolerite with few plagioclase phenocrysts (p. 7)
9, 10	Porphyritic dolerite, Gerlesborg, 2.5 km. NE of Bovallstrand church	11	0.6	9.8				No sharp contact between Da and Dp (p. 8)
11–14	Porphyritic dolerite, Lyrön, S. Orust	≈10	≈1	≈8				Contact zone (0.3 m.) with xenoliths of i. a. rhomb-feldspar (p. 9)
–	Porphyritic dolerite	0.2						Small dike with porphyritic "streams" occupying alternating central and marginal positions (p. 11)
16–19	Porphyritic dolerite, Valön, WSW of Svenneby	>8						Doleritic dike very rich in different xenoliths, i. a. rhomb-shaped feldspar (p. 19)
20–32	5 km. SW of Hunnebostrand church	32			1	7	16	Contacts in part covered with lichens (p. 19)
–	Tryggö, 4.5 km. NNW of Kungshamn church	30			0.5	6	17	Rather distinct contacts
33–35	Raftötången, 2.5 km. N of Havstensund chapel	13			0.5	3	6	The width of the Dm-RPm contact is 0.3 m. The RPm-RPs contacts are distinct (p. 16)
–	1 km. SW of Grebbestad church	17			1	2.5	10	Contacts are diffuse
–	1.7 km. SSW of Grebbestad church	30			1	4	20	Contacts are diffuse
–	1.1 km. N of Hamburgsund chapel	40			0.6	3	33	The Dm-RPm contact is diffuse The RPm-RPc contact is distinct
–	2 km. SW of Hamburgsund chapel	>18			1	7	>10	The contacts are diffuse
–	4 km. WSW of Hunnebostrand church	30			0.6	7	15	Distinct contacts. Dm partly occupies separate dikes (p. 17)
36	Skogen, 4.5 km. NNE of Kungshamn church	≈20			0.6	≈5	>3	The contacts are diffuse 300 m. to the north of this locality RPc occupies a separate dike (1.5 m.) (p. 19)
40	Vägga, 2 km. E of Kungshamn church	≈30			0.7	5	19	The Dm-RPm contact is diffuse The RPm-RPc contact is distinct

Table 2 a Chemical analyses, percent by weight. Analyses I and III—VII have been carried out at the laboratories of SGU, Stockholm (P.-E. Isaksson and G. Svedbäck), no. II by AB Analytica, Sollentuna (I. Nilsson), nos. VIII—XIX by the Geological Institute, Aarhus University (S. F., I. V., and I. F.)

	I	II	III	IV	V	VI	VII	VIII	IX	X
SiO_2	43.3	47.4	45.5	51.3	56.4	56.6	58.5	49.05	49.10	50.00
TiO_2	4.07	2.3	4.18	2.75	1.91	1.11	0.78	3.62	3.09	3.57
Al_2O_3	13.2	19.4	14.2	16.4	17.2	21.3	20.8	13.79	14.65	14.07
Fe_2O_3	9.3	4.1	6.0	4.2	3.2	1.4	1.5	5.79	5.68	5.47
FeO	7.5	5.0	8.3	6.2	4.3	2.6	1.8	7.06	5.58	6.90
MnO	0.25	0.13	0.23	0.18	0.17	0.08	0.07	0.17	0.17	0.16
MgO	5.6	4.65	5.6	3.7	2.5	1.7	0.94	5.53	4.81	4.88
BaO	0.10	–	0.04	0.07	0.08	0.08	0.11	–	–	–
SrO	0.04	–	0.03	0.03	0.03	0.04	0.04	–	–	–
CaO	9.0	10.7	7.9	6.1	4.9	6.6	5.2	6.01	8.44	6.10
Na_2O	2.9	2.79	4.0	4.1	4.7	5.4	6.3	4.34	3.37	4.24
K_2O	1.0	0.95	0.8	2.7	3.7	2.6	3.0	1.82	1.35	1.93
H_2O+	2.9	1.95	2.7	1.4	1.0	0.7	0.4	–	–	–
H_2O-	0.5	0.31	0.4	0.3	0.2	0.2	0.1	–	–	–
P_2O_5	0.56	0.49	0.47	0.65	0.32	0.36	0.27	–	–	–
CO_2	–	<0.1	–	–	–	–	–	–	–	–
Sum	100.22	100.27	100.35	100.08	100.61	100.77	99.81			

