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GRAHAM PARK ALAN BAILEY ALAN CRANE
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CONTENTS

ABSTRACT

The Stora Le—Marstrand rocks of western Orust consist of psammitic to semipelitic paragneisses which, with a suite of amphibolites, form the palaeosome of a migmatite complex. These gneisses are intensely deformed and cut by the Hälleviksstrand amphibolite with an Rb/Sr whole-rock age of 1432±92 m.y. and by numerous minor acid intrusions varying from quartz-diorite to alkali-granite. Further deformation was followed by the intrusion of a younger set of acid (mainly granodiorite) sheets and by a suite of basic dykes. The complex appears to have undergone high amphibolite-facies metamorphism during the early part of its history and to have cooled prior to the basic dyke intrusion. Four post-dyke deformations are distinguished, the metamorphism varying from amphibolite facies in the earlier to low greenschist facies in the later. The metamorphic complex is cut by the post-tectonic 900 m.y. old Bohus granite.

INTRODUCTION

The area described in this paper is centred on Stocken, on the west coast of Orust (Fig. 1, Pl. 1). It occupies 45 sq. km of very well exposed terrain between Lavö and Hälleviksstrand, west of the Ellös—Mollösund road, including the island of Härmanö and many smaller islands along the adjoining coast. The area was mapped on a scale of 1:10 000 using maps of the "economic" series prepared from aerial photographs.

REGIONAL CONTEXT

The island of Orust lies within the outcrop of the Stora Le—Marstrand "Series" (Magnusson *et al.* 1960) whose age and origin is one of the major stratigraphic problems of the Sveconorwegian province in southwestern Sweden. The Stora Le—Marstrand "series", first described by Larsson (1956) and Lundegårdh (1958), comprises a supracrustal suite of slates, greywackes and quartzites. This group of rocks, which will be termed the Stora Le—Marstrand "mega-unit" following Gorbatschev (1975), was considered by Magnusson (1965) to be older than the "Gothian" supracrustals and granites to the east but younger than the "Pregothian" gneiss complex which forms the bulk of the Sveconorwegian block of southwestern Sweden and which, he believed, forms the basement on which the Gothian supracrustals (the Åmål "series") were laid down. According to Lundegårdh (1964, p. 112) the Stora Le—Marstrand series is possibly of Svecofennian age.

The only previous definite chronological evidence bearing on the age of the Stora Le—Marstrand mega-unit is an Rb/Sr isochron age of 910 m.y. ($=891 \pm 34$ m.y. using $^{87}\text{Rb}=1.42\times10^{-11}\ \text{y}^{-1}$) on the Bohus granite (Skiöld 1976) which is a late Sveconorwegian pluton cutting the Stora Le—Marstrand rocks. K/Ar ages of 1040 and 1060 m.y. had previously been obtained from Stora Le—Marstrand rocks by Polkanov and Gerling (*in* Magnusson 1960) but these are now generally believed to reflect Sveconorwegian regeneration of the region as a whole (e.g. see Skiöld op. cit.). Two intrusive bodies in Orust have been dated in connection with the present study — an amphibolite and an augen granite — which yield whole-rock Rb/Sr ages of 1432±92 m.y. and 1379±46 m.y. respectively (Daly, Park and Cliff, in press).

The main purpose of this paper is to describe in detail the various rock units, their chronological relationships, and their deformational and metamorphic history, in a small but very well exposed part of the Stora Le—Marstrand outcrop in order to produce some sound factual evidence wich can be brought to bear on the problem of the stratigraphic relationship of the Stora Le—Marstrand mega-unit to the Sveconorwegian province.

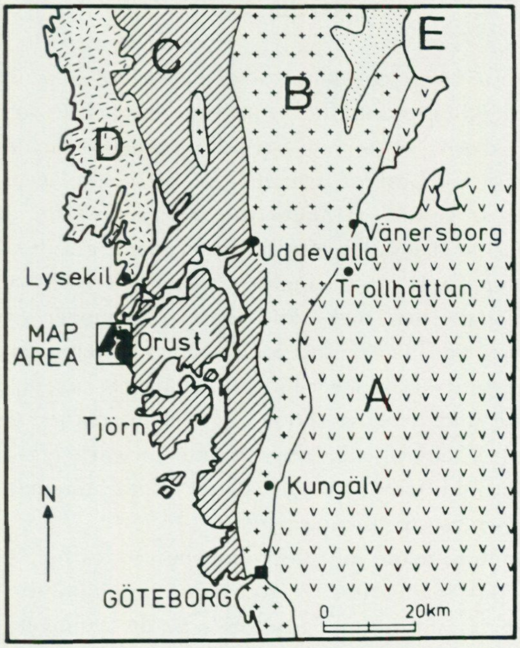

Fig. 1. Simplified regional geology of south-western Sweden showing the main tectonic sub-division of the Sveconorwegian province — the Pregothian (A), Åmål (B) and Stora Le—Marstrand (C) mega-units, the Bohus granite (D) and the Dalslandian supracrustals (E) — together with the location of the map-area.

PREVIOUS WORK

The island of Orust is included in the Uddevalla map-sheet published by SGU (Geological Survey of Sweden) on a scale of 1:100 000 and described by Lindström (1902). No detailed work has previously been done in western Orust. Bergström (1963) has described the petrology of the island of Tjörn, immediately south of Orust, with a map on a scale of 1:50 000. Many of the rock-types described by Bergström are also found in Orust. The rocks of western Orust are the northward continuation of a belt of "medium-grained gneisses with pegmatitic veins" mapped by Bergström on the west side of Tjörn and which he considered to be metasediments of mainly greywacke composition representing the more migmatised equivalents of the fine-grained gneisses and schists on the eastern side of Tjörn whose sedimentary origin could be more convincingly demonstrated.

The northeastern part of Orust has been mapped on a scale of 1:20 000 and described, mainly from a structural viewpoint, by Berthelsen and Murthy (1970) who were particularly concerned with the relationships between the Stora Le—Marstrand paragneisses and the large bodies of granitoid rocks occurring within them.

ROCK TYPES

The rocks of western Orust consist of acid gneisses of a generally granodioritic composition but including psammitic to pelitic paragneisses together with a large number of bands, dykes, veins and irregular bodies of material varying from acid to ultrabasic in composition which have been emplaced within this gneiss complex. Large areas consist of migmatitic gneisses where the original nature of the country rock is largely obscured by pervasive granitoid material, but in many places it is possible to distinguish clearly between an older group of gneisses representing the host rock and a series of younger granitoid rocks. The latter can themselves be divided into a number of different types some of which form a set of discrete dyke or sheet-like bodies which can be distinguished from earlier more diffuse and irregular bodies of the migmatite complex. The basic and ultrabasic bodies may also be divided into an earlier group of irregular or sheet-like bodies forming part of the host rock of the migmatite complex and a later suite of dykes which cut the migmatites.

A division is therefore made into the following groups for descriptive purposes: 1, the gneisses and migmatites, 2, the older amphibolites, 3, the Hälleviksstrand amphibolite, 4, the older "granites", 5, the younger "granites", 6, the dyke suite (mainly basic but including acid to ultramafic varieties). All these groups of rocks have been deformed and metamorphosed to varying degrees and in some cases several times. There is a seventh category consisting of a single dyke which post-dates the regional metamorphism.

THE GNEISSES AND MIGMATITES

Medium-grained granodioritic gneisses are by far the most abundant rock type in the area. They contain quartz + plagioclase (c. An 30) + biotite ± muscovite ± microcline ± garnet ± chlorite with accessory apatite, zircon and opaques. Quartz is slightly more abundant than plagioclase and micas vary from about 20 % to about 40 % of the rock. Mean grain size is variable but typically below 1 mm.

In the field, these rocks appear as medium-grained migmatites with well-developed stromatic structure and prominent banding (Fig. 2). The palaeosome is a grey leucocratic gneiss with 1—2 mm thick micaceous bands alternating with 1—5 mm thick more quartzo-feldspathic bands, and less commonly bands of more micaceous or more quartzo-feldspathic type occur with thicknesses of 2—10 cm or even greater. The margins of the bands are usually sharp but grading occurs occasionally. The neosome is a white, cream-weathering quartzo-feldspathic material forming sharply-defined bands or lenses which are either concordant or discordant to the foliation of the palaeosome. The bands typically

Fig. 2. Migmatised semipelitic gneiss with thin psammitic layers showing interference between F1 and F2 folds. F1 fold closures affecting early migmatitic neosome in the lower part of the photograph trend E—W. They are refolded by upright F2 folds trending approximately N—S. Looking north. Sollid, SE of Hälleviksstrand.

range from 2 mm to 10 cm in thickness and are continuous over distances of several centimetres to over 1 m although often showing pinch-and-swell structure. The neosome frequently also takes the form of small, 1 cm long, lenses or irregular patches 2—10 cm thick, or 2—3 cm thick discordant irregular veins which sometimes possess a biotite selvedge. The irregular patch and vein type of neosome is typically more diffuse than the concordant bands.

At many localities it is possible to distinguish between two generations of migmatitic leucosome, the earlier, which has been intensely folded during the D_1 deformation, now forming generally thin concordant veins or stripes and the later, emplaced after D_1, forming discordant bodies of widely varying shape and appearance. The discordant granitoid material associated with the second migmatisation is described under "older granites".

Within these granodioritic gneisses, certain distinctive units have been recognised and mapped on account of their more micaceous nature (up to 50 % mica) and more clearly defined lamination. This type of mica-gneiss is particularly common on the Lavö peninsula and forms thick belts several hundred metres in width in Härmanö. Thin bands of fine-grained, "flinty", more siliceous rock several centimetres in width occur within the gneisses and also hornblende-bearing varieties of the normal gneiss type, but these are comparatively rare. The regular banding of the gneisses where relatively free from migmatisation is strongly suggestive of a sedimentary origin despite their overall "granitic" composition and this view is strengthened by the presence of grading and of the occasional more siliceous and micaceous bands. However, there is a considerable proportion of probably magmatic granite in the area and compositional banding of the type described can certainly be produced by deformation and metamorphism of originally igneous material. We believe, however, that the rocks are basically paragneisses of generally semipelitic type but divisible into more "psammitic" and more "pelitic" varieties. It is hoped that geochemical work now in progress will throw more light on their origin.

