Geological Survey of Finland

Bulletin 289

Shearing and multiple intrusion in the diabases of Åland archipelago, SW Finland

by Carl Ehlers and Mary Ehlers

Geologinen tutkimuslaitos · Espoo 1977

Geological Survey of Finland, Bulletin 289

SHEARING AND MULTIPLE INTRUSION IN THE DIABASES OF ÅLAND ARCHIPELAGO, SW FINLAND

BY
CARL EHLERS and MARY EHLERS

WITH 23 FIGURES, ONE TABLE AND ONE APPENDIX

GEOLOGINEN TUTKIMUSLAITOS
ESPOO 1977

Ehlers, C. and Ehlers, M. 1977: Shearing and multiple intrusion in the diabases of Åland archipelago, SW Finland. *Geological Survey of Finland, Bulletin 289,* 31 pages, 23 figures, one table and one appendix.

A set of narrow diabase dykes runs in a NE-SW direction outside the eastern contact of the Åland rapakivi massif. Chilled margins between adjacent dykes, composite dykes consisting of several intrusion phases, and areal differences in mineral composition show that the dykes were intruded in pulses of slightly different ages. Many dykes exhibit cataclastic right-hand shearing. A connection between this shearing and the intrusion of the rapakivi granites is suggested.

Chemically the dykes are rich in iron. Mineralogically they consist of hornblende and plagioclase with a subophitic texture. It is suggested that the diabases intruded as a very liquid, water-rich magma which rushed into fissures, resultning in rapid quenching at the contacts and slower crystallisation, possibly under rising water-pressure, in the central parts of the dykes. The pressure builds up until new fissures are formed and a new intrusion pulse is initiated.

It is conceivable that the diabase dykes are connected to the rapakivi granites but are a little earlier in their intrusion because of their lower viscosity.

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ISBN 951-690-071-2

Helsinki 1977. Valtion painatuskeskus

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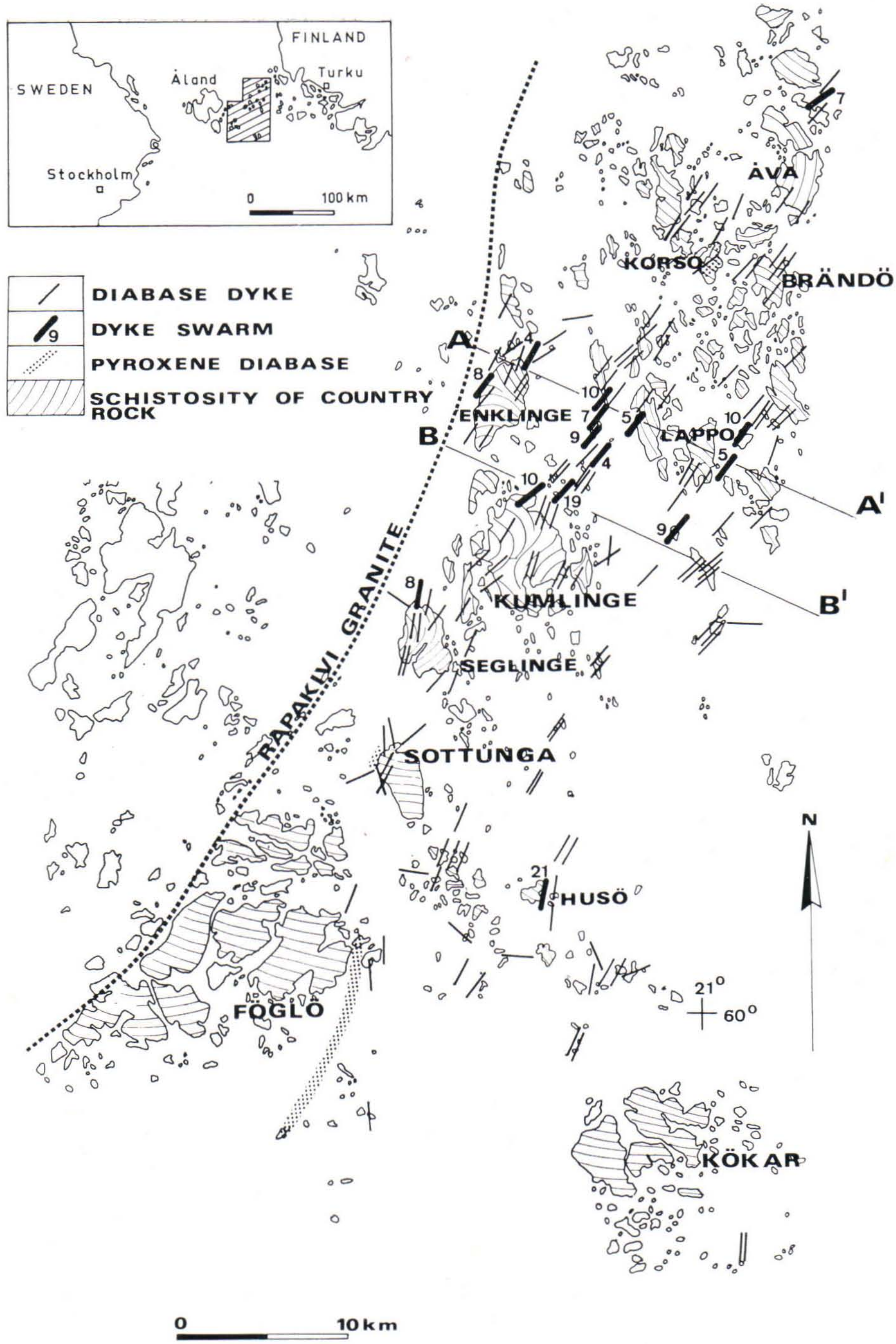

Fig. 1. Extent of diabase dykes in the eastern Åland archipelago.

INTRODUCTION

The diabase dykes in the eastern Åland archipelago, so-called trapp diabases, have been known since Åland was first mapped geologically (Moberg 1890, Frosterus 1894, Sederholm 1934).

The diabases form a SW-NE trending set consisting of more than 300 dykes. They occur densest close to the Åland rapakivi massif and thin out towards the SE (see Fig. 1). Hausen (1964) has described the dykes and discussed their origin. Further east in the Åboland archipelago there are only a few sparse diabase dykes most of which have already been studied (Laitakari 1921, Pehrman 1933, Törnqvist 1943, Edelman 1949, 1960, 1972, and Bergman 1973). There are also considerable numbers of diabase dykes to be found in the vicinity of Kustavi and Uusikaupunki (Gylling 1888, Hietanen 1943).

In this paper it is the densest areas where the dykes are to be found, in the communes of Kumlinge and Brändö, that have been studied in most detail. This is principally because the fieldwork and sampling have been carried out in conjunction with our geological mapping of sheet "1023 Kumlinge" which is being done for the Geological Survey of Finland. In addition we have amassed a large number of observations made by other geologists who have worked or are working in the Åland archipelago. The work of compiling these materials was begun by Prof. Hans Hausen, who kindly has placed his notes at our disposal. We have compiled all the observations in a list (Appendix 1) and plotted them on a map (Fig. 1).

The large pyroxene diabase dykes on Föglö, Sottunga, and on Korsö have not been studied in detail since they have, in part at least, been described earlier (Frosterus 1893, Wahl 1906, Sederholm 1934, Springert 1951, and Kaitaro 1953). Instead, we have concentrated on the numerous narrow dykes to be found in large numbers in the eastern part of the Åland archipelago.

GENERAL DESCRIPTION OF THE DIABASE DYKES

Width and length of the diabase dykes

The width of the diabase dykes varies from a few millimetres to 11 m. Most of the dykes, however, are about 1 m or less wide. From the diagram in Fig. 2 it can be seen that more than half the dykes are less than 1 m in width. Only 14 of the dykes exceed 5 m and only 4 are more than 10 m broad.

Outcrops in the area permit observation of the width of dykes in all cases but it is impossible to measure the length of individual dykes. Usually they are exposed only along a strip of shore a few metres wide and then they disappear under the water or vegetation. On the basis of aerial photographs and by studying individual dykes that are better exposed it is possible to arrive at a general estimate of the length of the dykes. On Bärö, east of Lappo, it has been possible to follow a dyke approximately 0.5 m broad (no. 287) a distance of some 300 m and another about 0.5 m broad (no. 163) on Högholm east of Enklinge likewise about 300 m. Further observations confirm that individual dykes are seldom more than a few hundred metres in length and usually much shorter. This agrees with what Currie and Ferguson (1970) observed about the length of diabase dykes.

Most of the diabase dykes lie en echelon (left-hand), Fig. 3 b, and often a new diabase dyke is found to begin alongside one that tapers out. The indi-

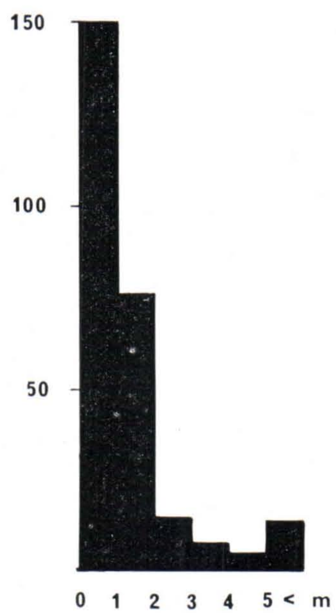

Fig. 2. Diagram showing the width of the diabase dykes. The number of dykes is indicated by the vertical axis, and the width in metres by the horizontal axis.

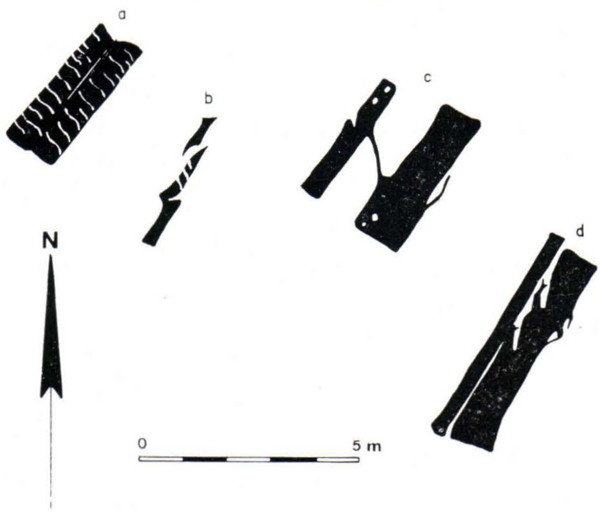

Fig. 3. Sketch map from Börsskär, NE of Kumlinge, showing part of a dyke swarm. a) cataclastic shearing along the dyke with sigmoidal schistosity (no. 131), b) left-hand en echelon structure (no. 135), c) (nos. 136 and 137), d) multiple intrusions: two diabases have intruded into the same fissure at different times. A thin strip of gneissose granite runs between the two dykes (nos. 138 and 139).