	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX
SiO_2	49.39	46.12	55.25	60.03	59.25	60.03	57.98	60.08	51.53
TiO_2	2.95	4.84	2.80	1.76	0.96	0.73	1.22	0.84	0
Al_2O_3	15.05	13.19	15.44	16.62	19.36	19.81	19.40	19.96	27.48
Fe_2O_3	5.84	5.15	2.90	0.37 }	Fe_2O_3 }	Fe_2O_3	0.76	1.07 }	Fe_2O_3
FeO	5.22	9.58	6.20	5.48 }	3.20 }	2.44	3.20	1.46 }	0
MnO	0.14	0.16	0.13	0.12	0.06	0.06	0.07	0.06	0.02
MgO	4.61	4.85	3.36	1.83	1.00	0.65	1.25	0.60	0.20
CaO	8.51	8.46	5.61	3.88	5.06	4.65	5.74	4.75	9.05
Na_2O	3.38	4.03	4.75	5.60	6.40	6.38	6.13	6.77	3.74
K_2O	1.36	0.76	3.01	4.27	2.81	3.18	2.55	3.06	2.83

Table 2 b Contents of trace elements in p.p.m. in some of the rocks of Table 2 a

	I	III	IV	V	VI	VII
Co	50	60	50	40	15	10
Ni	35	35	45	30	15	5
Cr	10	5	15	20	< 5	< 5
V	550	550	350	250	150	80
Cu	50	55	60	40	25	15
Pb	40	50	30	30	20	20
Zn	130	150	130	130	60	40
Ag	< 3	< 3	< 3	< 3	< 3	< 3
Sn	< 5	< 5	< 5	< 5	< 5	< 5
Bi	< 5	< 5	< 5	< 5	< 5	< 5
Mo	<10	<10	<10	<10	<10	<10

Table 2 c C.I.P.W. norms

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XVII	XVIII	XIX
Q	0.9	–	–	0.3	2.2	–	–	–	4.4	1.1	4.3	–	1.3	–	–	0.1	–
or	6.1	6.1	4.5	16.1	21.7	15.6	17.8	10.6	7.8	11.1	8.3	4.5	17.8	25.6	15.6	18.4	16.9
ab	24.6	23.6	34.1	34.6	39.8	45.6	52.4	36.7	30.0	35.6	28.8	34.1	40.4	47.2	51.9	57.1	31.0
an	19.7	37.3	18.4	18.4	15.0	26.1	19.5	12.8	21.1	13.9	21.7	15.6	11.7	7.5	17.5	15.0	44.8
ne	–	–	–	–	–	–	0.6	–	–	–	–	–	–	–	–	–	0.6
ol	–	–	6.2	–	–	2.6	1.2	3.8	–	–	–	8.5	–	3.7	2.7	–	0.8
di	16.6	9.7	13.7	6.0	6.0	3.2	3.6	10.6	13.2	10.1	13.2	18.3	10.1	8.4	6.7	3.2	–
hy	6.2	9.3	2.4	10.0	5.7	2.2	–	8.5	6.4	9.8	5.4	2.9	8.0	4.8	1.4	–	–
mt	13.2	6.0	8.8	6.0	4.6	2.1	2.1	8.4	8.4	7.9	8.4	7.7	4.2	0.7	1.2	2.6	–
hm	0.2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
il	7.8	4.4	8.1	5.3	3.7	2.1	1.5	6.8	5.9	6.8	5.6	0.9	5.3	3.3	2.3	1.5	–
ap	1.3	1.3	1.3	1.7	0.7	1.0	0.7	1.3	1.3	1.3	1.3	1.3	1.3	0.7	1.0	0.7	–
wo	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.0	–
cr	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.9