The well-banded "paragneisses" are best developed in Härmanö, on the western coastal strip of Lavö and Stocken, and on the intervening small islands. Towards the east, however, they are replaced by coarser-grained (1—2 mm), more thoroughly migmatitic gneisses in which the palaeosome becomes altered to such an extent that it often becomes difficult to distinguish from the granitic neosome, particularly when deformed. A complete gradation can be observed between the well-banded paragneisses and homogeneous coarse-grained granodiorite, but the most commonly developed rock type in the eastern part of the area is a coarse-grained schlieritic or nebulitic gneiss with relatively weak migmatitic banding which is neither so continuous nor so sharp as in the Härmanö gneisses. Typically, micaceous bands about 5 cm thick alternate with quartzo-feldspathic bands 5—10 cm thick. Micaceous schlieren 1—2 cm long are also common and may entirely replace the banding. Lenses and irregular discordant veins 1—20 cm thick of quartzo-feldspathic neosome are also present. This material passes into the more homogeneous granodiorite which may show nebulitic structure and contain xenoliths of amphibolite or paragneiss.

THE OLDER AMPHIBOLITES

The older basic and ultrabasic bodies which form part of the migmatite complex include the earliest recognisable intrusions into the paragneisses. These bodies are found throughout the area and vary widely in size and shape from small pods and narrow bands several centimetres in width to large sheet-like or plug-like masses several hundred metres in width which can be traced over distances of over 1 km (see Pl. 1).

These amphibolites are medium- to coarse-grained rocks (1—2 mm mean grain size) with essential minerals amphibole (usually hornblende) and plagioclase in the range An30—An50. In addition, biotite is common (up to 30 %) and also garnet and quartz (in small quantities). Zoisite, clinozoisite, epidote, chlorite, and calcite are found as alteration products and sphene and opaques as accessories. One sample contained 20 % clinopyroxene.

Textures are variable. Relict ophitic or sub-ophitic texture has been observed in several bodies and faint mottling or banding due to varying concentrations of hornblende and plagioclase are common. Some of the banding may be of igneous origin.

Migmatisation is variable and typically less intense than in adjoining gneisses. A diktyonic or agmatitic structure is typical with elongate rounded pods of dark palaeosome several centimetres thick set in a network of veins 5 mm—2 cm thick of white neosome. With intense flattening, this structure gives rise to a fine banding 1—5 mm thick composed of alternating felsic and mafic layers. Thicker (up to 40 cm) more irregular veins and lenses of medium- to coarse-grained quartzo-feldspathic neosome also occur.

The margins of these amphibolites are typically concordant with the foliation and compositional banding in the adjoining paragneisses but occasional discordance betrays the intrusive nature of at least some of the bodies. The homogeneous texture and often sheet-like nature suggest that they probably originated as basic igneous intrusions. They are cut by both generations of migmatitic leucosome and by members of the older granite suite.

THE HÄLLEVIKSSTRAND AMPHIBOLITE

The Hälleviksstrand amphibolite is a medium- to coarse-grained rock varying between mesocratic and melanocratic and contains inclusions of mafic and ultramafic amphibolite similar to the older amphibolites. Over part of the outcrop the rock is essentially a metadiorite but elsewhere it is metagabbroic. It is cut by irregular veins and sheets of older granite in a similar way to the older amphibolites but itself cuts the older amphibolites and the early migmatitic banding in the paragneiss.

It contains hornblende, plagioclase (andesine), quartz, and biotite, with accessory epidote, sphene, apatite, and opaques. The proportions of the main minerals, and the An-content of the plagioclase, vary considerably between the mesocratic and melanocratic types.

THE OLDER GRANITES

The older granite suite includes a wide variety of rocks ranging from very leucocratic acid types to quartz-diorite. They occur throughout the map area and are the most common rock group after the gneisses. Individual bodies are typically small and irregular with diffuse margins, difficult to distinguish from the paragneisses. Larger bodies form mappable units several hundred metres in extent (see Pl. 1) but these are mostly very variable and heterogeneous in nature and contain many inclusions of migmatised paragneiss and older amphibolite. Three main widespread types are distinguishable — augen granite, grey quartz-diorite or granodiorite, and white (cream-weathering) leucogranite.

The *augen granites* are granodioritic in composition and are distinguished from the other older granites by their uniformly porphyroblastic nature. The megablasts are mainly alkali-feldspar 0.5—4 cm in length and the groundmass, with grain size about 1 mm, contains quartz, K-feldspar, plagioclase (An40), biotite, and muscovite. Feldspars make up around 50 % of the mode, quartz 25 %, and micas 25 %. The megablasts frequently show replacement of plagioclase by microline. Accessories are garnet, apatite, sphene, and allanite. Chlorite occurs as an alteration product.

These granites are much less common than either of the two subsequent types. They form two large outcrops in southern Härmanö (see Pl. 1) and a number of smaller outcrops. The large outcrops are broadly concordant sheets of relatively homogeneous material surrounded by zones of "granitised" augen gneiss. Screens of augen gneiss and xenoliths of paragneiss occur within the bodies which are cut by sheets of both grey granite and leucocratic granite.

The *grey granites* vary from granodioritic to quartz-dioritic in composition. They are typically medium-grained (0.5—1 mm) granoblastic rocks and contain quartz, plagioclase (An15) biotite, and muscovite. Plagioclase is the most abundant mineral (55—65 %) and micas form about 10—15 % of the rock. Microcline may be present in small amounts and garnet may also occur. Accessories are apatite, zircon, allanite, and opaques with secondary zoisite and calcite.

These granites are typically homogeneous and occasionally contain xenoliths of migmatised paragneiss (Fig. 3). They form small bodies of the order of 10 cm to 10 m thick which are frequently concordant with the banding of the paragneiss and difficult to distinguish from it. They occur throughout the western half of the area and in the eastern half, where the paragneisses become heavily migmatised, a similar though coarser grained granodioritic material forms quite large diffuse patches up to several hundred metres in extent (see Pl. 1). Grey granites cut the early migmatitic banding of the paragneisses and intrude the Hälleviksstrand amphibolite. They are themselves cut by the white leucogranites.

The *white leucogranites* are easily recognisable cream-weathering rocks varying from coarse or pegmatitic to medium-grained (1 mm). They typically contain quartz, K-feldspar, plagioclase (c. An15), biotite, and muscovite. Feldspars make up 55—65 % of the mode, quartz 30—40 % and micas 5—10 %. Accessories are sphene, apatite and opaques. Zoisite occurs as an alteration product. There is considerable variation in feldspar composition from predominantly plagioclase to predominantly K-feldspar (microcline, sometimes as perthite). Megablasts of

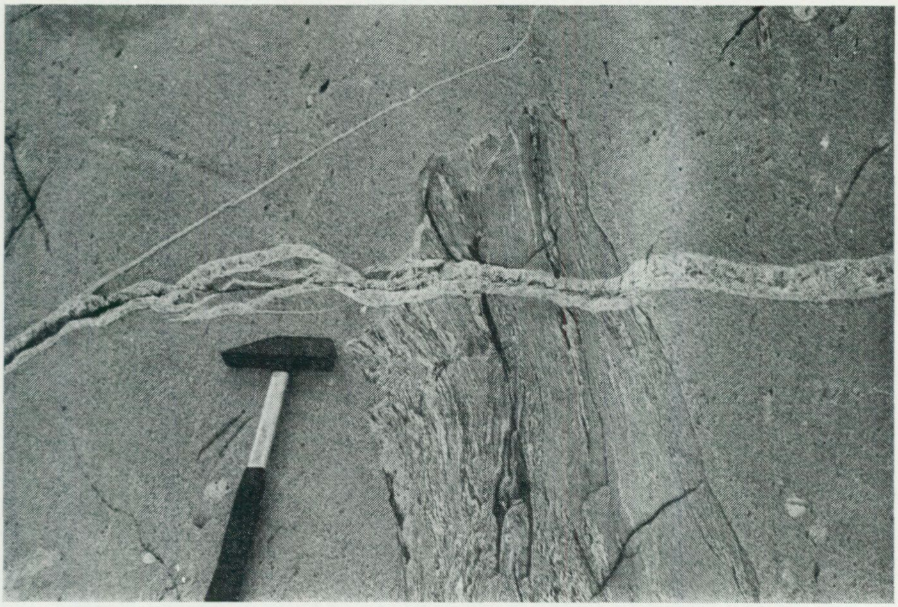

Fig. 3. Grey granite of the older granite suite enclosing a xenolith of migmatised semipelitic gneiss. The early migmatite has been deformed in F1 before the intrusion of the grey granite. Both are cut by pegmatite belonging to the younger granite suite. Sollid, SE of Hälleviksstrand.

both K-feldspar and plagioclase occur and frequently show replacement of plagioclase by microcline.

White leucogranite is of widespread occurrence and forms the second-generation leucosome of the migmatitic gneisses. It is often very similar petrographically to the first-generation leucosome material and can only be clearly distinguished from it where it is discordant to S1 or where it cuts other bodies (e. g. grey granites) wich are themselves post-S1. It occurs as lenses, sheets and irregular patches ranging in thickness from about 1 cm to several metres. The larger bodies are usually pegmatitic in part and send tongues into the host gneisses.

The abundance and general characteristics of the leucogranite vary somewhat across the area from west to east in conjunction with the change in character of the migmatites. The larger discrete, discordant bodies are most abundant in the west where the paragneisses are less pervasively altered by the migmatisation and reach their greatest concentration in some of the small islands east of Härmanö. In the eastern half of the area where the migmatisation has been most pervasive, such bodies are relatively uncommon and the coarse-grained schlieritic, nebulitic or homogeneous granodiorite is the typical product of the migmatisation.