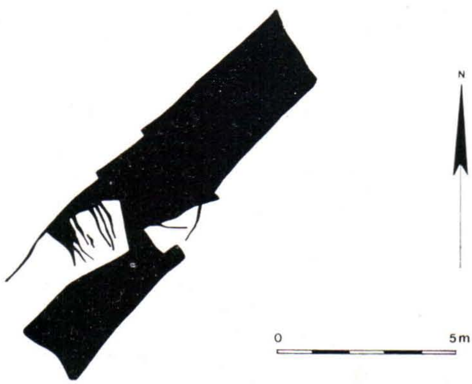

Fig. 4. Example from Långören of "horned offsets" (Currie & Ferguson 1970). The diabase has intruded into a pre-existing system of parallel fissures lying en echelon. The magma has forced its way from one fissure into another (no. 176).

vidual dykes are shaped like elongated lenses that become narrower and finally taper out. In many cases the dykes cease rather abruptly, breaking up into several branches that quickly taper out (Fig. 18). One dyke some 5 m broad (no. 163) ends in this way within a few metres. Different types of en bayonette structures are often to be found when one dyke ends and another begins (Fig. 4). Many diabase dykes have a large number of apophyses of differing thickness.

Even though the individual dykes are only a few hundred metres in length, or shorter, together they form swarms of dykes that can be followed for many kilometres (Fig. 1). It seems as if the densest part of the set of diabase dykes in the eastern Åland archipelago is made up of a number of smaller swarms.

The strike and dip of the diabase dykes

The strike of the dykes is very consistent. Rather more than 50 per cent of the dykes lie in the direction N 30—40 E and the remaining directions are distributed evenly around this peak (see Fig. 5). The directions of the dykes in the table in the Appendix are given in degrees from N to S via E.

The dykes in the southern parts of the eastern Åland archipelago (Kökar-Sottunga) seem to lie in a more N-S direction while those in the central parts, where the dykes are densest, are oriented more N 30—40 E. In the NE, in the Åva area, the direction is once more about N 20—30 E.

The pole diagram in Fig. 6 shows that most of the dykes dip steeply SE. The profile in Fig. 7 indicates that some of the dykes farthest west have a tendency to dip more to the SE (approx. 60°). Earlier observations usually only mention that the dykes dip steeply in those cases where the dip is referred to at all.

The strike of the dykes in relation to the schistosity and banding of the country rock can be seen from the map (Fig. 1). The strike is shown by means of thin lines drawn on the larger islands in the area. It can be seen that the dykes cut right through the older tectonic structures of the bedrock but that there is no

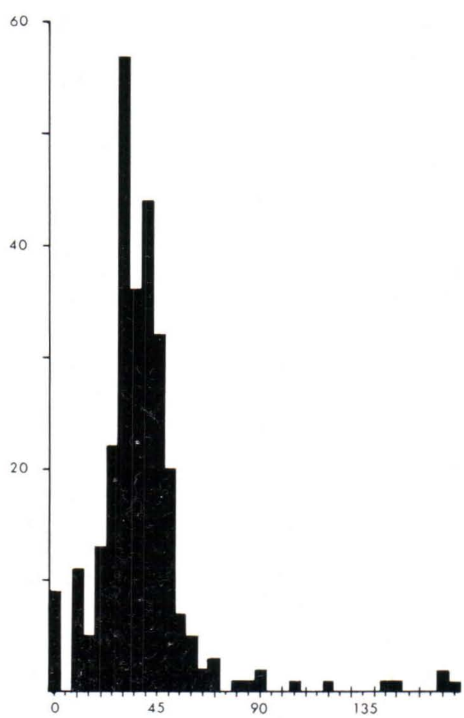

Fig. 5. Diagram showing the direction of the diabase dykes. Number of dykes on the vertical axis. Compass direction (N = 0°, E = 90° and S = 180°) in degrees along the horizontal axis.

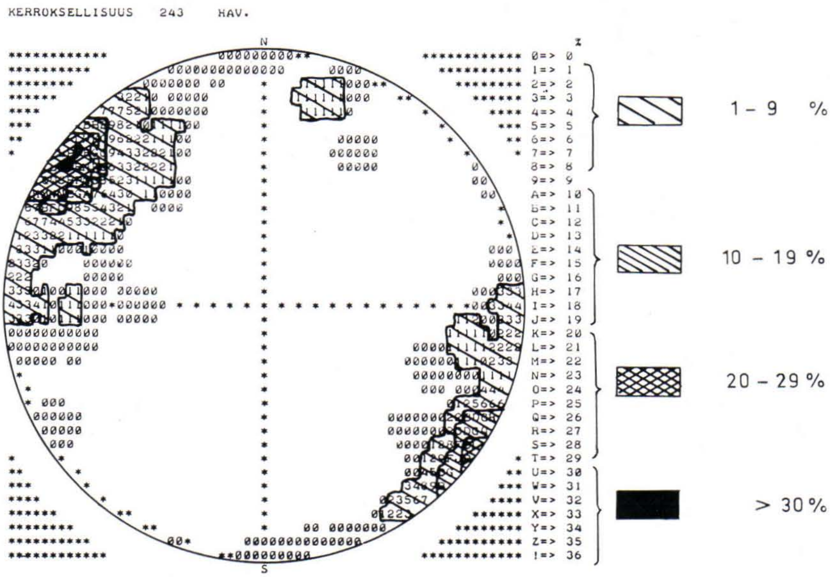

Fig. 6. Pole diagram of 243 measured diabase dykes. The diagram shows the consistent direction of the dyke swarms and the general, steep dip SE.

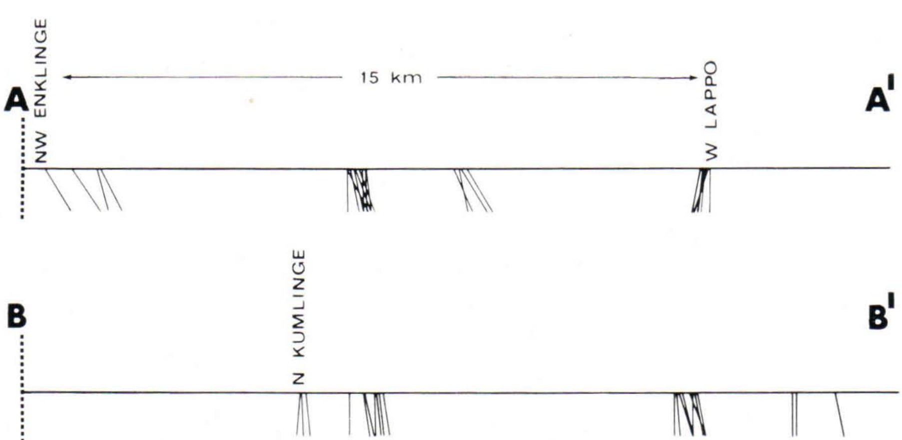

Fig. 7. Two profiles A-A' and B-B' (see fig. 1) cutting across the east Åland swarm of diabases. The profile shows quite clearly several sub-swarms. The sub-swarm on Enklinge dips more SE than diabases farther E.

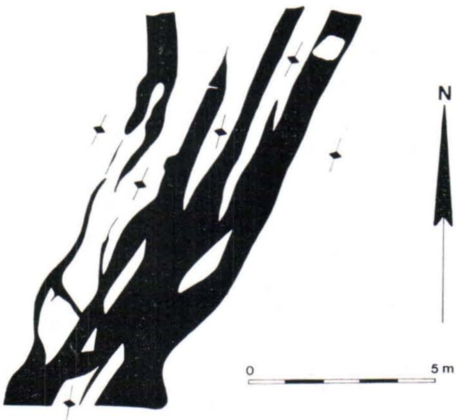

Fig. 8. Diabase dyke on Snäckö, SW of Kumlinge, which has intruded parallel to the schistosity of the surrounding gneisses. It contains numerous fragmnets of country rock (no. 107). The symbols show direction of strike and dip (vertical) in the country rock.

consistent tendency in relation to the bedrock (e.g. the Kumlinge-Enklinge area, and the circular structure on Åva). In spite of the fact that many of the dykes lie almost at right angles to the schistosity of the bedrock, this fact does not seem to have affected the direction of the dykes to any great degree. In some cases the strike of the surrounding rock has influenced the appearance of the diabases insofar as the diabase magma has penetrated into the plane of the schistosity (Figs. 8 and 9).

Contact conditions

As a rule the diabase dykes cut sharply through the country rock. Most of them are straight and have sharp parallel contacts. Many of the dykes have a stepped structure with narrower parts in a different direction (Figs. 11 and 18). This is clearly the result of the diabase magma opening up neighbouring, en echelon lying fissures that already existed and breaking up the rock lying between the fissures. The linking crack has consequently been split open less when the walls of the main cracks have been forced apart. In many places that the diabase magma has broken out of a parallel crack and into another before the end of the crack. The result is then so-called "horned offsets" as in Fig. 4, for example (see Currie & Ferguson 1970).

Approximately 11 per cent of the diabase dykes contain fragments of the surrounding rock. In all cases these xenoliths lie near the contact and consist of local country rock. The xenoliths are sharp-edged and generally have undergone little change macroscopically.