Table 2 d Niggli values

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XVII	XVIII	XIX
si	101	118	110	143	176	175	196	128	129	134	131	114	162	200	191	208	162
qz	–31	–14	–34	–21	–9	–9	–12	–28	–15	–22	–13	–30	–14	–8	–9	–12	+28
ti	7	4	8	6	4	3	2	7	6	7	6	9	6	4	3	2	0
al	18	29	20	27	32	39	41	21	23	22	24	19	27	33	38	41	51
fm	50	35	49	39	31	18	13	48	43	46	41	48	37	26	17	12	2
c	23	29	20	18	16	22	19	17	24	18	24	22	18	14	20	18	30
alk	8	8	11	16	21	21	27	14	11	14	11	11	19	27	25	30	17
mg	0.38	0.50	0.41	0.39	0.38	0.43	0.33	0.44	0.44	0.42	0.44	0.38	0.40	0.46	0.36	0.26	0.56
k	0.19	0.15	0.11	0.31	0.34	0.24	0.24	0.21	0.21	0.23	0.21	0.11	0.29	0.34	0.22	0.23	0.33
p	0.56	0.60	0.58	0.86	0.37	0.56	0.40	–	–	–	–	–	–	–	–	–	–
w	0.52	0.42	0.39	0.37	0.39	0.33	0.41	0.42	0.48	0.41	0.50	0.33	0.30	0.07	0.18	0.52	0

List of rocks in Table 2 a—d. For localities see Fig. 1

I. Dolerite, Hasselösund, Smögen. See also Table 3: no. 5.
II. Porphyritic dolerite, central part of dike, Gerlesborg. See also Table 3: no. 10.
III Marginal dolerite in a rhomb porphyry dike, 5 km. SW of Hunnebostrand church. See also Table 3: nos. 20, 21, 32.
IV. Marginal rhomb phorphyry, the same dike as no. III. Se also Table 3: nos. 22–26, 31.
V. Central rhomb porphyry, the same dike as no. III. See also Table 3: nos. 27–30.
VI Rhomb feldspars from no. IV.
VII Rhomb feldspars from no. V.
VIII. Dolerite, 0.5 m. inward the western contact. Central part of Lyrön, Orust. See also Table 3: no. 11.
IX. Porphyritic dolerite, central part of the preceding dike (width 10 m.). See also Table 3: no. 12.
X. Dolerite, 0.1 m. inward the western contact. Southern shore of Lyrön, Orust. See also Table 3: no. 13.
XI. Porphyritic dolerite, central part of the preceding dike. See also Table 3: no. 14.
XII. Marginal dolerite in a rhomb porphyry dike (width 13 m.). 0.1 m. inward the western contact. Raftötången, 2.5 km. N of Havstensund chapel. See also Table 3: no. 33.
XIII. Marginal rhomb porphyry, the same dike as no. XII. See also Table 3: no. 34.
XIV. Central rhomb porphyry, the same dike as no. XII. See also Table 3: no. 35.
XV. Rhomb-feldspar from no. XIII.
XVI. Rhomb-feldspar from no. XIV.
XVII. Rhomb-feldspar from no. IV.
XVIII. Rhomb-feldspar from no. V.
XIX. Megacryst of plagioclase from the contact between marginal and central rhomb porphyry, 4 km. WSW of Hunnebostrand church.

Table 3 Partial chemical analyses executed at the laboratory of the Department of Geology, Chalmers University of Technology, using the atomic absorption-spectrophotometer (see p. 2). The results are given in percent by weight. a and b represent samples from the same locality. They have been prepared and analysed at different times