Leucogranites cut both the porphyritic granites and the grey granites and are in turn cut by the younger granite sheets.

THE YOUNGER GRANITES

The younger granite suite occurs as dykes and sills of quartz-dioritic to adamellitic composition which, though not as abundant as the older granite suite, are nevertheless widely distributed throughout the area (Fig. 4). Two main types are recognised — quartz-diorite and leucogranite, the latter being commonly pegmatitic or composite, with pegmatitic bands. There are also a few thick pegmatite sheets occurring in the north which may be later than the other bodies.

The *quartz-diorites* (tonalites) are homogeneous, even-grained rocks with mean grain size in the range 0.5—0.8 mm. They contain quartz, plagioclase (c. An13), biotite, and muscovite. Plagioclase makes up about 50 % of the rock, quartz around 30 % and micas 15 %. Accessories are apatite, sphene, zircon, and opaques. Garnet occurs in some bodies, and chlorite and epidote are present as alteration products.

Although compositionally similar to the grey granites, these rocks can be distinguished from them by their occurrence as sheets, normally with discordant, sharply-defined margins which cut the migmatites and are not themselves veined or cut by older granite material. The sheets vary in thickness from about 5 cm to 5 m and typically are 1—2 m thick. Individual sheets are rather variable in thickness. Only a few bodies are large and persistent enough to form mappable units — one such sheet in southeastern Härmanö extends for 1.5 km (Pl. 1). The attitude of the sheets is very variable and individual sheets frequently show abrupt changes in direction.

The *leucogranites* are less common than the quartz-diorites and are typically partly pegmatitic and partly medium-grained (c. 0.5 mm). They differ from the quartz-diorites in their higher proportion of feldspar (about half of which is K-feldspar), and lower proportion of micas (about 5 %). The only recorded accessories are apatite and opaques.

A common form taken by these sheet-like bodies is a pegmatitic border, with large megacrysts of K-feldspar aligned perpendicular to the margin, and a medium-grained central part. Such bodies cut the quartz-diorites but other pegmatitic sheets are cut by the quartz-diorites so that there is probably no significant age difference between them. The thick *pegmatite sheets* occur in Lavö and on the islands near Gullholmen (Pl. 1). They contain megacrysts of K-feldspar and plagioclase and large books of muscovite, along with quartz and garnet. These bodies are probably later than the basic dykes but their precise position in the chronology is uncertain.

THE DYKE SUITE

The dyke suite is mainly composed of mafic amphibolites but includes ultramafic, intermediate and acid types. Individual dykes are much more straight and

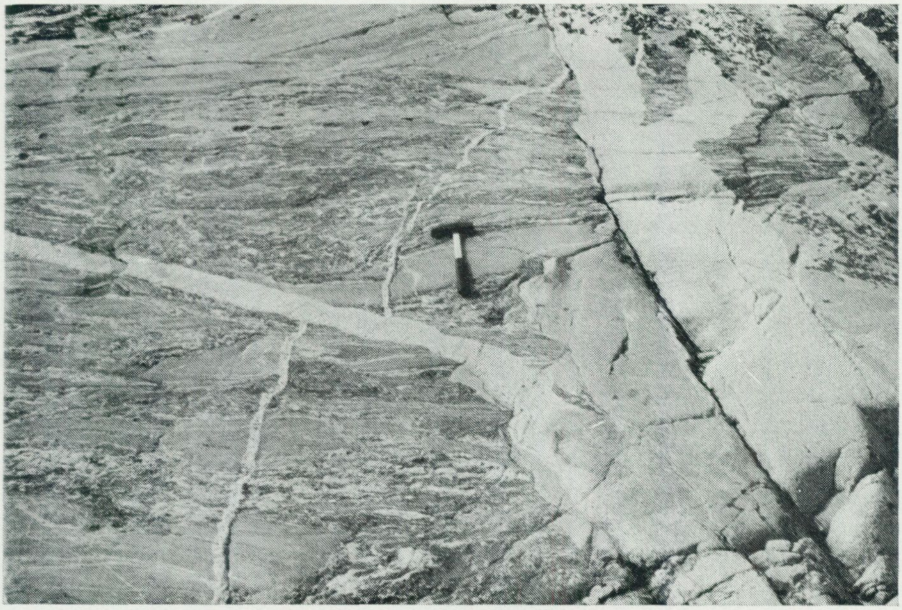

Fig. 4. Dykes and veins belonging to the younger granite suite cutting migmatised semipelitic and psammitic paragneisses. Coast of southern Härmanö.

regular than the granite sheets and, where undeformed, show sharp, chilled margins. They vary in thickness from a few centimetres to 60 m but most dykes are between 1 m and 5 m thick. The thicker dykes are shown on the map (Pl. 1) from which the overall distribution and orientation can be assessed. They are much more numerous on Härmanö, where they are particularly concentrated in belts of well-laminated, more micaceous or well-foliated gneisses to which they are frequently near-concordant. Dykes are much less common in the eastern half of the area. There is also a marked change in orientation from N—S with steep eastward dips in the west to NE—SW or NW—SE in the east, often with a moderate or low dip similar to that of the host gneisses. Near-concordant sill-like relationships are common but in some cases are accentuated by later deformation.

The *mafic amphibolites* include coarse-grained metabasalts of which there are porphyritic and garnetiferous varieties. They contain hornblende, plagioclase (c. An35), quartz, ±biotite, ±garnet, and chlorite, epidote and calcite as alteration products. Accessories are sphene and opaques. Hornblende varies between 50 % and 80 % of the rock and quartz+plagioclase between 10 % and 30 %. Biotite (frequently chloritized) occurs in most examples, often making up 15 % of the mode. Porphyroblastic garnets occur in many dykes and appear to be unrelated to any systematic variation in bulk composition. They are often arranged in zones parallel to the margins or along joints. Porphyritic varieties with recrystallized feldspar phenocrysts are also common. Grain size varies from less than 1 mm in the finer-grained varieties to more than 2 mm in the coarse meta-gabbros.

There are several thick multiple dykes (ranging from 10 m to 60 m in width) in western Härmanö with metagabbroic central parts and medium-grained marginal parts which contain xenoliths of the metagabbro. The coarse material contains rounded inclusions of ultramafic amphibolite and in places exhibits a faint compositional banding consisting of alternating mafic and felsic material.

Intermediate and acid members of the dyke suite form a number of thin sheets in Härmanö and on some of the small islands. They are pale grey-weathering rocks studded with garnet porphyoblasts and usually contain feldspar phenocrysts. Mean grain size is around 0.2—0.3 mm. The more mafic varieties (metadioritic) contain hornblende (c. 20 %) in addition to biotite. Apart from their more felsic nature, they appear to be similar to the other amphibolites. The acid dykes are *micrdeveloper* with 15—30 % quartz, 55—70 % feldspar and about 10 % biotite. Accessories are garnet, sphene, apatite, zircon, muscovite, and opaques. Calcite, epidote and chlorite are also present. K-feldspar is the dominant feldspar and forms the phenocrysts where present.

POST-TECTONIC DYKE

After the intrusion of the dyke suite, a period of deformation and metamorphic activity affected the area, causing all the previously formed rocks to suffer some degree of metamorphism and affecting particularly the younger granites and the dyke suite. A single intrusion has been observed which cuts these bodies and is unaffected by the post-dyke metamorphism and deformation. It cuts a NW—SE shear-fault which is one of the latest structures recognised in the area, and may belong to the widespread Permian suite recognised in this region (Samuelsson 1971).

STRUCTURE

On a large scale, the structure of the area is superficially fairly simple (Fig. 11). The dominant foliation trends N—S in the west and in the east forms an arc, convex to the west, from NE—SW in the northeast to NW—SE in the southeast. The dips are typically high, in the range 45° to 80° to the east. In more detail, the foliation shows numerous deflections locally and the lithological boundaries, usually parallel to the foliation, show a complex outcrop pattern which has the appearance of interference structures due to superimposed folding (Pl. 1).

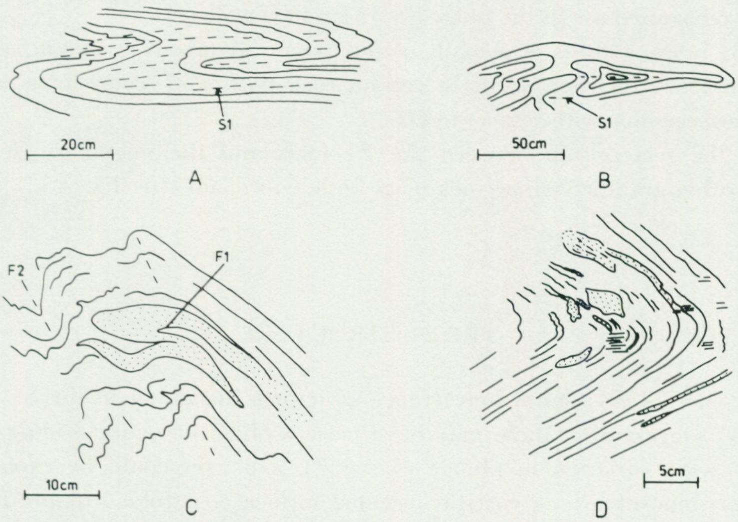

Fig. 5. Pre-dyke small-scale folds (F1—2).
A. Tight to isoclinal F1 fold showing folded layering (bedding and early migmatite veins) cut by S1 planar fabric.
B. Interference structure of layering, intrafolial to S1 and cut by S1 planar fabric.
C. Tight asymmetric F2 folds affecting S1 foliation and an F1 isoclinal fold. There is no new S2 planar fabric developed. A thin sheet of leucosome (dotted ornament) is folded by F1.
D. Detail of an F2 fold closure showing folding of leucosome lenses (dotted ornament) and the local development of a crenulation cleavage parallel to the axial plane.
Drawn from photographs.