In the majority of cases the diabases have a fine-grained chilled margin 3—10 cm broad with the country rock. It is not possible to prove any relation between the width of the dykes and that of the chilled contact. In the fine-grained chilled

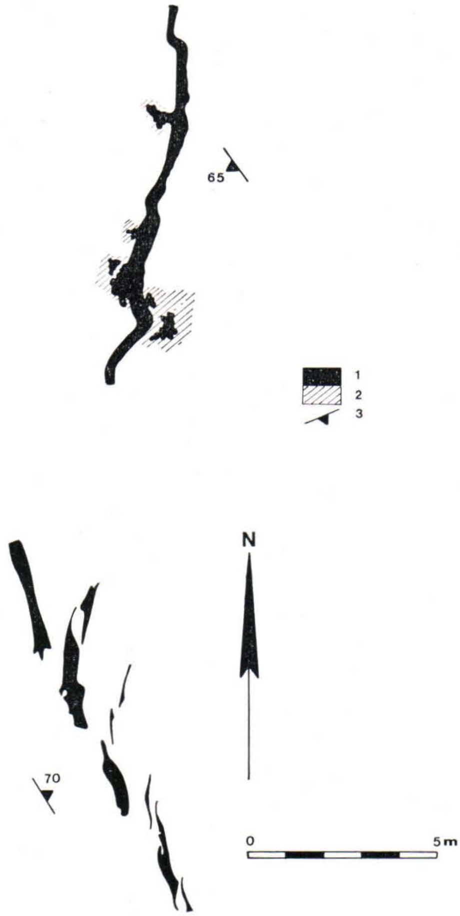

Fig. 9. Diabase dyke on Granskär, N of Enklinge. The N part shows evidence of local melting of the country rock in places where the dyke cuts through quartz blobs. The diabase forces its way into the quartz in the form of lobes and contains large (1—2 cm) quartz crystals. The dyke is unusually irregular and winding. In the S part can be seen an en echelon structure caused by the schistosity of the surrounding rocks. 1) diabase, 2) quartz blobs in gneissose granite, 3) strike and dip in the country rock (no. 225).

contact the plagioclase laths are usually parallel with the contact. This contrasts with the subophitic texture in the middle of the dykes, where there is no definite orientation. Many narrow dykes, those less than 10 cm wide, are in general fine-grained throughout and often lack chilled margins.

There is usually no indication that the diabase magma has affected the country rock. However, two exceptions to this have been observed in the Kumlinge-Enklinge area: a slightly winding diabase on Granskär N of Enklinge (no. 225, Figs. 9 and 10) cuts through a couple of quartz blobs in the surrounding gneissose granite. The diabase magma has obviously melted the quartz and as a result the diabase has expanded and contains large quartz crystals (Fig. 10). This diabase dyke does not have fine-grained chilled margins.

Fig. 10. Detail from Fig. 9; the picture shows quartz crystals in the dyke where it has become wider and melted quartz blobs in the country rock (no. 225).

A further example of how the diabase magma has penetrated the country rock can be seen on the island of Sälgören, NE of Kumlinge (Fig. 14). Here a 1—2 cm broad apophysis, forming part of diabase no. 150, has created a grey reaction rim a few millimetres in thickness in the surrounding gneissose granite (Fig. 15). The diabase dyke itself is not marked by a similar rim, only the apophysis.

Multiple intrusions

In some of the dykes the diabase magma has forced its way into the same crack on several occasions. This has led to differing results. One is that parallel diabase dykes have been formed that share the same fissure and have chilled margins against each other (Figs. 3d, 11 and 12). The chilled margin with neighbouring diabase dykes can be up to 10 cm wide and is quite comparable with the chilled margin between diabase dykes and the surrounding rock. In a few cases there is a narrow rim of country rock between the two phases (Fig. 3d).

A further result of multiple intrusions are different kinds of "composite dykes" resulting from different intrusion phases and built up concentrically within each other in the same fissure (Figs. 12 and 14). On Rosmunklobb NE of Kumlinge there is a diabase dyke some 8 m broad which consists of two intrusion phases. Along the contacts of the diabase there is a medium-grained subophitic type of diabase that becomes more coarse-grained farther from the contacts. This

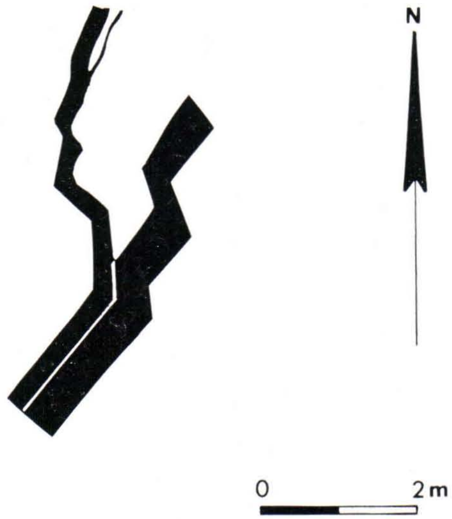

Fig. 11. Multiple diabase dyke on Långören. Two diabase intrusions with a thin wall of gneissose granite in between. Typical "stepped structure" where the dykes have moved between different parallel pre-existing fissures (nos. 179 and 180).

"marginal diabase" is about 0.5 to 1 m wide at each contact. Within this there is a finer-grained type of diabase containing feldspar phenocrysts and isolated quartz-filled irregular amygdales (Fig. 13). The contact between the fine-grained "central diabase" and the coarser "marginal diabase" is sharp but there is no chilled margin. The "central diabase" cuts into the coarse section of the "marginal diabase" and is of a later date. In this complex dyke there are aplitic blebs (Fig. 13) and curving dyke sections that usually lie at right angles to the direction of the diabase and that do not continue into the country rock (Fig. 12).

Another example of a "composite dyke" is that on Sälgören, Kumlinge (no. 150, Fig. 14). At its edges the dyke consists of a porphyritic diabase which has also filled fissures round the dyke with apophyses (Fig. 15). The core of the dyke is made up of another, rather more coarse-grained non-porphyritic type. The contact between the two types is sharp.

Intrusion mechanism

On the basis of stepped dykes that intrude into suitable parallel fissure systems that lie en echelon and jump in small steps from one fissure to another, Currie and Ferguson (1970) have proposed an intrusion mechanism characteristic of volatile and gas-rich magmas. They assume that there must exist a pressure head along an intruding dyke. If the magma comes into contact with a fissure in the surrounding bedrock or if it creates a new fissure, the gases rush into the fissure

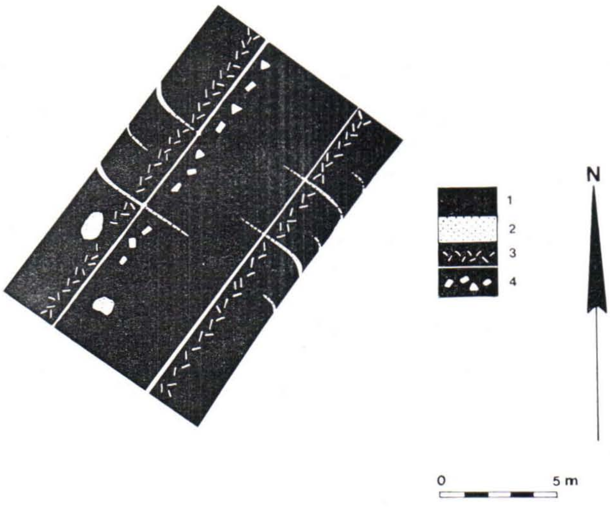

Fig. 12. A "composite dyke" on Rosmunklobb, NE of Kumlinge. The dyke consists of two types of diabase: a "marginal diabase" about 1 m wide, along the contacts and a "central diabase" about 5 m wide cutting through the marginal diabases. Aplitic dykes and lumps are present (see fig. 13). 1) diabase, 2) aplite, 3) coarse-grained "marginal diabase", 4) feldspar phenocrysts (nos. 154 and 155).

Fig. 13. Detail from Fig. 12. The "central diabase" cuts into the more coarse-grained "marginal diabase". Note the phenocrysts and the quartz vesicules in the "central diabase". An oval aplitic blob occurs in the contact between the different diabases (nos. 154 and 155).

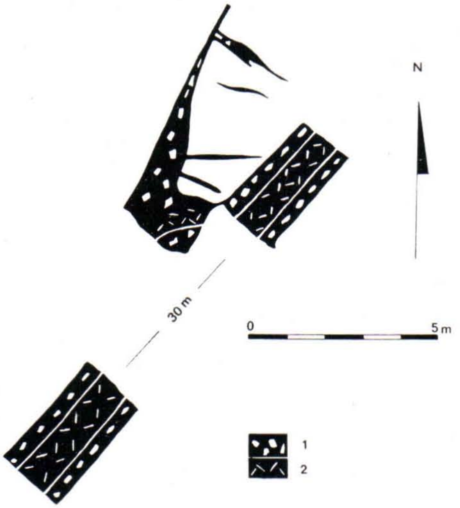

Fig. 14. "Composite dyke" on Sälgören, NE of Kumlinge. Here the dyke has a fine-grained "marginal diabase" about 50 cm wide with feldspar phenocrysts. In the middle there is a coarser subofitic diabase with sharp contacts with the "marginal diabase". Around a couple of the narrow E-W apophyses can be seen a thin rim of transformed country rock (Fig. 15). Phenocrysts of the marginal diabase" can also be seen even in the narrowest apophyses. 1) feldspar phenocrysts, 2) coarse-grained subofitic texture. (No. 150).

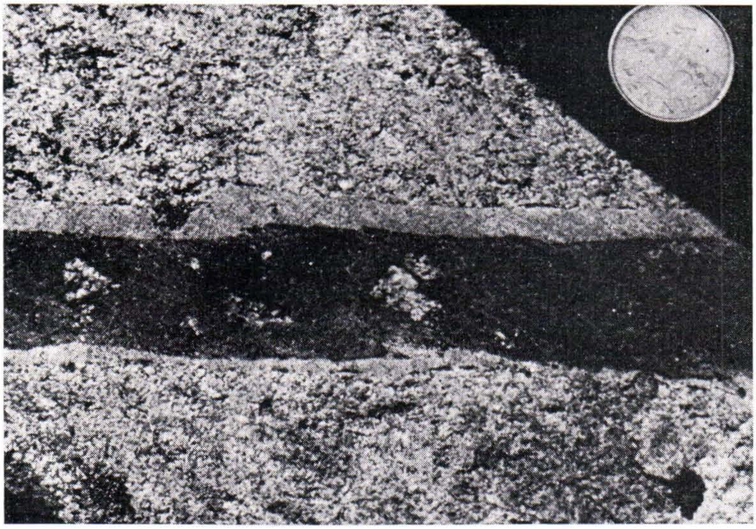

Fig. 15. A narrow apophysis forming part of the "marginal diabase" containing feldspar phenocrysts in dyke no. 150 (Fig. 14). Round the apophysis can be seen a narrow rim of transformed country rock.