Sample no.	Ca	Fe	K	Mg	Mn	Na
1	6.9	10.8	1.3	6.9	0.12	0.7
2	6.6	10.8	0.9	8.1	0.17	0.5
3	7.5	13.4	1.0	6.9	0.13	0.2
4 a	6.4	13.9	0.5	7.0	0.17	0.42
4 b	6.4	13.8	0.5	7.0	0.17	0.45
5	5.2	9.5	0.6	3.0	0.16	1.8
6	5.0	11.0	0.6	2.9	0.14	1.9
7	4.4	8.9	0.6	3.1	0.15	2.8
8	5.5	8.7	1.0	3.0	0.14	3.5
9	4.9	9.0	0.8	2.9	0.14	2.8
10	6.6	6.9	0.5	2.5	0.07	2.0
11	3.9	9.0	1.1	3.4	0.15	2.9
12	4.5	8.5	0.9	3.3	0.15	2.3
13	4.0	8.5	1.2	3.1	0.14	2.8
14	5.3	8.3	1.0	2.8	0.12	2.0
15	5.3	5.0	1.6	0.7	0.01	3.2
16	4.6	9.2	0.6	2.7	0.13	3.0
17	3.3	9.4	0.9	2.8	0.14	2.9
18	4.9	9.2	1.0	2.9	0.13	2.3
19	5.6	8.5	1.0	3.1	0.14	2.2
20	4.5	10.8	0.3	3.4	0.16	2.6

Table 3 (Continued)

Sample no.	Ca	Fe	K	Mg	Mn	Na
21	4.9	9.9	0.5	3.0	0.15	2.7
22	3.7	8.7	1.6	2.8	0.14	2.9
23	3.6	7.8	1.7	2.3	0.15	2.8
24 a	3.9	7.6	1.6	2.3	0.12	2.75
24 b	4.0	7.8	1.6	2.3	0.12	2.63
25	4.5	7.8	1.6	2.2	0.12	2.6
26	4.0	7.7	1.7	2.0	0.12	2.6
27	3.3	5.7	2.3	1.2	0.12	3.1
28	3.2	6.0	2.2	1.3	0.05	3.1
29	3.4	5.6	2.1	1.3	0.05	3.0
30	3.4	5.9	2.3	1.3	0.13	3.1
31	3.9	7.8	1.6	2.1	0.12	2.6
32	5.0	10.4	0.3	3.0	0.15	2.5
33	4.6	11.0	0.4	3.3	0.14	2.7
34	3.8	7.0	1.9	1.9	0.12	3.1
35	2.6	4.6	2.8	1.1	0.11	3.7
36	5.5	9.0	0.5	3.4	0.15	2.9
37	4.5	6.3	1.9	3.1	0.14	2.4
38	4.4	8.0	1.7	2.6	0.12	2.9
39	3.1	5.6	2.5	1.7	0.11	3.1
40	5.0	11.0	0.6	2.8	0.13	2.0
41	4.0	7.8	1.7	2.2	0.12	2.6
42	4.0	8.1	1.5	2.2	0.13	2.6
43	3.0	5.6	2.3	1.3	0.11	3.1
44	2.7	5.3	2.7	1.3	0.10	2.5
45	3.0	4.6	2.7	1.1	0.11	3.5

Analysed samples in Table 3

1 Mafic dike, 5–10 cm. from the margin of the dike. 4.7 km. NW of Strömstad church.
2 Mafic dike, central part of narrow dike (width 0.5 m.). Kålhagsklovan, Hållö, Smögen.
3 Alnöitic dike, central part of dike (width 1.3 m.). Hålkedalen, 2 km. ESE of Strömstad church.
4 Mafic dike, central part of dike (width 1.1 m.). Valön, 2.8 km. SW of the old church of Svenneby.
5 Dolerite, central part of dike (width 1 m.). 200 m. S of the fishing harbour of Hasselösund, Smögen (p. 5).
6 Dolerite, margin of the dike (width 1.3 m.). The small island Kålen, 1.2 km. S. of the triangulation point of Tryggö, Sotenäset peninsula (p. 7).
7 Dolerite, the western margin of non-porphyritic dike (width 10 m.). Road cutting 4.3 km. ESE of Fjällbacka church (p. 7).
8 Dolerite, central part of the preceding dike.
9 Porphyritic dolerite, the eastern margin of dike (width 11 m.). Gerlesborg, 2.2 km. NE of Bovallstrand church (p. 8).
10 Porphyritic dolerite, the central part of the preceding dike.
11 Porphyritic dolerite, 0.5 m. inward the eastern contact of dike (width 10 m.). 200 m. S of Bot, Lyrön, Orust (p. 9).
12 Porphyritic dolerite, central part of the preceding dike.
13 Porphyritic dolerite, the western margin of the preceding dike, 500 m. to the south of locality no. 11.