D1 STRUCTURE

Typically, the dominant foliation referred to above appears as a compositional banding or gneissosity defined by alternating more micaceous and more quartzofeldspathic layers. The general form and character of the gneissose banding has already been described. A schistosity produced by the parallel alignment of micas or, in the mafic rocks, hornblendes is usually parallel to this banding. Much of the banding is thought to reflect compositional variation of sedimentary origin but many of the quartzofeldspathic bands have been subsequently introduced and form the first-generation migmatitic leucosome.

The schistosity is frequently observed as an axial-planar structure to folds of the gneissose banding (Fig. 5A). In such structures it is apparent that the dominant foliation is a composite planar structure composed partly of transposed earlier banding and partly of a new axial-planar schistosity. The deformation responsible for this ubiquitous and penetrative foliation is referred to as D1, the folds as F1 and the foliation (schistosity) as S1. No large-scale folds of this generation have been definitely recognised but some of the apparent closures in the early basic bodies (e. g. at 448465) may be due to F1 folding. Most of the F1 folds recognised are in the range 5—50 cm in wavelength.

The S1 fabric consists principally of the planar alignment of biotite, muscovite and hornblende. Garnet occurs in certain rock types and seems to be generally late or post-tectonic with respect to D1.

From the relationship between the F1 folds and the migmatitic leucosome it is clear that granitic veining took place both before and after F1.

PRE-D1 STRUCTURE

The presence of occasional interference structures intrafolial to the S1 foliation (Fig. 5B) suggests that there may have been a phase of minor folding prior to F1. The wide variation in plunge of the F1 fold axes could be explained by their superimposition on a variably-oriented surface (i. e. folded by pre-F1 folds) although it is also possible that this variation is entirely due to heterogeneous flow during F1.

D2 STRUCTURE

The S1 foliation and the post-S1 granites and migmatites are affected by a widespread set of folds (Figs. 2, 5) which trend parallel to the present dominant foliation trend (i. e. varying from NE—SW to NW—SE). The change in trend is due to later re-folding. These folds (F2) are characteristically tight or isoclinal, and often asymmetric, with long limbs dipping east at a moderate angle, and short limbs with a much steeper dip (Fig. 5C). The wavelength varies from quite small (1 cm to 1 m in outcrop-scale folds) to mappable major folds with wavelengths of several hundred metres. Several of these major folds have been mapped from the north coast of Lavö to Hälleviksstrand (Pl. 1, Fig. 11). Mesoscopic parasitic folds of the type shown in Fig. 5C are relatively widespread and abundant.

The compositional banding and the S1 schistosity are folded around the F2 fold hinges (Fig. 5D) and appear to be relatively un-modified there, but on the F2 fold limbs the banding is thinned and the S1 fabric extensively modified by shearing producing a distinctive new fabric marked by a diminution of grain-size and by a variable degree of mineral replacement (e. g. biotite by muscovite). The effect of this new fabric is particularly evident in the previously undeformed granitic veins which were post-tectonic in relation to F1. New penetrative axial-planar fabric is only locally produced.

STRUCTURAL RELATIONSHIPS OF THE YOUNGER INTRUSIONS

Acid and basic intrusions forming discrete, mainly dyke-like, bodies cutting the S1 foliation and the granitoid bodies of the migmatite complex are very numerous throughout the area. These sheet-like younger intrusions are distinguished from the older granites by their relationships to the D2 structures. The younger intrusions cut F2 folds and associated shear belts which deform the older granites.

Since many of these younger intrusions have been deformed and possess a foliation which may be near parallel with that in the host rocks, the age relationship of dykes and structures is more difficult to interpret than would be the case with undeformed intrusives. On the other hand, the presence of the intrusives offers a useful stratigraphic marker to separate pre-dyke and post-dyke deformations which otherwise might be difficult to distinguish. Although many dykes (particularly of the basic suite) are superficially concordant with S1 and S2, it is clear on close examination that this concordance is due to a tendency to sill-like, i.e. concordant intrusion, and local discordance of apparently concordant bodies can usually be found.

PRE-DYKE DUCTILE SHEARS AND BRITTLE FAULTS

Ductile shears are common in the area and may displace and thus post-date the dykes. Others equally clearly pre-date the dykes (cf. Fig. 6A). There are several good examples in the small island off the southwest point of Härmanö of NE—SW dykes meeting N—S shears and being deflected along them. In some cases further movements along the shears have deformed the dykes after emplacement. There must therefore have been two periods during which these shears developed, although it is often difficult to establish the age of a particular shear if its relationship to a dyke is not seen. The pre-dyke shears appear to be mainly N—S in orientation and have only been observed on Härmanö. There is also evidence of brittle faulting both before and during the emplacement of the younger intrusions many of which appear to be intruded dilationally along fractures (Fig. 6C).

EMPLACEMENT OF THE YOUNGER INTRUSIONS

The granitic dyke-like intrusions exhibit a wide range of trend and dip and there does not appear to be any clearly defined preferred orientations.

The basic dyke suite is much more regular in orientation. On Härmanö, Råön and south of Stocken, the basic dykes are most frequent and generally trend

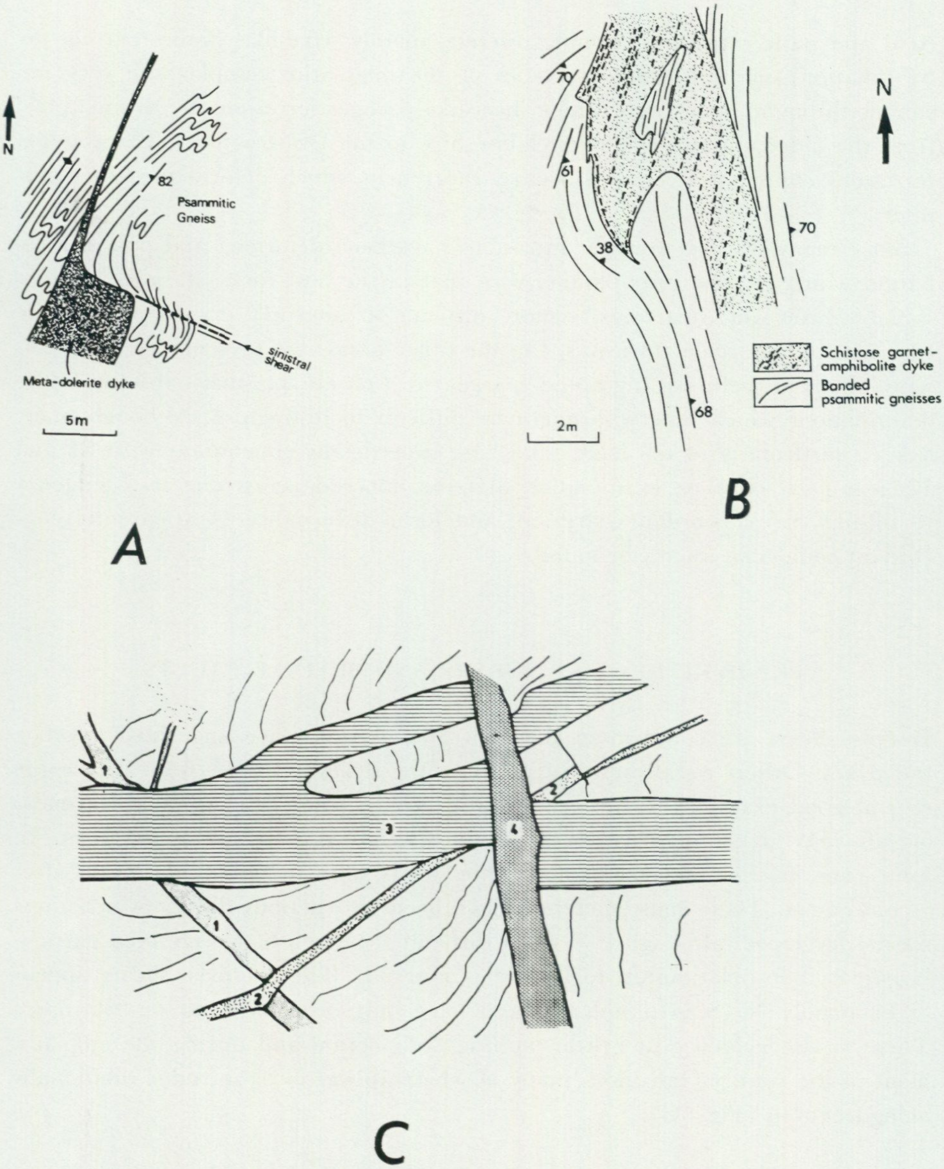

Fig. 6. Structural relations of the dykes.
A. Metadolerite dyke cutting psammitic gneisses affected by a sinistral WNW—ESE shear. The eastern margin of the dyke follows the shear for about 5 m before returning to its NNW—SSE trend. The western margin is straight and presumably follows a fault which displaces the shear. The dyke is clearly later than both the fault and the shear.
B. Basic dyke (now garnet-amphibolite) cutting banded psammitic gneisses. The dyke possesses a schistosity oblique to its margins resulting from simple shear parallel to the margins.
C. Four generations of granitoid sheets cutting banded gneisses. The sheets appear to be cut by faults along which the later sheets have been intruded.

N—S to NNE—SSW with a steep dip to the east. They are concentrated in the steep N—S shear belts where they are broadly concordant with the foliation although showing numerous local deflections. Away from these shear belts, the trend is more typically NNE—SSW. In the eastern half of the area dykes are much less frequent and directions more variable — both NW—SE and NE—SW trends are found here. It could be argued that both the concordance and greater density of the dykes in western Härmanö are effects of the post-dyke deformation. We believe, however, that the variation in spacing is mainly original although it has undoubtedly been accentuated during the post-dyke shearing.