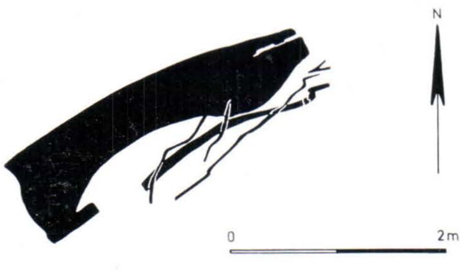

Fig. 16. Diabase dyke on Kumlinge. The apophyses cut each other and the dyke itself (nos. 146, 147 and 148).

and the pressure in the dyke falls: "such a drop in pressure at constant temperature must result in boiling off of a volatile phase. This volatile phase would rush down the fissure until arrested by the end of the channel, resulting in abrupt adiabatic cooling, and chilling of any silicate liquid droplets entrained in the fluid. Behind this initial explosive burst the water-saturated magma would advance through a fissure partially opened and cleared of obstruction. As the magma advanced, if the fluid phase was unable to escape, it would be reheated and redissolved in the magma, producing a water-saturated magma at considerably higher water pressure than that remaining after the initial devolatilisation." . . . "The adiabatic quenching resulting from the expansion of the boiled off gases will result in the formation of a thin layer of chilled silicate material along the margin" (Currie & Ferguson 1970, pp. 533—534).

If intrusion is arrested, the gas pressure will again rise and the chilled margins melt and disappear. Local melting of the surrounding rock may then occur.

The intrusion mechanism described here presupposes a local differentiation between a volatile phase with magma drops and a magma phase with a different chemical composition that follows and that may enrich the volatiles once more if they cannot penetrate further. This mechanism is supposed to produce thin chilled margins, possibly of a different chemical composition, e.g. contacts rich in carbonate. Likewise, it is to be expected that the tips of the thin apophyses would cause enriching of carbonates (Currie & Ferguson 1970).

The diabases in the Åland archipelago generally have a chilled margin up to 10 cm thick which gradually takes on the normal subophitic texture of the diabase the farther it is from the contact. No distinctive difference in chemical composition between narrow and wide dykes has been observed. Mineralogically the chilled margins are rather richer in hornblende than the central parts of the dyke (Table 1). In "composite dykes" the marginal diabases are 0.5—1 m thick and resemble both chemically and mineralogically the central diabase.

On northern Kumlinge there is a diabase dyke approximately 1 metre wide (no. 146) with several narrow apophyses (nos. 147 and 148). The apophyses belong to somewhat different intrusion phases and cut through each other (Fig. 16). One small apophysis can be seen to cut the chilled margin of the diabase dyke.

These observations suggest that the intrusion of the diabases in the Åland archipelago took place in a somewhat different manner. The diabases, probably in the form of a very liquid water-rich magma, penetrated fissures, resulting in rapid quenching at the contacts. The parallel feldspar laths within the margin suggest that the flow of magma into the fissures was laminar. Thereafter the magma continually forced the sides of the fissure apart and filled it from within with new material that crystallised more slowly and formed the characteristic subophitic texture. The pressure that was created as the fissure expanded and was filled results in the formation of new fissures which are in turn filled with liquid water-rich magma. A new pulse of intrusion into dykes 1—2 m wide where the core had possibly not hardened completely may be the explanation of the composite dykes described. The stepped structures and horned offsets that are common in the diabase dykes may well have been formed in the way described by Currie and Ferguson (1970) even though a liquid water-rich magma of the same composition as the main diabase magma filled the fissures in the surrounding bedrock rather than a gas phase.

Shearing along the diabase dykes

In many cases, and especially in the densest parts of the set of diabases there is evidence of a shearing movement that has taken place along the diabase dykes. The shearing is right-hand in the horizontal plane. The direction of shearing is always the same. This right-hand shearing can also be seen in the vertical plane in some cases. The movement has taken place at an angle of approximately 30° to the horizontal. The shearing can be seen since a number of the dykes have a sigmoidal cleavage which, at the contacts, often becomes a schistose shear zone a few centimetres thick (Figs. 3 a and 17). Under the microscope it can be seen that there has been cataclastic crushing of the diabase material at the same time as the formation of the sigmoidal schistosity. It is clearest close to contacts where curvature is strongest. In some cases a schistose shear zone several centimetres thick has been formed nearest the contact.

The amount of shearing in the horizontal plane is quite small. Displacements of 1.5—2 m have been measured but often the shearing is in all probability less. The amount of displacement can sometimes be measured if there are good markers in the country rock. In Fig. 18 several narrow quartz dykes on either side of the diabase dyke have been displaced in relation to each other. A large proportion of the diabase dykes lack any trace of shearing along the contacts and in such dykes the contact with the surrounding rock is sharp and there is no fissuring between the diabase and the country rock.

Suominen (1973) reports a different type of shearing of a diabase dyke from the easternmost swarm (E of Sottunga). This diabase runs through a layer of limestone surrounded by more brittle types of sedimentary rock. As a result of

Fig. 17. Shearing along a diabase dyke on Börsskär. Strong deformation can be seen in the curved sections of the dyke nearest the contact (no. 134).

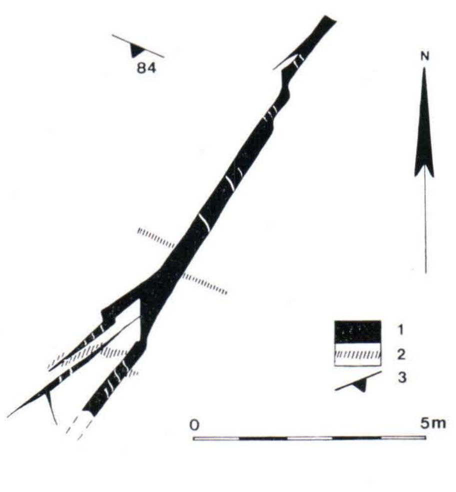

Fig. 18. Diabase dyke on Kogrundet, Börsskär, showing shearing with approx. 0.5 m displacement along the dyke. The dyke splits up into several small branches, which also exhibit shearing. The steplike structure and small apophyses are characteristic. 1) diabase, 2) quartz veins, 3) strike and dip in the country rock (no. 127).

pressure the limestone has been deformed and the diabase dyke broken into small sections along a series of left-hand shear zones (total offset 17.5 m) Another diabase dyke cuts through the same limestone zone without being affected by deformation. The deformation is, therefore, of the same age as the diabases while some of the diabases are younger than this deformation. It is difficult to say whether there is any connection between the deformation described by Suominen and the general right-hand shearing in the swarms. However, it is conceivable that the same forces that caused cataclastic shearing of certain of the diabase dykes may also have given rise to shearing in the relatively easily deformed limestone. The direction and type of shear fit in well as a conjugate direction of shear to the predominant right-hand shearing of the diabases.

The fact that not all the diabases have been subjected to shearing may be linked with the fact that they were presumably intruded at different times. Some of the dykes are perhaps of younger age than the shearing, or perhaps much older and more firmly "glued" to the country rock. Others were more recently intruded and perhaps more easily deformed. If the pressure is released through shearing along one dyke, then the strain on dykes in the vicinity is reduced so that they may escape shearing. The multiple diabases with chilled margins against each other also show that the diabases were intruded at different periods. This was Hausen's (1964) assumption, too.

The vertical shear component shows that the country rock on the NW side of the sheared dykes has been raised compared with the SE side. Shearing along the diabase dykes is obviously of later date than the intrusion of the dykes. Consequently, it is unlikely that there is any connection between the shearing and the en echelon position of the dykes.

DESCRIPTION OF TYPES OF ROCK

Mineralogy

Macroscopically the diabases are fine to medium-grained, black-grey or blac-green dykes that cut sharply through the older types of rock. The characteristic subophitic texture can often be distinguished with the naked eye on a weathered surface. In the chilled margins the plagioclase phenocrysts lie parallel to the contacts and form a flow structure (Fig. 19). A few isolated dykes are rich in phenocrysts of plagioclase (nos. 150, Fig. 14, 155 Fig. 12, and 158). A rather higher proportion (approximately 10 per cent) have quartz and/or calcite-filled amygdales about 1 mm in cross section. The subophitic texture is formed by plagioclase laths of andesine-oligoclase composition some mm or less in length. Between these there is a fibrous or fine-grained mass of green hornblende.

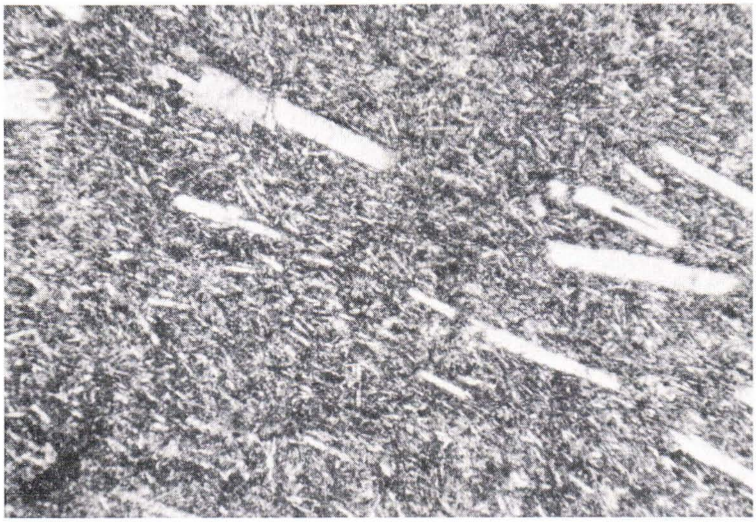

Fig. 19. Photomichograph of chilled margin; feldspar laths lie parallel to the contact. The intervening rock consists of fine-grained hornblende and small plagioclase laths.

Most of the dykes studied contain considerable amounts of opaque minerals, usually magnetite, but also pyrite. The magnetite is normally found as skeleton-like protruding needles and sometimes as irregular grains or fine pigment. The pyrite is found as isolated irregular grains or aggregates. The pyrite seems to have crystallised at a later stage than the magnetite and in places it replaces grains of plagioclase. The opaque grains are often surrounded by a rim of biotite. In addition to varying amounts of biotite, many dykes contain chlorite and also apatite and sphene.

Table 1

Modal analyses of two diabase dykes. The analyses show that the percentage of hornblende is higher near the contact while the plagioclase distribution is denser in the centre of the diabase. The mineral composition is typical of the densest swarms in the Kumlinge area (nos. 129 and 138).