Analysed samples in Table 3 (Continued)

14 Porphyritic dolerite, the central part of the preceding dike.
15 Xenolith, in the preceding dike.
16 Doleritic dike rich in xenoliths, 0–0.1 m. from the western margin. Valön, 2.3 km. WSW of the old church of Svenneby (p. 19).
17 1 m. from the western margin of the preceding dike.
18 3 m. from the western margin of the preceding dike.
19 8 m. from the western margin of the preceding dike.
20 Marginal dolerite, 0.1 m. from the western margin of a rhomb porphyry dike (width 32 m.). Hällingedalen, 5 km. SW of Hunnebostrand church (p. 19).
21 Marginal dolerite, 0.5 m. from the western margin of the preceding dike.
22 Marginal rhomb porphyry, 1.0 m. from the western margin of the preceding dike.
23 Marginal rhomb porphyry, 2.0 m. from the western margin of the preceding dike.
24 Marginal rhomb porphyry, 4.0 m. from the western margin of the preceding dike.
25 Marginal rhomb porphyry, 5.0 m. from the western margin of the preceeding dike.
26 Marginal rhomb porphyry, 6.5 m. from the western margin of the preceding dike.
27 Central rhomb porphyry, 8.1 m. from the western margin of the preceding dike.
28 Central rhomb porphyry, 11.5 m. from the western margin of the preceding dike.
29 Central rhomb porphyry, 14.0 m. from the western marginof the preceding dike.
30 Central rhomb porphyry, 16.0 m. from the western margin of the preceding dike.
31 Marginal rhomb porphyry, 2.0 m. from the eastern margin of the preceding dike.
32 Marginal dolerite 0–0.5 m. from the eastern margin of the preceding dike.
33 Marginal dolerite 0–0.1 m. from the eastern margin of a rhomb porphyry dike (width 13 m.). Raftötången, 2.5 km. N of Havstensund chapel (p. 16).
34 Marginal rhomb porphyry, from the eastern margin of the preceding dike.
35 Central rhomb porphyry, 5.5 m. from the eastern margin of the preceding dike.
36 Marginal dolerite, the western margin of a rhomb porphyry dike (width 10 m.). 150 m. E of the farm Skogen, 4.5 km. NNE of Kungshamn church (p. 19).
37 Marginal rhomb porphyry, 0.6 m. from the western margin of the preceding dike.
38 Marginal rhomb porphyry, 5 m. from the western margin of the preceding dike.
39 Central rhomb porphyry, the central part of a narrow dike (width 1.6 m.) 3 m. to the east of the preceding dike.
40 Marginal dolerite in apophysis (width 5 cm.) from the margin of a rhomb porphyry dike (width 30 m.). Vägga, 2 km. E of Kungshamn church.
41 Marginal rhomb porphyry, 5 m. from the eastern margin of the preceding dike.
42 Marginal rhomb porphyry, from the preceding dike.
43 Central rhomb porphyry, from the preceding dike.
44 Central rhomb porphyry, central part of a narrow dike (width 1.5 m.). The island Fånyt, 800 m. S of the triangulation point on Tryggö, Sotenäset peninsula (p. 19).
45 Rhomb porphyry, central part of a rhomb porphyry dike (width 30 m.). Homburgsund, 12 km. S of Grimstad, Norway (p. 38).

Table 4 Estimated accuracies of the analyses in Table 3. The results have been obtained from 25 analyses of the same rock, viz. a granitic augen-gneiss. The investigation have been made by Dr. B. Ronge, Department of Geology, Chalmers University of Technology, Gothenburg

Elements	Mean value, weight percent	Accuracy, percent of value indicated
Ca	0.64	±8
Fe	2.26	±2
K	3.69	±4.5
Mg	0.27	±2
Mn	0.28	±3
Na	1.87	±4

Table 5

Rock type	No. in Table 3
Dolerite	5
Porph. dolerite	10
Porph. dolerite	14
RP - Dm	18 - 19
Dm	21
RPm	23 - 24
RPm	25
RPm	26
RPc	27 - 28
RPc	28 - 29
RPc	30
Dm	33
RPm	34
RPc	35
RPm	38
RPc	39
RPc	44