POST-DYKE STRUCTURE

The structures which post-date the younger intrusions are characterised by their more heterogeneous and localised development. The type of structure found depends on whether the rock has already been deformed or not and thus the granites and metadolerites of the younger intrusive suites show quite different effects from the generally well-foliated gneisses and migmatites of the earlier complex. Because of their previously undeformed nature, the intrusions may be used as a guide to the later structural history of the area. This may be simply divided into a foliation-producing phase (D3) followed by three fold-producing phases (D4—6) and by the formation of shear belts and faults.

D3 STRUCTURE

The D3 structure of the basic dyke suite consists of a planar mineral fabric (S3) caused by the dimensional orientation of felsic or mafic aggregates and by the alignment of biotite and hornblende. Where the dykes are N—S and steep in attitude, the foliation is usually concordant with the dyke margins but where the dykes have different orientations, the foliation may be oblique or sigmoidal (e.g. see Fig. 6B). Many dykes, particularly in the west, are weakly deformed or even apparently undeformed. The extent of deformation is not simply related either to the width of the dykes or to its location. The widest dykes, in south-western Härmanö, which possess coarse gabbroic textures, are often little deformed in their central portions but may be foliated near their margins. However, many very narrow dykes are also undeformed or weakly deformed. Although individual exceptions occur, it is generally true that the dykes in the pre-dyke shear belts are more strongly deformed than those outside, presumably due to reactivation of the shears during D3. F3 folds are uncommon in the basic dykes, presumably due to the generally unfavourable orientation of the latter with respect to the compressive stress.

The granitic dykes show a much greater variety of structure due to their more varied orientation and lithology. S3 foliation, expressed mainly as a planar alignment of biotite and muscovite, is widespread and is often highly oblique to the dyke margins. Dykes with trends around E—W may be locally folded with S3 assuming an axial planar relationship and passing into the host gneisses.

Deformation in the gneiss complex was probably confined to flattening and shearing of the previous planar fabric which, in western Härmanö where the deformation can be most easily recognised, is sub-parallel with the S3 fabric in the dykes.

D4 STRUCTURE

There are three sets of folds which post-date the D3 foliation in the dykes, and the relationship between them is rather difficult to ascertain. F4 and F5 may well be coeval. F4 which is virtually confined to the northern part of the area from the north coast of Härmanö to the Lavösund is characterised by horizontal to moderately south- or southeast-dipping axial planes. The folds vary from open to tight and from several millimetres to tens of metres in wavelength. Their intense development in a 1 km-wide belt in Lavö is probably responsible for the NE—SW trend of S1 in that area (see Fig. 11). At Bjönni, a N—S F2 fold is partly re-oriented into the NE—SW orientation (see P1. 1) and this phenomenon is repeated at outcrop scale throughout the belt.

The minor folds typically exhibit chevron style with local crenulation cleavage (Figs. 7A, 8) which is particularly evident in the more schistose rocks (e.g. well-foliated amphibolites and mica-gneisses). Although the S4 planar fabric is mainly achieved by the rotation of micas, etc. on crenulation limbs (Fig. 7B), some recrystallisation of micas has also occurred.

From the geometry of the chevron folds, which commonly have more sheared south- or southeast-dipping limbs, the overall relative sense of movement of the D4 structure seems to have been upwards towards the north or northwest.

D5 STRUCTURE

D5 folds and foliation have a NE—SW to ENE—WSW trend similar to that of D4 but are distinguished by their steep dip. They are more widespread than the D4 structures but are concentrated in a belt through the centre of the area

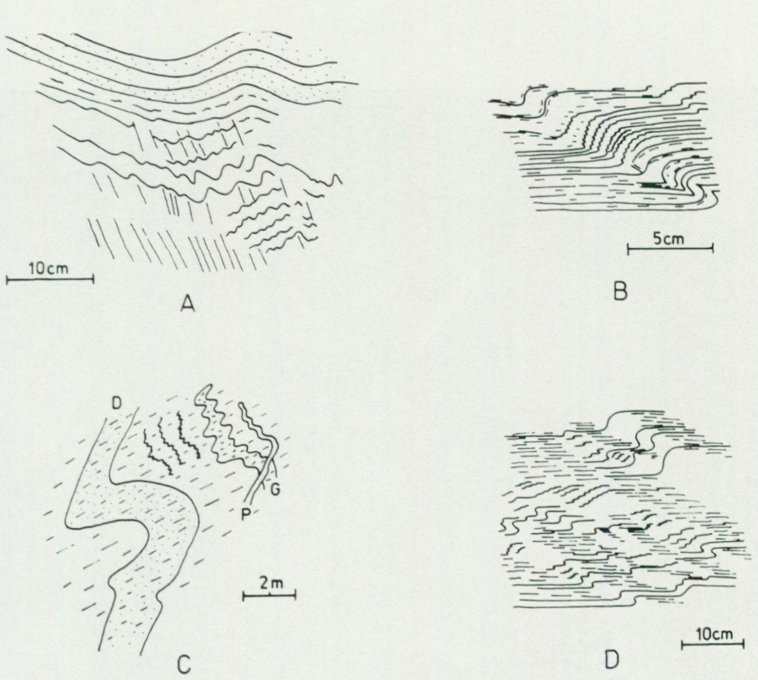

Fig. 7. Post-dyke small-scale folds (F4—6).
A. Open F4 fold in psammitic layer passing into tight chevron folds with a crenulation cleavage in the more micaceous semipelitic layers.
B. Detail of an asymmetric F4 fold in semipelitic gneiss showing the bending of micas (S1) around the fold hinge and the local development of crenulations.
C. F5 buckle folding of varying amplitude affecting a basic dyke (D) a granite sheet (G) and a pegmatite (P). S1 in the gneisses is also affected by the folding and a new penetrative planar fabric (S5) is present both in the gneisses and in the newer igneous rocks but is particularly evident in the granite as a biotite orientation.
D. Asymmetric F6 folds, mainly of chevron style, affecting highly sheared semipelitic gneisses.
Drawn from photographs.

from southern Råön to just north of Hälleviksstrand (Fig. 11). In the most strongly deformed part of this zone, which is about 300 metres wide and includes the islands north of Saltö, the older structure is almost obliterated. Farther north, in the small islands east of Rörholmen, on the peninsula south of Stocken and in east central Härmanö, S5 is widespread in the gneisses but the older foliations and the compositional banding are clearly distinguishable. The S5 foliation shows much variation in orientation on a small scale and is refracted from more micaceous into more quartzo-feldspathic layers.

The folding and associated crenulation cleavage are similar in style to those of D4. The D5 fabric also bears a close similarity to that of D4 except that a strong penetrative planar fabric is more typical (Fig. 9). In the intensely deformed zone especially, many previously undeformed granitic rocks of both ol-

Fig. 8. F4 crenulations and crenulation cleavage affecting semipelitic paragneisses and an amphibolite sheet of the basic dyke suite. Southwestern Härmanö.

der and younger suites develop a planar biotite fabric, the dykes and gneisses are folded together and possess a common penetrative S5 foliation (see Fig. 7C).

There appears to be only a narrow zone of overlap between the D4 and D5 belts, within which, at a few localities on the northern coast of Lavö, SE-dipping S4 foliation is affected by upright NE—SW F5 folds. The dip of the axial planes of F4 folds appears to steepen southeastwards toward the zone of D5 deformation, which could either be an original feature or an effect of the D5 deformation itself. The similarity in geometry and orientation between the two phases suggests a genetic connection.

South of the main belt of D5 deformation, around Hälleviksstrand, there are numerous gentle to open folds with relatively steep NE—SW and NW—SE limbs, the latter often sheared. The axial surfaces of these folds are parallel to the E—W S5 mica fabric developed in the granites north of Hälleviksstrand.

Fig. 9. F5 folding and associated shears affecting migmatised semipelitic paragneiss with alternating more psammitic and more pelitic layers. Note the penetrative S5 planar fabric to which the shears are sub-parallel. Coast E of Koskär island.

D6 STRUCTURE

Many folds of buckle, chevron or kink-band type do not appear to belong to the D4 or D5 sets and are included in a separate phase (F6) which probably post-dated D5 although their relative age is very difficult to establish. Such structures are found throughout the area but are much more localised and less pervasive than the D5 structures. On Härmanö, where the previous foliation is fairly regular with a generally N—S trend, F6-type folds occur with a wide variation in trend but uniformly steep dip. One set are asymmetric, trending ENE to NE, parallel to F5 elsewhere and difficult to distinguish from them. There is also a set of symmetrical chevron folds, sometimes accompanied by a crenulation cleavage, with a strike of between 100° and 120°. A few asymmetric folds with trends around 160° were observed in addition.

Fig. 7D shows typical F6 chevron folds in a finely laminated gneiss. In the micaceous bands a closely-spaced crenulation cleavage is evident. Unlike the D5 structures, there is no general penetrative fabric associated with these folds and biotite has not recrystallised.

POST-DYKE SHEARS AND FAULTS

Ductile shears are common throughout the area and vary widely in orientation. Most shears are steep with either a sinistral or a dextral sense of movement (Fig. 10). Sinistral shears vary in trend from around NW—SE to NE—SW and dextral shears from NE—SW to WNW—ESE. Although there is an overlap between the trend range of sinistral and dextral shears over the area as a whole, in various parts of the area (e.g. southern Härmanö, Lavö, see Fig. 13C), the sinistral and dextral sets cluster about mean positions which are quite distinct. Many of the N—S shears in Härmanö which have a steep eastwards dip show an east-side-up as well as sinistral sense of movement. Some of the N—S shear belts in western Härmanö reach about 100 m and the total movement across them must be substantial.

Some narrow N—S shears are very well exposed on the extreme southwestern part of Härmanö and on the adjoining island where they clearly offset basic dykes. Several of these shears appear to be pre-dyke structures re-activated in post-dyke times. The dykes here trend NE—SW, which enables their displacement by the N—S shears to be determined. Similar movements on other N—S shears in Härmanö have probably taken place but are undetectable because they affect mainly N—S trending structures and lithologies.