Dyke no.	Margin 138	Centre 138	Margin 129	Centre 129
Amphibole	75.6 %	65.8 %	75.4 %	59.3 %
Plagioclase	14.3 »	29.1 »	16.8 »	34.6 »
Opaque	9.4 »	4.1 »	7.4 »	5.6 »
Biotite	0.6 »	0.6 »	0.3 »	0.4 »
Chlorite	0.4 »	0.6 »	0.1 »	0.2 »

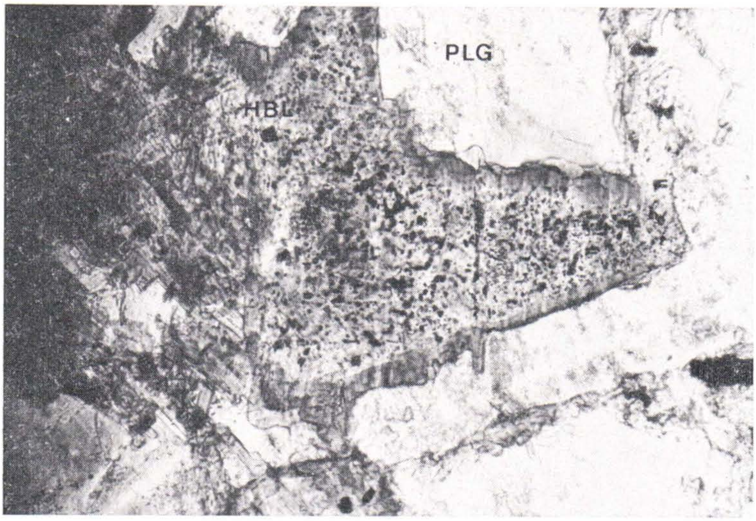

Fig. 20. Light fields of felty amphibole densely interspersed with magnetic pigment. The light fields are surrounded by a darker green border of crystallised hornblende. In certain cases there can be seen small residues of transformed pyroxene in the light fields (no. 320).

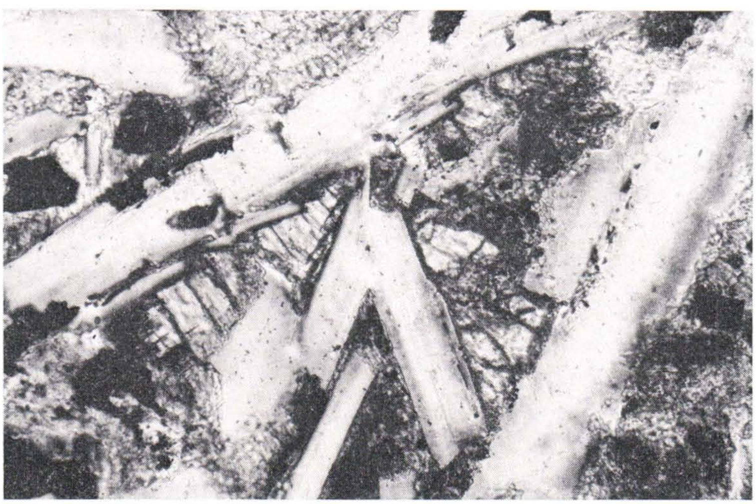

Fig. 21. Pyroxene in a diabase dyke approx. 1 m wide in the pyroxenic diabases of the Lappo area (no. 289).

Table 1 shows the mineralogical composition of the diabase dykes in the Kumlinge area. The difference in composition between the chilled margins and the cores of the dykes should be noted. In the central parts of the diabase dykes hornblende exists as dense, fibrous masses surrounded by plagioclase laths. Very

Fig. 22. Small prisms of hornblende forming a dense network between plagioclase borders. Note how the hornblende has grown into the pigmented and brown-coloured plagioclase (no. 136).

small grains of quarz lie interspersed in the fibrous hornblende. The fibrous hornblende often forms lighter parts in the middle with opaque pigments densely intersperced in it. The lighter parts (Fig. 20) are usually surrounded by a dark green rim of coarser-grained hornblende. The same appearance of hornblende is reported by Windly (1970) in "C-type dykes" among the so-called ferro-dolerites of western Greenland. The lightcoloured fibrous central parts seem to be alternation products from pyroxene. In some of the broadest dykes small residues of pyroxene can be found in the hornblende, or even whole grains of pyroxene (Fig. 21).

In general the fibrous or fine-grained hornblende extends over the rims of the plagioclase borders (Fig. 22) and in many places there are signs of resorption of plagioclase. The plagioclase is replaced by hornblende.

In the fine-grained chilled margins the proportions are somewhat different. In the chilled margin against the surrounding rock the plagioclase laths lie parallel to the contacts in a flow structure (Fig. 19). The plagioclase occurs partly as isolated grains several millimetres in length in a very fine-grained matrix of hornblende and plagioclase. The hornblende and plagioclase in the matrix have in places merged in a subophitic texture. The hornblende is fine-grained and consists of large numbers of small prisms. In the chilled margin there is generally no trace of pyroxene or of pseudomorphs. Nor do the fields of pale fibrous hornblende with green margins described earlier exist here. Instead the majority of the available evidence suggests that the hornblende in the chilled margins, at least for the most part, is primary and crystallised at almost the same time as the plagioclase. The isolated grains of plagioclase in the chilled margin are usually clear and exhibit only faint traces of resorption and ingrown hornblende. In the middle of the dykes, on the other hand, it is common for the plagioclase to be brown in colour and corroded and overgrown with hornblende.

Particularly in the chilled margins the diabase dykes are in their mineral composition and also to some extent in their texture very similar to the crystalline products of water-rich basalt melts obtained experimentally by Yoder and Tilley (1962). The contact zone with its relatively rapid cooling corresponds to a kind of "quenched sample" obtained by experiment. This agrees well with the intrusion mechanism already described and which presupposes a liquid water-rich magma that first rushes in, opens the fissure and forms a quenched border zone. The rest of the diabase magma then forces its way into the fissure, which, as long as the fissure remains tight leads to an increasing water pressure in the magma. This goes on until a new fissure opens and is filled by a new rush of diabase magma. This may account for the resorption of plagioclase, uralitisation and growth of hornblende that can be seen in the middle of many dykes. It may also provide an explanation for the primary hornblende in the marginal zones. In the diabases of the Kumlinge-Enklinge area pyroxene is to be found only sporadically and then usually as uralitised remains in the widest dykes.

Quartz/calcite-filled amygdales

Some 10 per cent of the diabase dykes contain small round amygdales filled with quartz or, more rarely, calcite. The amygdales are about 1 mm in diameter. In general they occur only sporadically but a few of the dykes are rich in amygdales. They are often surrounded by a rim of biotite.

The dykes that are rich in amygdales do not differ in their mineral composition from those that do not contain amygdales. The fact that amygdales can be found in some dykes indicates that the pressure in these was lessened, thereby causing the gases to begin to expand. Some of the diabases may possibly have extended to the surface. (see Watterson 1968 for discussion on vesicles and depth of emplacement of the dykes.) Edelman (1972) has described a spilitic dyke in the Åboland archipelago. The dyke is rich in amygdales and differes from other diabase dykes in direction but in other respects is similar. In some of the diabase dykes of the eastern Åland archipelago there are signs of spilitisation and albitic feldspars can be found in places.

Areal variations in mineral composition

As was pointed out earlier, pyroxene is usually not found in the diabase dykes of the Kumlinge area, where the set is densest. Apart from the large, broad pyroxene diabases on Föglö, Sottunga and Korsö, which are not dicsussed here, pyroxene is not a common mineral in the Åland diabases. However, there are certain variations in mineral composition in different parts of the area where the diabases are encountered.

In the Enklinge—Kumlinge—Lappo area it seems as if the set of diabases were divided into three smaller swarms with a high density of diabases separated by areas with fewer diabases (Figs. 1 and 7).

All the mineral samples studied (7 in all) from the dyke swarm E and S of Lappo contain remains of pyroxenes which fill the gaps between the plagioclase laths (Fig. 21). There is no pyroxene in a few samples taken from Husö, Sottunga, and from the swarm on Ljunskär S of Lappo. On the other hand, in the southern end of the same swarm Hausen has a report in his notes of a hypersthene diabase on Svinskär, N of Kökar. In all the descriptions of the isolated dykes to be found in the Åboland archipelago East of our study area there are reports of pyroxene (e.g., Laitakari 1921, Pehrman 1933, Törnqvist 1943).

In the dense dyke-swarms found on Kumlinge—Enklinge and up towards Åva pyroxene is almost entirely absent. Only in a few of the broadest dykes (nos. 220 and 226) can traces of pyroxene be seen in the middle of the dykes in the lighter, pigmented fields of hornblende between the plagioclase borders. (Altogether 50—55 samples were studied in the Kumlinge—Enklinge area). On northern Enklinge there are several diabases in which the plagioclases are almost entirely destroyed and which contain increasing quantities of chlorite and talc.

Generalising somewhat, it may be said that the pyroxene in the diabases seems to disappear westward. West of Lappo, i.e. towards the rapakivi contact, there is no pyroxene at all. Exceptions to this are the 100 m wide pyroxene diabases on Föglö and Korsö, of which mention has already been made. However, it should be pointed out that in the irregularly shaped Korsö massif there is a narrower section 6—8 m wide where there is no pyroxene. In the Lappo area the pyroxene seems to be completely independent of the width of the dyke and it is present in all the dykes studied, most of which are about 1 m broad. It would seem that there is an areal variation in the mineral composition of the diabases.

CHEMICAL COMPOSITION OF THE DIABASE DYKES

The earlier literature dealing with the diabases of the Åland and Åboland archipelago contains analyses (Frosterus 1893, Wahl 1906, Pehrman 1933, Törnqvist 1943, Springert 1951) but most of these analyses were made from the large pyroxene diabases.

In conjunction with this study a number of partial quantometer analyses were made of the diabases in the Kumlinge area by the Geological Survey of Finland. The result of about 60 of these analyses are shown in the form of an

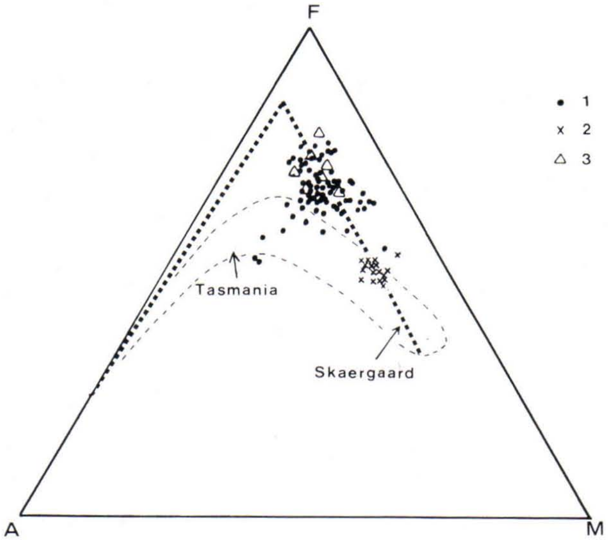

Fig. 23. AFM-diagram showing the composition of the iron-rich Åland diabases compared with the ferrodolerites of W Greenland (Windley 1970) and normal basalt composition according to Kuno (1968). Also included in the diagram are the differentiation trend of the Skaergaard intrusion and the differentiation area for some Tasmanian diabase sills. 1) the east Åland diabases, 2) normal basalt composition, 3) ferrodolerites on W Greenland.