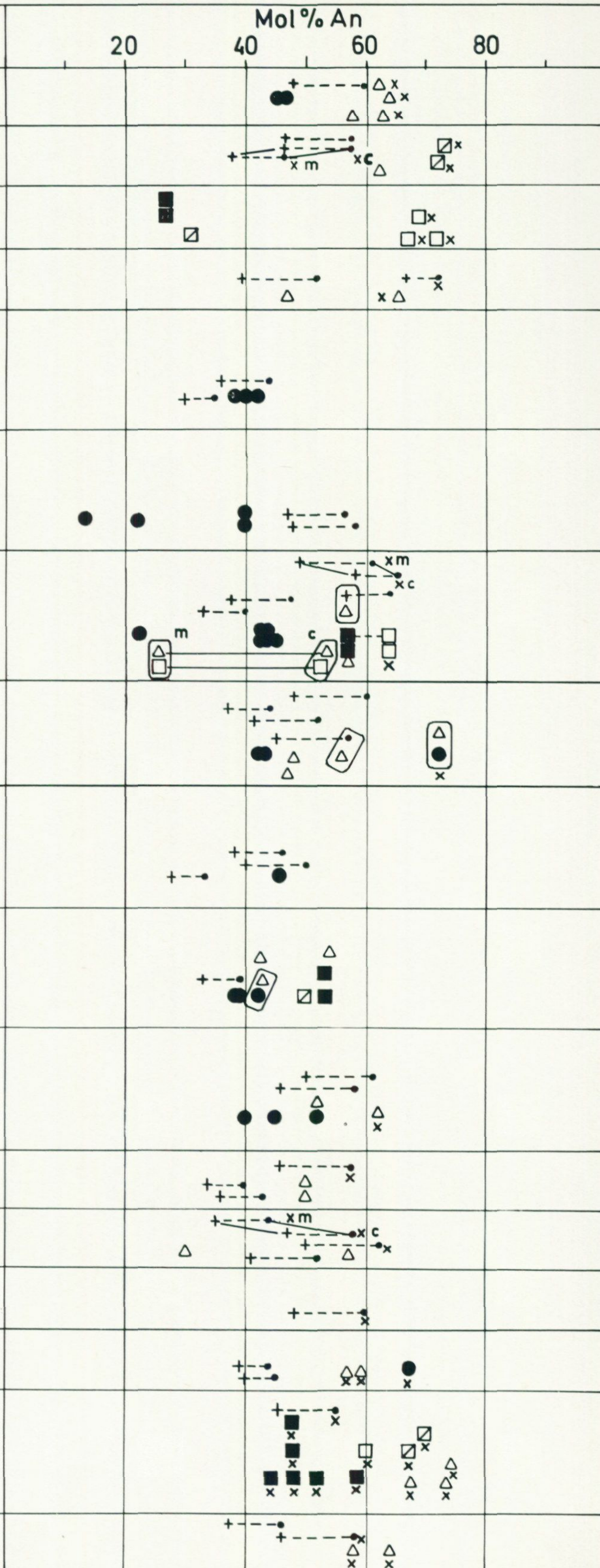

Table 5 The compositions of the plagioclases according to different optical methods. The rhomb-shaped feldspars are not included

● Refractive indices (Deer-Howie-Zussman 1963, Fig. 49)
△ Extinction angles of combined Carlsbad-albite twins (op. cit. Fig. 56)
• Extinction angles in the zone ⊥ (010). Low temp. (Tröger 1959, p. 111)
+ Extinction angles in the zone ⊥ (010). High temp. (loc. cit.)
□ Orientation of indicatrix. Low temp. (Tröger, 1959, Beilage I–II)
■ Orientation of indicatrix. High temp. (loc. cit.)
▨ Orientation of indicatrix. High or low temp. form could not possibly be determined (loc. cit.)
- - - connects An-values according to the high and low temp. curves, when the method does not give the character
—— connects different measurements in a zoned crystal
[△ ●] The line encloses different measurements of the same crystal
× Indication of phenocrysts or xenocrysts
c Central part of zoned crystal
m Marginal part of zoned crystal