The precise age of many shears in relation to the fold sequence and the dykes cannot be determined. However, there seems to be no very marked change in orientation between proved pre-dyke and post-dyke shear sets. Evidently some of the post-dyke shearing is of D3 age since many basic dykes have acted as small shear belts and possess sigmoidal S3 foliation. Sheared gneisses in some of the wide N—S shear belts are deformed by F4, F5 and F6 folds but other shears displace F5 folds and S5 foliation. Since any subsequent deformation would cause the reactivation of suitably oriented shears, shear movements therefore probaly took place throughout the period of F3, F4 and F5 folding and perhaps outlasted it. Examination of the shear fabrics shows some retrogressive recrystallisation involving, for example, the replacement of biotite by chlorite and the breakdown of plagioclase. However, the retrogressive fabric may have developed at a late stage in the history of the shearing.

There are a number of faults in the area with various orientations. Several NW—SE faults in the Lavö-Bjönni area have a largely vertical displacement. Two NE—SW faults near Hälleviksstrand are probably also normal. The NW—SE sinistral faults in southwestern Härmanö may have originated as ductile shears. The large fault which bounds the area on its eastern side, occupying a prominent valley, is exposed in a small quarry at Bro where it strikes N—S and dips 60°E. A wide quartz vein has been emplaced along the fault here. The fault varies in trend from NW—SE in the south to N—S along the central and northern parts of the map. The major NW—SE and NE—SW faults of the

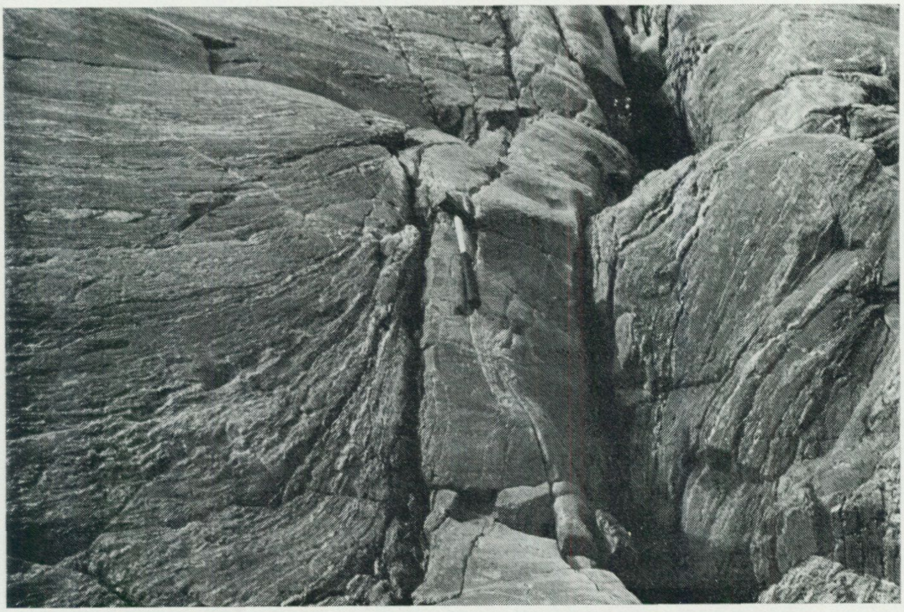

Fig. 10. Steep sinistral shear-zone along a "younger granite" sheet. Southwestern Härmanö.

mainland end at this major fault which is probably a normal fault with an easterly downthrow.

LARGE-SCALE STRUCTURE

The large-scale structure will only be completely understood when a larger area has been mapped. The main elements of this structure are indicated on Fig. 11A. In those areas least affected by subsequent deformation, the trend of the S1 banding is N—S (or NW—SE in the southeast). This trend results from the intense regional F2 folding with steeply east-dipping axial planes. Major F2 fold closures can be seen at Hälleviksstrand, Hästekälla and Björnni.

This F2 structure is affected by large E—W or ENE—WSW trending folds (see below) with similar geometry to the mesoscopic F5 folds. The relationship between the large-scale F2 and F5 structure is shown diagrammatically in Fig. 12A. A large arc of S1 banding and foliation extends from the northeastern coastline at Lavö, through Stocken to Hälleviksstrand. This fold is open, with a maximum fold angle of 100°, and closes to the west. It has a steep eastwards plunge. Further west, this simple structure is replaced by a zone of smaller-scale folds with the same trend. This zone corresponds to the domain of mesoscopic F5 folding and S5 foliation. The largest structure in this zone is an asymmetric

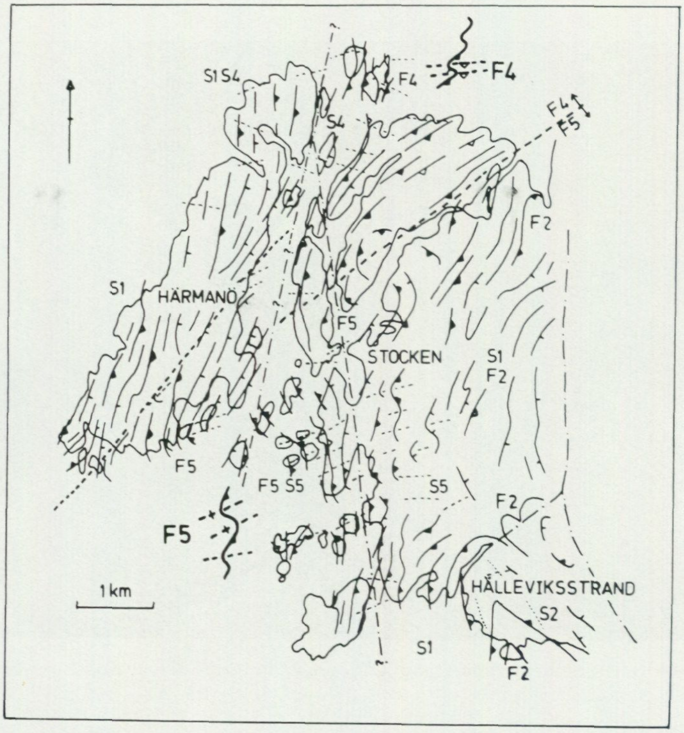

Fig. 11. A. Simplified structural map of western Orust, showing S1 trend lines. Low dips (0°—30°) = open triangles, moderate dips (30°—60°) = closed triangles, steep dips (60°—90°) = short lines. S4 and S5 trends are shown by dashed lines. The northern margin of the zone of F5 deformation is shown by a heavy dashed line.

double-fold with N—S steep limbs and a middle limb with variable and often low dips to the north or northeast. This fold can be traced through the small islands between Härmanö and Stocken, and is displaced northwards into the fold of s. Lavö. In Lavö the structure is complicated by interference between F2, F5 and, in the north, F4.

The islands east of Gullholmen and northwest of the Lavö coast show a transition between the dominantly N—S trending banding of Härmanö and the NE—SW banding of Lavö. The change appears to be due to the increase in frequency and eventual dominance of F4 folds with NE—SW axial surfaces dipping at low to moderate angles to the southeast.

The geometry of the F4 folds and their apparent restriction to the northern part of the mainland suggest that they may be explained by a low-angle shear zone as shown diagrammatically on Fig. 12B. If this model is correct, it implies that most of the area lies above the shear zone and has been transported northwards relative to the rocks below and to the north.

Comparison between Härmanö and the east. The zone of F4 folding cannot

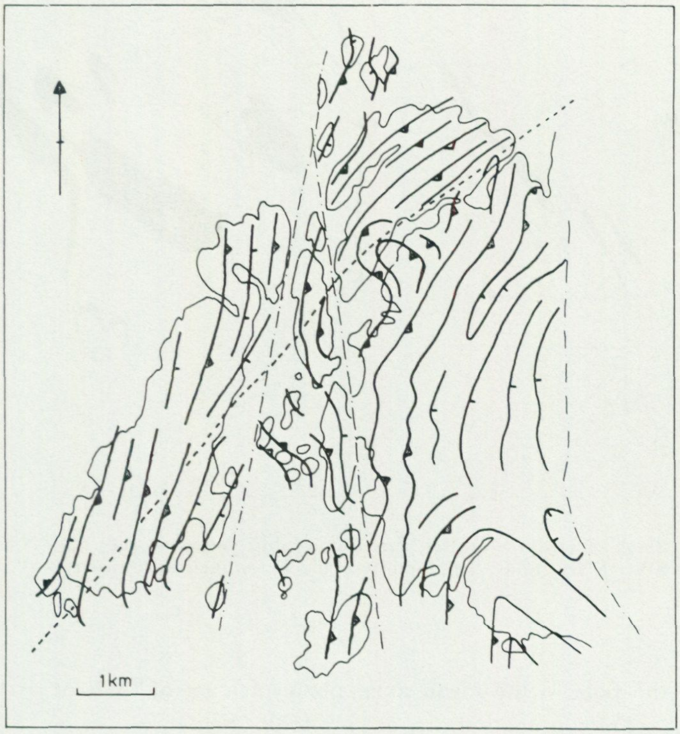

Fig. 11. B. Reconstruction of the area assuming that the F5 zone margins was originally straight.

be traced directly into Härmanö from Lavö although individual F4 folds occur throughout that island with axial planes generally steepening southwards. Intense F4 folding is confined to the northern coast of Härmanö. This lack of continuity is probably to be explained by a fault or shear along the east side of Härmanö which could also explain the apparent dextral displacement of the northern margin of the zone of strong F5 deformation.

Fig. 11B shows a reconstruction of the area with the postulated fault movement restored assuming that the margin of D5 deformation was continuous.