AFM diagram (Fig. 23). The diagram shows that the diabases of the Åland archipelago are very rich in iron and that they differ considerably in their composition from the diabase analyses published previously. The ferrodolerites in the west of Greenland described by Windley (1970) are very similar in chemical composition. A proportion of the high iron content is present in the form of magnetite and pyrite (up to 10 per cent opaques) in the diabases. In the Skaergaard intrusion there are parts rich in iron, the composition of which is also rich in hornblende. This suggests strong fractionation of a basic magma at a low stage of oxidisation (Wager & Brown 1967).

The AFM diagram gives the results of the analyses not only of the Åland diabases but also of Windley's (1970) ferrodolerites in the west of Greenland and the differentiation trends in the Skaergaard massif and some diabase sills in Tasmania. It should be mentioned that, according to analyses published earlier (Frosterus 1893, Wahl 1906, and Springert 1951), the large pyroxene diabases of Föglö and Korsö fall within the same area on the AFM diagram and chemically they closely resemble the trapp diabases.

DISCUSSION

The strongly iron-rich composition suggests that the dykes of the diabase set were formed by basaltic magma that was already greatly diffenrentiated. The chemical variations within the set are small and it is hardly possible to prove any differentiation differences between different parts of the set.

Yoder's and Tilley's (1962) experimental results show that natural olivine-tholeiitic or aluminium-rich basalts crystallise as amphibolitic rocks at high water pressure. Amphibolitic types of rock begin to crystallise when the water pressure exceeds 1500 bars. However, there are no experimental results that are directly applicable to basaltic magmas very rich in iron. In an iron-rich magma the pyroxene, for example, must crystallise at a lower temperature: this may lead to the hornblende crystallising in a primary form at a lower water pressure (cf. Yoder and Tilley 1962, p. 449, fig. 27).

It is quite clear that a part at least of the plagioclase crystallises at an early stage; in the fine-grained chilled margins in particular where a clear flow structure has been formed from earlier crystallised plagioclase this is evident. In the middle of the diabase dykes hornblende has often replaced the pyroxene entirely. Some of the hornblende may naturally be primary. This seems to be the case particularly in the fine-grained chilled margins. Here there are no traces of uralitisation and the hornblende is fairly well crystallised in small prisms that sometimes lie in the form of radial aggregates. In contrast to the middle of the dykes, residues or pseudomorphs of pyroxene have not been encountered in the chilled margins.

Table 1 shows the differences in mineral composition between the chilled margins and the centres of two diabase dykes 1—2 m in breadth. It can be seen that the proportion of hornblende in the marginal zone is larger and the amount of plagoioclase lower than in the middle of the dykes.

What has been said above suggests that the magma was very rich in water at the intrusion stage and that hornblende, at least in the chilled margins, crystallised in its primary form. The rapidly cooled chilled margins form a skin of "quenched rock" around the central part of the diabase dyke. The centre then crystallised more slowly and possibly under increasing water pressure. It is possible that this might explain the more worn and resorbed feldspars in the middle of the dykes. Crystallisation from the water-rich magma was slower there and some pyroxene has been formed. The pyroxene was later transformed into hornblende. In certain cases the chilled margin may have melted again as a result of which local melting of the surrounding rock may have ensued (Figs. 9 and 10). In general, however, it seems that the hot magma did not melt the bedrock.

The origin of the water in the basalt magma is obscure but it seems clear that it was present at the time of the intrusion of the diabase dykes. It is evident that there must have been great variations in water pressure in the diabase dykes. The pressure within a dyke must have varied as it pushed its way through the earth's crust, perhaps faster than the minerals had time to achieve equilibrium with the varying PT conditions. The water pressure is not just a function of the water content but it also depends on the pressure of the surrounding rock. When the magma comes into contact with a new system of fissures and rushes into them there may occur temporary reductions in the gas pressure in the magma. In a dyke E of Lappo (no. 289) there are a number of armoured relicts indicative of such rapid changes in conditions. The relicts are small brown, strongly pigmented mineral grains, some of which are marked by clear cleavage. These grains (olivine?) are encircled by a kelyphitic ring of pyroxene and hornblende. These have not been studied in detail.

As far as the areal variations in mineral composition are concerned, it is possible to speculate as to whether the rapakivi granite may have contributed to these in any way. As has been mentioned, there is no pyroxene in the densest dyke swarms closest to the edge of the rapakivi granite but it begins to appear at a distance of 15—20 km from the rapakivi. Thereafter pyroxene seems to be present in most of the diabases of the Åboland archipelago. On northern Enklinge there are several dykes that are greatly transformed and contain amounts of tremolite, talc and chlorite.

The trapp diabases have been assumed to be older than the rapakivi. This seems to be correct for the most part.

There are often small fragments of material resembling diabase encapsuled in the Åland rapakivi massif. Hietanen (1943) has described a locality 25 km NE of Åva in the northern contact of the Vehmaa rapakivi massif where there exist angular pieces of diabase in the rapakivi in abundance. Similar observations have been reported by Vorma (1975). Edelman (1960) and Bergman (1973) have described cases where aplite dykes from the Fjälskär rapakivi massif cut diabase dykes in the vicinity of the granite massif. However, Bergman (1976) is at present working on a study of a diabase dyke which seems to be of "intra rapakivi" age. It lies within the Åland rapakivi massif at the contact between two different types of granite and seems to be younger than the one granite intrusion but older than the other.

It seems probable that the diabases are of much the same age as the rapakivi granite and that an overlapping of intrusions has occurred. The diabase magma has penetrated the earth's crust much more quickly because of its lower viscosity. Consequently the diabases have intruded earlier than the rapakivi granites.

It is clear that another factor besides the spatial position determines the presence of pyroxene in the diabases. In the diabase swarms that cover Kumlinge and Enklinge, which are in general free of pyroxene, there are small residues of pyroxene in a few of the widest dykes. It seems as if the width of the dykes also affects the presence of pyroxene. This is quite in accordance with the suggested intrusion mechanism and it is also corroborated by the fact that the narrowest part of the Korsö diabase, which is elsewhere rich in pyroxene, lacks pyroxene.

There is a large gap between the size of the numerous trapp diabase dykes and that of the 2—3 large pyroxene diabases in the archipelago. The former achive a width of 10 m only in exceptional cases while the latter are usually more than 100 m wide.

The areal variation in mineral composition of the diabase dykes has no corresponding variation in chemical composition. If these mineral variations are not connected with a possible effect of rapakivi intrusion, then they must be the result of other causes directly linked with the conditions existing at the time of their intrusion. A question that might well be asked is whether the different dyke swarms are of somewhat different age and represent different intrusion pulses during which there were variations in water content, pressure, etc. The multiple diabase dykes show that the intrusions even within the individual swarms occurred at rather different periods.

Older dyke systems in the same direction can be seen on NW Enklinge, for example. They are schistose amphibolite dykes lying in the same direction as the diabase dykes which cut sharply through the older gneissose granites. They are probably older than the microcline granites. The amphibolite dykes are, however, intersected by the diabases, which do not in any case exhibit schistosity or lineation. W of Brändö, on Likholm, a diabase dyke approx. 1 m wide of a very different character has been observed. It differs from the other dykes of the swarm in that its contacts are very irregular and winding. Furthermore, there are clear signs of schistosity. The texture is amphibolitic as opposed to the normal subophitic diabase texture. The dyke is reminiscent of the diabases in its outward appearance but it is obviously more metamorphosed. It seems clear, however, that there are many generations of basic dyke intrusions in the area. The difference between amphibolite and diabase dykes is not distinct.

The right-hand shearing that has affected some of the diabase dykes can perhaps be seen in conjunction with the intrusion of the rapakivi granites. Field observations show that the same shearing also has a vertical component, which means that the surrounding rock on the NW side of the sheared dykes has been displaced upwards compared to those on the SE side. The diabase dykes have, it would seem, been intruded somewhat earlier than the rapakivi magma, some perhaps at the same time, and, when the rapakivi forced its way in, part of the pressure affecting the surrounding rock may have been released by shearing movements along the relatively recently intruded diabase dykes. The fact that not all diabase dykes are sheared may be seen as a sign that they are of somewhat later (or very much earlier) age than the shearing.

Several writers have pointed out the connection between the diabases and the rapakivi massifs (Edelman 1960, Bridgewater, Sutton and Watterson 1968, Laitakari 1969, Vorma 1975). It is clear that these intrusion phases are oriented in the same direction and they have some link. The form of the diabases and their occurrence show that they have been intruded into a tension field the maximum tension of which lay in the direction NW-SE. It has already been mentioned that the individual dykes are only a few hundred metres long at the most in the horizontal plane. In a horizontal pressure field it may be assumed that the fissures in part at least may extend considerably further downwards since the origin of the magma presumably lies several kilometres below the erosion level today. The direction of maximum pressure was probably in the direction NE-SW while minimum pressure was at right angles to this, approximately in a horizontal direction. This NW-SE direction is also at right angles to the direction of the rapakivi massifs in SW Finland. A closer study of diabases encapsuled in the rapakivi massif and more careful petrographic studies of the trapp diabases, the different rapakivi types and olivine diabases and a collation of existing material might cast more light on this complex intrusion system of basaltic and granitic magmas.

ACKNOWLEDGEMENTS

The authors wish to thank professor Nils Edelman for valuable discussions while the manuscript was prepared and for critically reading it.

Information about diabases was given by Professor Hans Hausen, Mr. Leif Bergman, Fil.lic. (Brändö), Mr. Leif Björk, M.Sc. (SW Kumlinge), Mr. Kurt Karlsson, M.Sc. (Sottunga) and Mr. Veli Suominen, Fil.lic. (Föglö, S. Kumlinge, Kökar and Sottunga).

The authors also wish to express their gratitude to Professor Herman Stigzelius for letting the manuscript be published in the Bulletin series of the Geological Survey of Finland.

Mr. Christopher Grapes, B.A. translated the manuscript into English.