Table 6 Optical data for different feldspars of the rhomb-shaped phenocrysts. The first half of the table refers to the measurements made by Ljungner (1927). The second half of the table contains observations from the present investigation. The tentative interpretation has been made according to the tables in Tröger (1959) and Deer-Howie-Zussman (1963). HT and LT refer to high- and low-temperature forms respectively

	Refractive indices	$\alpha' \wedge [100]$ on (001)	$\alpha' \wedge [100]$ on (010)	Maximum in zone ⊥ to (010)	2 V	Orientation of indikatrix	Tentative interpretation
Ljungner (1927: pp. 49): "Hauptfeldspat" (No. 1 in Fig. 15)	$\alpha < 1.5445$ ($An_{<36}$HT & $An_{<33}$LT) $\beta > 1.5445$ ($An_{>25}$HT & LT)	0° (An_{40}HT, An_{30}LT)	0–1° (An_{30}HT, An_{27}LT)	$\alpha' \wedge$ (010) = = 17° (An_{29}HT, An_{33}LT)	$2V_{\alpha} = 75°$ (An_{30}HT)		Plagioclase An_{30}HT
"Zweiten Feldspat" (No. 5 in Fig. 15)	$\beta = 1.529$	0°	+5°–+7°		$2V_{\alpha} = 64°$ ($Or_{65}Ab + An_{35}$)		Alkalifeldspar Or_{75}, Ab_{17}, An_{8}. (column 1 and 3) The orthoclase – low-albite serie
Inner zone (Nos. 2, 3, 2 in Fig. 15)	>"Hauptfeldspat"		–17° (An_{50}HT,LT)		Opt+		Plagioclase with max. in labradorite
Outer zone (No. 4 in Fig. 15)	< Inner zone				Opt–		Alkali feldspar
New determinations: Central part of core may contain: Plagioclase alone	$\alpha' = 1.543$ (An_{30} HT, LT)				$2V\gamma \geq 84°$ ($An_{<46}$HT, $An_{<37}$LT)	An_{30} between HT and LT (2 measurements) An_{30} (1 measurement)	Plagioclase An_{30} Intermediate to high temperature optics.

Clear plagioclase surrounded by	$\alpha' = 1.553$ (An_{49} HT, LT)					An_{51}HT	Plagioclase An_{50}HT
clouded alkali-feldspar	$\alpha' = 1.524$ ($Or_{48}Ab+An_{52}$) $\beta' = 1.528$ ($Or_{45}Ab+An_{55}$)						Alkalifeldspar abt. $Or_{48}Ab+An_{52}$
Plagioclase in unmixed part of core (No. 1 in Fig. 15)	$\alpha' = 1.543$ (An_{30}HT & LT)			$\alpha' \Lambda$ (010)= =31° (An_{57}LT, An_{45}HT)	Opt– $2V_{\alpha} = 70$	An_{28}HT	Plagioclase An_{30}HT
Alkali feldspar in unmixed part of core. (No. 5 in fig. 15)	$\alpha' = 1.523$ $\beta' < 1.535$ (abt. $Or_{60}Ab+An_{40}$)				$2V_{\alpha} = 60$–70 ($Or_{70}Ab+An_{30}$)		Alkalifeldspar Or_{65} $Ab+An_{35}$. The orthoclase – low-albite serie
Inner zone (Nos. 2, 3, 2 in Fig. 15)	$\alpha' > 1.543$ ($An_{>30}$HT & LT)				$2V\gamma = 83$–90 (An_{40-47}HT (An_{40-42}LT)		Plagioclase $An_{>40}$ probably HT
Outer zone (No. 4 in Fig. 15)	α' abt. 1.523 $\beta' < 1.535$ (abt. $Or_{60}Ab+An_{40}$)				$2V_{\alpha}$ abt. 70 ($Or_{60}Ab+An_{40}$)		Alkalifeldspar abt. $Or_{60}Ab+An_{40}$ (The orthoclase – low-albite serie)

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