ANALYSIS OF STRUCTURAL ORIENTATIONS

The orientation of the bulk finite strain axes resulting from each deformation can be approximately determined from the geometry of the various structures and is summarised in the form of the mean "apparent shortening axis" Z_{ap} —

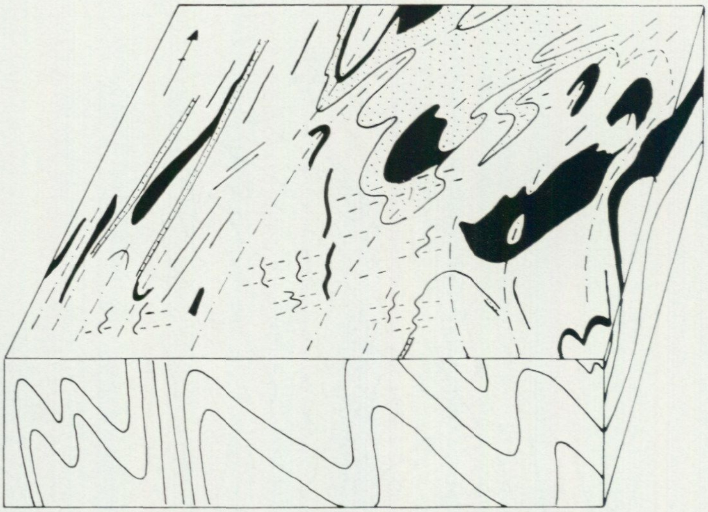

Fig. 12. A. Block diagram showing the relationship between the F2 (N—S) and F5 (WSW—ENE) folds. Amphibolites = black, semipelites = dotted.

defined as the pole to the mean axial plane of a set of folds or as the (short) bisector of a set of conjugate shears or kink-folds (Fig. 13).

Under certain strictly defined conditions, the orientation of the maximum compressive stress σ_1 can be obtained directly from the sense of shear on sets of sinistral and dextral shears (Davidson and Park 1978). However, in general, the relationship of Z_{ap} to the regional stress-field will depend on a number of factors, in particular whether the shortening was accomplished by pure shear or simple shear.

The rather flat-lying enveloping surface of F2 folds (Fig. 12A) implies a sub--vertical Z_{ap} in D1. For D_2, Z_{ap} is E—W with a low plunge to the east (Fig. 13A). The D3 position is WNW—ESE with a probably low plunge (Fig. 13B) and is indistinguishable from the poorly-defined position obtained from the pre-dyke and post-dyke shears (Fig. 13C). Some stress relaxation must have accompanied the dyke intrusion since many dykes are approximately perpendicular to this direction. Z_{ap} changes to a N—S azimuth in D4 with a steep plunge to the north (Fig. 13D). The azimuth is approximately the same for D5 but the plunge is sub-horizontal (Fig. 13E). The position of Z_{ap} in D6 (Fig. 13F) is poorly defined but is probably similar to than in D5.

Not enough is known about the regional structural context of Orust to assess the significance of the structural geometry. However, it may be assumed that the change from E—W to N—S shortening implies a significant change in the stress field between D3 and D4.

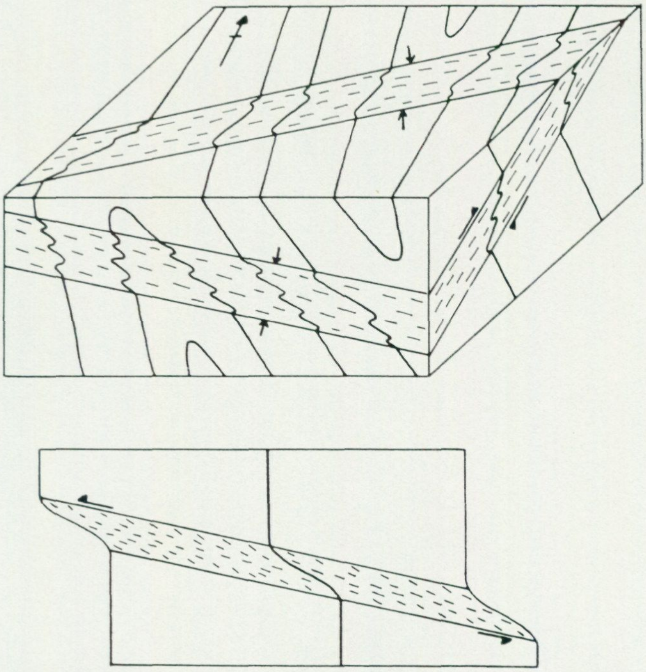

Fig. 12. B. Block diagram showing how the zone F4 folding could be explained by a shallow shear zone with WNW—ESE outcrop and low dip to the SSE. The short dashes indicate the attitude of F4 axial planes.

METAMORPHISM

Pre-dyke metamorphism. The S1 fabric consists principally of biotite, muscovite and hornblende. Garnet is probably post-tectonic. No minerals diagnostic of the upper amphibolite facies have been found, but this is presumably due to the absence of suitable rock types or to subsequent recrystallisation. The ubiquitous occurrence of granitic secretion veins is indicative of the upper amphibolite facies. The migmatites produced before and after D1 are deformed by F2 folds. Individual granitic veins are folded, sheared and recrystallised, but no new granitic secretion veins are formed at this time. This suggests that the metamorphic grade might be lower during D2 than in D1 although there is no evidence of retrogression below amphibolite facies.

Temperatures during dyke intrusion. The complex must have cooled sufficiently before the dyke intrusion for brittle fractures to form. There is no evidence in the basic dykes to suggest that the country rocks were particularly hot during emplacement.

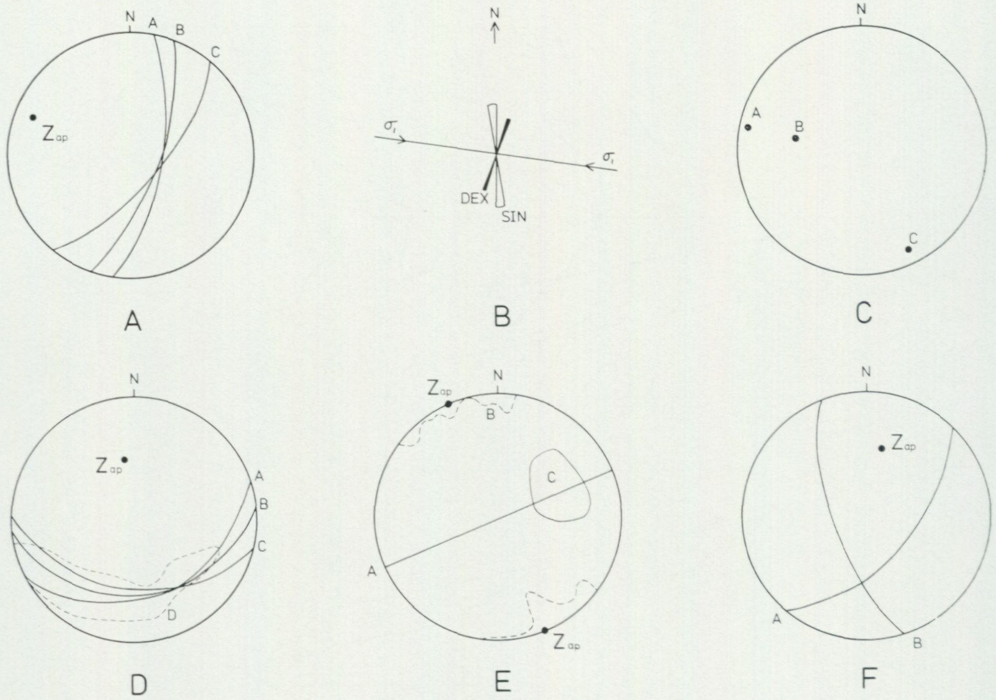

Fig. 13. Analysis of structural orientations.

A. D2 folding: Stereogram showing mean axial planes of F2 folds from northern Härmanö (A = 9 measurements), Stensbo (B) and Hälleviksstrand (C). The position of Z_{ap} is assumed to correspond with the pole to the mean of A, B and C (see text).

B. D3 deformation: Rose diagram showing trend concentrations of sigmoidally-foliated dykes in west central Härmanö (4 sinistral and 3 dextral). The trend of σ_1 is assumed to bisect the angle between the last dextral and the first sinistral dykes. The dip of the dykes is steep (c. 70° E).

C. Pre-dyke and post-dyke shears: Stereogram showing position of σ_1 calculated from sets of conjugate shears in northern Härmanö (A), southern Härmanö (B) and Lavö (C).

D. D4 folding: Stereogram showing mean axial planes of F4 folds from Lavö (A = 11 measurements), central Härmanö (B = 52 measurements) and northern Härmanö (C = 34 measurements). Spread of F4 fold axes from central Härmanö is enclosed by a dotted line = D. The position of Z_{ap} is assumed to correspond with the pole to the mean of A, B and C.

E. D5 folding: Stereogram showing mean S5 axial planar foliation (A), spread of poles to S5 foliation enclosed by dotted line (B = 33 measurements), and spread of F5 fold axes enclosed by a continuous line (C) which includes both individual minor fold axes (7 measurements) and π-poles for 8 sub-areas showing major fold axes. The position of Z_{ap} is assumed to correspond with the pole to the mean orientation of S5.

F. D6 folding: Stereogram showing mean axial planes of two conjugate sets of F6 folds in Härmanö (9 measurements). Z_{ap} is assumed to bisect the conjugate axial planes normal to their intersection.

Post-dyke metamorphism. The first metamorphic fabric in the dykes (usually D3) consists mainly of hornblende and biotite. Garnet tends to overgrow the first fabric. Plagioclase of An35 composition suggests the amphibolite facies but the precise grade is not yet known.

Subsequent deformations produce retrogressive fabrics in the dykes. F4 chevron folding produces crenulation cleavage accompanied by limited recrystallisation of micas. Biotite is still stable but epidote partly replaces plagioclase, and in the gneisses there is considerable growth of muscovite due to the recrystallisation of the feldspars. Garnet is apparently not retrogressed. D4 is therefore considered to have taken place during upper greenschist-facies metamorphism. The F5 folding produces similar fabrics with biotite still stable. D5 is often the first deformation to produce a planar fabric in many granitic rocks and is typically marked by biotite alignment.