Manuscript received 8 October 1976
Revised manuscript received 18 November 1976

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APPENDIX

APPENDIX 1

List of observed diabase dykes in Åland archipelago, SW Finland

Number	Parish	Coordinates X	Y	Name of locality	Known width m	Trend N→E degrees	Dip	Observer
1—2	Kökar	6640.20	503.00	Röjharun	0.1	0	80W	V. O. Suominen
3	»	6653.67	492.02	Träskskär	1.5	25	90	»
4	»	6653.70	492.00	»	0.5	30	90	H. Hausen
5	»	6657.35	493.53	Mälskär	5	10	90	V. O. Suominen
6	»	6657.54	493.56	»	2	30	80E	»
7	»	6657.50	495.60	Svinskär, Långskär	0.2	30	85E	»
8	»	6657.80	489.10		0.4	50	65S	»
9	»	6657.90	493.74	Antören	0.1—0.3	170	90	»
10	»	6658.20	494.90	Tistronhäran		40	85W	»
11	»	6658.23	488.84	Near Gusslan	1	70	90	»
12	Föglö	6645.1	447.30	W Sundskär	0.1—1	30	90	»
13—14	»	6648.0	479.6	Dödmanskär	3	175		Sederholm (1934)
15	»	6657.06	479.68	Rågskär	0.4	0	90	V. O. Suominen
16	»	6658.3	480.5	Långhäran	0.1	0	40E	»
17	»	6663.0	478.6	Gåsskärsklobb		20		H. Hausen
18	Sottunga	6656.40	485.70	Stenkläppen	0.5	40	90	V. O. Suominen
19	»	6657.10	485.34	W of Sundhära- kläppen	0.3	30	90	»
20	»	6658.00	484.15	E of S Hanskär	0.3			»
21	»	6659.32	485.30	Västerön	0.4	30	60S	»
22	»	6661.0	489.4	Gloskär, Husö				»
23—32	»	6661.3	490.0	Högklobben	0.05—0.5	10 30 105	90 80E 75S	»
33—36	»	6661.50	490.30	Dunminne	0.4	19		H. Hausen
37—40	»	6661.57	490.14	Flatskär	0.2—1.5	10		V. O. Suominen
41—42	»	6661.70	490.10	W Husö	0.3+0.9	0	70E	»
43	»	6661.80	489.92	»	0.5	40	80E	»
44	»	6661.80	490.45	SW of Bässkär	3	10	90	»
45	»	6661.80	490.44	»	0.3	10	90	»
46	»	6661.92	490.60	Bässkär	0.3	12		»
47	»	»	»	»	3	15		»
48	»	6662.16	483.64	S Betesön				»
49	»	6663.00	483.83	N Betesön	0.3	30	90	Karlsson (1973)
50	»	6663.18	482.58	Skomakaren	0.5	90	90	V. O. Suominen
51	»	6663.66	483.88	Häran	0.7	40	90	Karlsson (1973)
52	»	6664.04	484.14	Klasponskär	0.7	30		»
53	»	6664.04	483.3	Ljungö				V. O. Suominen
54	»	6664.40	485.20	Hjortronskär	1	30		Karlsson (1973)
55	»	6664.40	491.60	Långkläppen	0.2	30	90	V. O. Suominen
56	»	6664.66	484.67	Busskär	0.6	20		Karlsson (1973)
57	»	6664.68	492.36	Storören	2	25	85E	V. O. Suominen
58	»	6666.60	485.00	Synderskärs- grund	0.8	25	80E	Karlsson (1973)
59	»	6669.08	479.93	Sottunga	0.2	30	90	V. O. Suominen
60	»	6669.09	479.92	»	0.1	0	60E	»
61	»	6669.10	479.92	»	0.2	0	90	»
62	»	6669.68	480.10	»	0.1	30	90	»
63	»	6669.8	479.8	Islet W of Sottunga	1	45—70		H. Hausen
64	»	6671.35	481.15	Röörn	1	45		»
65	»	6671.40	481.70	Ljusklobben	0.05			»

Number	Parish	Coordinates X	Y	Name of locality	Known width m	Trend N→E degrees	Dip	Observer
66	»	6670.7	480.40	Nötholm	0.02	0	90	V. O. Suominen
67	»	6670.90	480.58	Norrholmarna	1	170	80E	»
68	Kumlinge	6669.0	489.3	Dömmansskär	2	35		H. Hausen
69	»	»	»	»	0.9	20		»
70	»	6672.51	491.00	Kvarnskär	0.25	40	90	Suominen (1973)
71	»	»	»	»	1.5	40	90	»
72	»	»	»	»	1.5	40	90	»
73	»	6672.72	491.18	Gloskär	0.3	30	65E	V. O. Suominen
74	»	6676.72	493.50	Storören	3—4	30	65E	»
75	»	6676.47	493.28	Kalskär	0.1	35	90	»
76	»	»	»	»	11	25—30		H. Hausen
77—84	»	6677.2	492.6	Ryggan	0.8—0.01			V. O. Suominen
85	»	6677.05	485.60	Slätskär	0.06	30	80E	L. A. Björk
86	»	6675.42	483.72	Båtskär	0.15	45	80NW	»
87	»	6675.43	483.70	»	1	30	90	»
88	»	6675.42	485.00	Långskär	2	30	85W	»
89—90	»	6676.40	481.53	Seglinge, Stangnäs	0.3	10—15		»
91	»	6679.16	483.56	Seglinge, Hommanäs	1.2	30		»
92	»	6679.82	482.90	Seglinge, Stornäset	1.5	26		»
93	»	6680.49	482.58	Komboskär	1.4	30	85E	Ehlers
94	»	6680.47	482.53	»	1.2	20—25	80W—60E	»
95	»	»	»	»	1.3	10	70W	»
96	»	6680.2	482.55	N of Seglinge	0.2	25	90	L. A. Björk
97	»	6680.0	482.5	»	1	25	90	»
98—99	»	6680.2	482.4	»	1.3	10	70W	Ehlers
100	»	»	»	»	0.9	10	86W	»
101	»	6679.44	482.33	N Seglinge	1.5	0		L. A. Björk
102	»	6679.00	482.34	Seglinge	0.8	150	85W	»
103	»	6679.15	482.36	»	0.8	20	90	»
104	»	6677.68	481.87	Seglinge, E of Sandvik	1	50		»
105	»	6677.84	481.94	»	1	10		»
106	»	6677.2	481.8	W Seglinge		20		»
107	»	6679.14	484.91	Snäckö	4	c. 25	80E—90	Ehlers
108	»	6680.70	486.00	Långskär	5	60	70S	»
109	»	6680.57	485.85	»	4.3	38	90	»
110	»	6682.50	485.75	Ämtholm	2.5	60	65S	»
111	»	6681.74	487.00	Kumlinge, Staksvik	4	40	90	»
112	»	6681.03	489.02	Kumlinge, Nötholm	2.2	30	75E	»
113	»	6681.06	489.01	»	1.3	19	76E	»
114	»	6684	487	NW of Kumlinge church		35		Sederholm (1934)
115	»	6681.6	491.3	Kumlinge, Käringudden	0.4	35	75E	Ehlers
116	»	»	»	»	0.8—1.5	15—30	85E	»
117	»	»	»	»	0.2	30		»
118	Kumlinge	6681.5	492	SW Ingersholm	0.2	45		H. Hausen
	»	»	»	»		40		Sederholm (1934)
119	»	6685.1	490.5	Dössängsören	3	23	82E	Ehlers
120	»	6685.4	490.2	Tallören	5	20	86E	»
121	»	6685.86	490.00	Fögelvarpsören	0.45	27	90	»
122	»	6686.3	490.4	Börsskärsören	1.2	40	80E	»

Number	Parish	Coordinates X	Y	Name of Locality	Known width m	Trend N→E degrees	Dip	Observer
123	»	»	»	»	1.15	35	82E	»
124—126	»	6686.39	490.76	Kogrundet	2 0.2 0.05	40—47	83SE	»
127	»	6686.4	490.7	»	0.5	36	85E	»
128	»	»	»	»	0.4	25	86E	»
129	»	»	»	»	1.2	40	90	»
130	»	6686.45	490.69	»	0.2	35	85E	»
131	»	6686.72	490.74	Börsskär	1.7	50	87S	»
132	»	»	»	»	0.05	50	87S	»
133	»	»	»	»	0.08	47	80S	»
134	»	6686.6	490.8	»	1.25	40	84E	»
135	»	»	»	»	0.25	30	82E	»
136	»	»	»	»	0.5	40	77E	»
137	»	»	»	»	1.2	35	85E	»
138	»	»	»	»	0.35	35	85E	»
139	»	»	»	»	0.9	35	85E	»
140	»	6686.68	490.21	Ramsholmsgrund	0.5	20—40	85E	»
141	»	»	»	»	0.1	20—40	85E	»
142	»	»	»	»	0.1	40	85E	»
143	»	6686.43	489.10	Kumlinge, Ramsholm	1—1.5	40	85W—90	»
144	»	»	»	»	4	40	87E	»
145	»	6686.10	488.67	»	0.3—0.9	30—40	60—80E	»
146	»	6686.08	488.68	»	1.3	60—70	73S	»
147	»	»	»	»	0.05	70		»
148	»	»	»	»	0.06	70		»
149	»	6686.05	488.72	»	3.2	40—45	80SE	»
150	»	6687.18	490.02	Sälgören	1.6—1.8	50	75S	»
151	»	6687.90	490.30	Slätskär	1.5	40	78E	»
152	»	6688.0	490.7	Slätskärsören	0.65	42	86E	»
153	»	6688.14	490.82	Märrgrund	1	40	70E	»
154	»	6687.43	491.60	Rosmunklobb	3.7	40	86E	»
155	»	»	»	»	5.8	40	86E	»
156	»	6687.77	492.14	Ugnklobb	0.5	30	81E	»
157	»	6688.06	492.32	Granklobben	8	42	82E	»
158	»	6688.70	491.90	Norrklobben	3.5	49	80S	»
159—162	»	6688.50	493.00	Livslandet	0.02+0.7	40	80E	»
163	»	6690.5	492.4	Högholm	4.5—5	45	85SE	»
164	»	»	»	»	0.15—0.2	70—35	84SE	»
165	»	»	»	»	0.03	50	90	»
166	»	»	»	»	0.1	45	75SE	»
167	»	»	»	»	0.03	38	82E	»
168	»	»	»	»	1.1	50	80S	»
169	»	»	»	»	0.1	50	80S	»
170	»	»	»	»	0.4	40	88W	»
171	»	»	»	»	0.25	30	90	»
172	»	»	»	»	1	36	85E	»
173	»	»	»	»	0.15	35	85E	»
174	»	»	»	»	0.05	36	85E	»
175	»	6691.1	492.8	Långören	0.15	45	88SE	»
176	»	»	»	»	2	40	90	»
177	»	»	»	»	1.2	44	89SE	»
178	»	»	»	»	0.45	30—40	89E	»
179	»	»	»	»	0.2	35	75E	»
180	»	»	»	»	0.35	40	90	»
181	»	»	»	»	1.3	33	90	»