Local retrogression of biotite and garnet to chlorite in rocks with D4 and D5 fabrics is attributed to post-D5 retrogression. Some of this retrogression is associated with later shears but the retrogressive effects are widespread and constitute a definite regional event which may or may not be accompanied by movements along pre-existing shear planes. The age of this lower greenschist-facies retrogressive event in relation to D6 is not clear. No new fabrics have been recognised in F6 folds.

GEOLOGICAL HISTORY

SEQUENCE OF EVENTS IN WESTERN ORUST

The formation of the early migmatite complex. The first recognisable event in the geological history of the area (see Table 1) is the deposition of the sediments of the Stora Le—Marstrand Group that have given rise to the paragneisses. The older amphibolites probably represent a suite of basic to ultrabasic sills and dykes (or possibly volcanics) emplaced within the sediments prior to deformation and metamorphism. The rocks were then transformed into migmatitic gneisses with the widespread development of veins of granitoid leucosome and intensely deformed during the D1 deformation, probably in the upper amphibolite facies.

The Hälleviksstrand amphibolite. This intrusion of intermediate to basic composition cuts migmatitic gneisses deformed in D1 and contains inclusions of the

TABLE 1. Sequence of events in western Orust.

	Deformation	*Metamorphism*
D1	intense regional folding, penetrative foliation	high amphibolite facies ?
D2	N—S tight asymmetric folds facing W	lower amphibolite facies
	shears and faults	cooling
D3	foliation in dykes, shears	low amphibolite facies
D4	zone of chevron folding, shallow axial planes	greenschist facies
D5	zone of NE—SW folding, steep axial planes, local penetrative foliation	
D6	local conjugate kinks, asymmetric folds and E—W chevrons	cooling
	shears and faults	

Migmatisation	*Igneous activity*
early granitoid leucosome ? ? later granitoid leucosome	ultrabasic to basic intrusives (older amphibolites) intrusion of Hälleviksstrand diorite-gabbro (amphibolite) emplacement of older granites
	intrusion of younger granite sheets followed by basic dykes
	↑ ? late pegmatites ? ↓ late dolerite dyke

older amphibolites. It has been dated by Daly, Park and Cliff (in press) and yields a perfect Rb/Sr whole-rock isochron giving an age of 1432 ± 92 m.y., interpreted as the age of emplacement in the crust.

The emplacement of the older granites. All the previous rocks are cut by members of the older granite suite and the accompanying migmatitic veining. These rocks range from melanocratic quartz-diorite through granodiorite to leucocratic alkali-granite, and from fine-grained to coarsely pegmatitic. They include several bodies of megacryst-bearing granodiorite. Most of these bodies are under 10 m in width. These rocks are deformed in the widespread and intense folding of D2 age with N—S to NW—SE trend and steeply eastward-dipping axial planes. Temperatures are thought to have remained high during the older granite emplacement and migmatisation but may have decreased during the D2 folding. This folding was followed by ductile shearing and by more brittle faulting.

The intrusion of the younger granites and basic dykes. The younger granites occur as widespread sheets of quartz-dioritic to adamellitic composition which cut the migmatitic complex and the D2 folds, and in some cases fill joints, small faults or shears. They are in turn cut by members of the basic dyke suite which contains minor ultramafic, intermediate and acid members, the latter distinguishable from the younger granites by their sharp chilled contacts. Some basic dykes are cut by minor acid pegmatites and aplite veins. Several thick pegmatite sheets in the north of the area may also be post-dyke in age.

The post-dyke deformation and metamorphism. The first post-dyke deformation D3 is expressed mainly as contact-parallel or sigmoidal foliation in the dykes and by shears in the gneisses which were formed in low or middle amphibolite--facies metamorphism. The sense of shearing indicates WNW—ESE shortening. This foliation is deformed by F4 and F5 folds (which may be essentially contemporaneous) with respectively shallow and steep axial planes but similar E—W to ENE—WSW trends. Both sets of folds can be explained by N—S to NNW—SSE shortening. They typically involve chevron folds with local crenulation cleavage and limited recrystallisation in middle greenschist facies, and occur in separate domains of limited lateral extent. The D6 folds are widespread but isolated in occurrence, of chevron or kink-band style, forming a conjugate set indicating further shortening along an approximately N—S axis. Metamorphism during the last folding appears to be no higher than low greenschist facies.

Later events. The latest structures are brittle faults, one of which is cut by an unmetamorphosed dolerite dyke in southwestern Härmanö which may belong to the Permian suite.

AGE OF THE COMPLEX

A younger age limit for the metamorphic and structural events of western Orust is provided by the undeformed and unmetamorphosed Bohus granite, which cuts the Stora Le—Marstrand rocks only a few km north of the mapped area, and has yielded an Rb/Sr isochron age of 891 ± 34 m.y. (Skiöld 1976).

The 1432 m.y. age of the Hälleviksstrand amphibolite is the first Rb/Sr age obtained from rocks of the Stora Le—Marstrand mega-unit and correlates with whole-rock Rb/Sr ages obtained on the augen granite of eastern Orust (Daly, Park and Cliff, in press) and on several other granites in the Sveconorwegian block of southwestern Sweden — the Harserud granite, the Ljungbergen granites and the post-Ellenö granite (all c. 1 400 m.y.; Skiöld 1976). It provides a younger limit to the age of the sediments of the Stora Le—Marstrand Group and of the early migmatisation and D1 deformation, and also an older limit to the later migmatisation which corresponds to a period of important regional plutonic activity recognisable throughout Orust and in Tjörn.

The suggestion by Gorbatschev (1971) that the Stora Le—Marstrand mega-unit may be equivalent to some of the early rocks and metamorphic events of the Pregothian receives some support from the above evidence, which is consistent with the proposition that the main gneiss-forming event in the Stora Le—Marstrand, as in the Åmål and Pregothian mega-units (Welin and Gorbatschev 1976a, b) occurred at or before c. 1 650 m.y. (see also Welin and Gorbatschev 1978).

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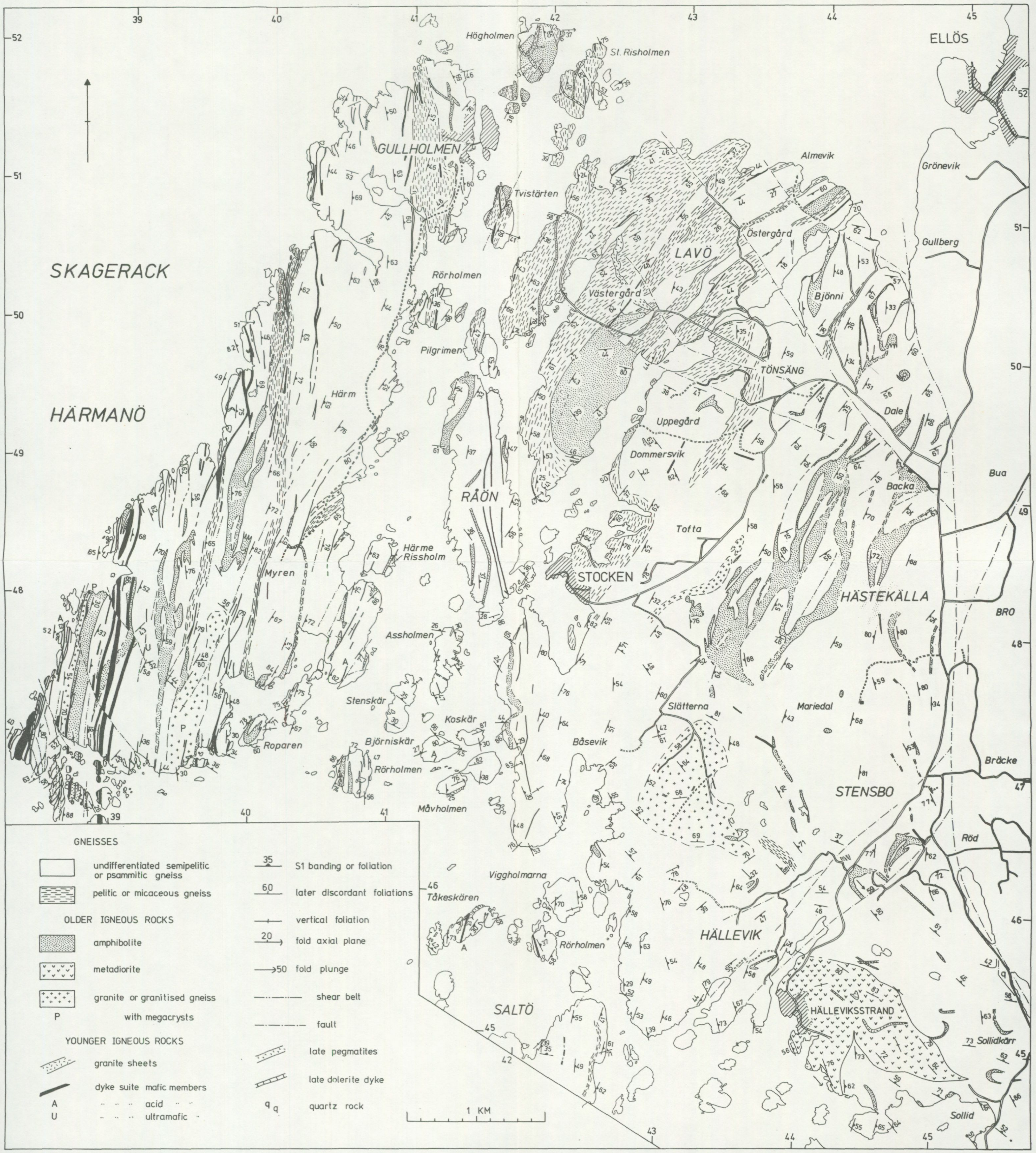
GEOLOGICAL MAP OF THE AREA AROUND STOCKEN, WESTERN ORUST

PL. 1



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