Number	Parish	Coordinates X	Y	Name of locality	Known width m	Trend N→E degrees	Dip	Observer
182	»	6692.16	493.43	Ljungskär, Lill Lappo	0.4—0.6	35	85E	»
183	»	»	»	»	0.5	45	85SE—85NW	»
184	»	»	»	»	0.8	35	70E—80W	»
185	»	6692.3	493.4	»	0.15	30	70E	»
186	»	»	»	»	0.8	35	70E	»
187	»	»	»	»	0.1—0.2	35	75—80E	»
188	»	»	»	»	0.15	45	80SE	»
189	»	»	»	»	0.25	30—40	55—70E	»
190	»	»	»	»	2	50	85S—90	»
191	»	6692.48	492.28	»	0.08	35—45	85SE	»
192	»	»	»	»	0.05	35—45	85SE	»
193	»	6692.50	493.75	Ljungskärsören	1.2	40	78E	»
194	»	»	»	»	0.15	50		»
195	»	6692.50	493.80	»	0.9	40	82E	»
196	»	»	»	»	1.5	40	82E	»
197	»	6693.35	493.55	Islet E of Lill Lappo	0.5	43	80SE	»
198	»	6694.42	493.32	Abborkrok, Lill Lappo	0.3	30	80E	»
199	»	6697.64	491.88	Rönnören	0.6	72	85S	»
200	»	6683.1	494.2	Kålskär	0.5	20	60W	»
201	»	»	»	»	0.3	45	80SE	»
202	»	6681.72	496.35	Lilla Bredgrund	0.6	45	90	V. O. Suominen
203	»	6690.2	486.3	S Enklinge		35		Rancken (1953)
204	»	6690.5	485.6	Enklinge, Bränningar		30		Ehlers
205	»	6691.08	485.51	W Enklinge	1.8	3	81E	»
206	»	6691.90	485.68	»	0.5—1.5	6	82W	»
207	»	6691.90	485.74	»	1.5	170	65E	»
208	»	6691.92	485.78	»	2—2.5	65	86N	»
209	»	6692.2	485.86	»	0.5	40		»
210	»	6692.7	488.2	E Enklinge	4.5	30		Rancken (1953)
211	Kumlinge	6693.90	486.44	NW Enklinge	1.1	20	78E	Ehlers
212	»	6694.2	486.7	»	1.3	30	65E	»
213	»	»	»	»	0.5	25	75E	»
214	»	6694.2	488.6	NE Enklinge	10	25—30	65E	»
215	»	»	»	»	1	40	75E	»
216	»	6694.62	486.91	Vindarskär	2.1	30	60E	»
217	»	6694.84	488.78	Söderbykarlarnas Ören	10	50	50S	»
218	»	6695.00	488.00	W of Skutnäsudden	2.2	20—30	57E	»
219	»	6695.10	489.03	Långa Skutnäsören	0.05	10		»
220	»	6695.16	489.00	»	6	25	75E	»
221	»	»	»	»	0.1	30		»
222	»	6695.24	488.90	»	2	60	65S	»
223	»	6695.24	488.05	Skutnäsudden	2.7	15	55E	»
224	»	6695.62	487.58	W Granskär	1.1	50—60	65S	»
225	»	6695.9	487.6	Granskär	0.2—0.3	170	65E	»
					0.35	15	85E	
					0.2—0.3	0	84E	
226	»	6696.10	490.00	Alöklubbsören	9	55	65—70S	»
227	»	6697.90	487.28	Lantö	1	30	90	»
228	»	6691.22	495.18	Björkö, Rankulvik	2	50	60S	»

Appendix 1, continued

Number	Parish	Coordinates X	Y	Name of locality	Known width m	Trend N→E degrees	Dip	Observer
229	»	»	»	»	4	20	80E	»
230	»	»	»	»	0.1	45	70SE	»
231	»	»	»	»	0.2	45	70SE	»
232	»	6690.89	495.28	Björkö, Storknoppa	2.5	32	60E	»
233	»	6691.33	495.30	Björkö, Nybroklint	0—0.1	50	60S	»
234	»	6691.97	495.83	Björkö, Åkerlind	1	40	70E	»
235	»	6691.86	495.80	Björkö	0.3	35	55E	»
236	»	6693.18	495.86	Björkö, Mickels-berget	0.6—1.1	35	75E	»
237	»	6692.22	496.05	Björkö, Ånholm	0.1	34	76E	»
238	»	6693.36	496.90	Hamnö, Ramsnäs	0.9	55	85N	»
239—241	»	6696	496	Islet E of Brändholm	0.9	25—30		H. Hausen
					1.6			
					1.35			
242	»	6696.04	495.29	Ängö	1.5	35—40	80—85E	Ehlers
243	»	6695.82	495.11	Ängö Ören	1.2	40	76W	»
244	»	6695.84	495.07	»	0.2	46	75S	»
245	»	6697.7	496.1	Gråörarna	0—0.6—0	30	85W	»
246	»			S Bredskär		60		H. Hausen
247	Brändö	6684.4	497.6	Ljungskär	1	30—35	85W—85E	Ehlers
248	»	»	»	»	0.4	30	85E	»
249	»	»	»	»	0.15	30	75E	»
250	»	»	»	»	1.8	30	80E	»
251	»	»	»	»	1.4	30	80—85E	»
252	»	»	»	»	0.05	20	70E	»
253	»	»	»	»	1.7	30	90	»
254	»	»	»	»	0.3	35	80E	»
255	»	»	»	»	0.3	40	80E	»
256	»	6682.7	499.2	Degerbrok	8—9	40—50		H. Hausen
257	»	6681.74	499.72	Långbrok	5	50	80S	Ehlers
258	»	6682.35	499.84	»	1	45	90	»
259—265	»	6682.72	499.5	»	5—0.01	40—60	90	»
266	»	6684	500	Lilla Busskär	1	45		H. Hausen
267	»	6679.26	501.72	Hamnklobbarna	1	c. 90		N. Edelman
268	»	6680	500	Gunnarskären	0.03	45		H. Hausen
269	»	6679.0	500.0	»	2	30	90	V. O.Suominen
270	»	6678.20	500.35	Söderlandet	2	30	90	»
271	»	6677.92	499.85	Ormskär	1	35	90	»
272	»	6689.04	498.04	Tistronören	0.2	25	90	Ehlers
273	»	6687.35	498.00	»	1.2	35	82E	»
274	»	6687.78	498.31	Gräsören	1.2	35	82E	»
275	»	6687	499	S Lappo	1.9			H. Hausen
276	»			Skötören	1.44	145		»
277	»	6688.6	500.6	Fåfängskär	0.9	27	80W	Ehlers
278	»	»	»	»	1.15	28	84W	»
279	»	»	»	»	1.5	30	85W	»
280	»	»	»	»	1.7	25	73W	»
281	»	»	»	»	1	31	90	»
282	»	6690.30	501.34	Bärö, Lappo	0.5—0.8	25—37	90	»
283	»	»	»	»	1	30—40	85E—90	»
284	»	6690.35	501.39	»	0.4	37—47	75SE	»
285	»	6690.42	501.47	»	0.3	25	80—85E	»
286	»	6690.50	501.54	»	0.11	29	81E	»

Number	Parish	Coordinates X	Y	Name of locality	Known width m	Trend N→E degrees	Dip	Observer
287	»	»	»	»	0.4	30	75—80E	»
288	»	6690.50	501.56	»	0.1	35	80—85E	»
289	»	6690.42	501.57	»	1	27	81E	»
290	»	6690.51	501.59	»	1.8	30	85E	»
291	»	»	»	»	2	34	90	»
292	»	6690.55	501.66	»	1.2	35	85W—90	»
293	»	6690.56	501.68	»	1.1	29	80E	»
294	»	6688	504	Måsskär, Asterholma	0.35			H. Hausen
295	»	6686.2	503.2	Dussören	3.2			»
296—297	»	6690.4	503.8	Skabbskär		20		Airphoto
298	»	6694.45	500.30	Lilla Börsskär		45		»
299—300	»	6692.8	507.00	Östra Bergholm	1.5	45	90	V. O. Suominen
301	»	6691.3	503.4	Västra Bergholm	0.25	Varying	90	Ehlers
302	»	»	»	»	0.25	,,		»
303	»	»	»	»	0.3	30	90	»
304	»	»	»	»	1	30	90	»
305—306	»	6692.42	502.92	Räddarskär, Torsholma	1.4	45		H. Hausen
307	»	6699.70	509.60	Ånholm	1.5	45	90	V. O. Suominen
308	»	669	505	Brunnsö	3	45		H. Hausen
309	»	»	»	E Torsholma	3.6			»
310	»	6700.7	499.3	Korsö	4	48	90	Springert (1948)
311	»	»	»	»		60		»
312	»	6701.0	502.2	NW Brändö	0.2	30	90	Leif Bergman
313—314	»	6701.1	504.0	Lammholm		40	90	»
315—317	»	6700.7	503.5	NE Brändö		25—40	90	Kaitaro (1953)
318	»	6671.80	500.78	SW Brändö	0.3	30	90	V. O. Suominen
319	»	6700.55	501.44	Likholmsgrundet	1.7	40	65W	Ehlers
320	»	6702.7	497.3	Gymmerholm	11	30	75E	»
321	»	»	»	»	1.2	40	70E	»
322	»	6703.00	500.12	Norrholm		25		Kaitaro (1953)
323	»	6704.25	498.63	Bernholm		45		»
324	»	6704.38	500.94	Österskär	1.15	18	84E	Ehlers
325	»	6704.46	498.83	Brändören		40		Kaitaro (1953)
326	»	6704.5	505.2	ESE Åva	0.1	30	90	Leif Bergman
327	»	6704.65	504.0	Bockholm, Åva		35		Kaitaro (1953)
328	»	6705.19	499.07			30		»
329	»	6701.0	502.0	Långö, Åva				»
330	»	6710.55	505.29	N Graneholm		45		»
331—335	»	6710.6	505.7	Bergholm	0.3	60	90	Leif Bergman
336	»	6711.04	505.90	Bergholm Ören		50		Kaitaro (1953)
337	»	6711.60	506.05	Finnäs Kobben		70		»
338	»	6712.30	507.00	Stångskär, Jurmo	0.7	80	90	V. O. Suominen

ISBN 951-690-071-2