

SVEN GAVELIN

THE VÄSTERVIK AREA
IN SOUTH-EASTERN SWEDEN

STUDIES IN PROTEROZOIC
SEDIMENTATION, HIGH-GRADE
METAMORPHISM AND GRANITIZATION

WITH ONE PLATE



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ABSTRACT

The present report deals with petrogenetic problems within the Västervik area in south-eastern Sweden. The rocks are now classified as Svecofennian, with ages around 1 700—2 300 Ma. They consist of metasediments (mostly meta-arenites), metavolcanics, metabasites, and granites. Primary sedimentary structures are frequently preserved in some of the metasediments. This has made it possible to identify conditions of sedimentation and also to solve the stratigraphic and tectonic problems within the area with a reasonable degree of certainty. On the whole, the original sediments appear to represent shallow water deposits. Together, they give the impression of having at one time been part of a large delta complex. Regional metamorphism has transformed most of the arkosic and argillaceous metasediments into gneisses of various types. Within the gneisses it has sometimes been possible to see continuous transitions into granitoid bodies. Field studies, combined with mineralogical and chemical data, have led to the conclusion that in many cases this granitization took place in the solid state. This process cannot be explained solely as a result of variations of P and T. The activities of H₂O, K, pH, and possibly O₂ have also been decisive. This in turn means that pressure gradients created by kinematic metamorphism of the physically heterogeneous rock masses must also be considered.

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Sven Gavelin, Geol. Dept., Stockholm University, 106 91 STOCKHOLM

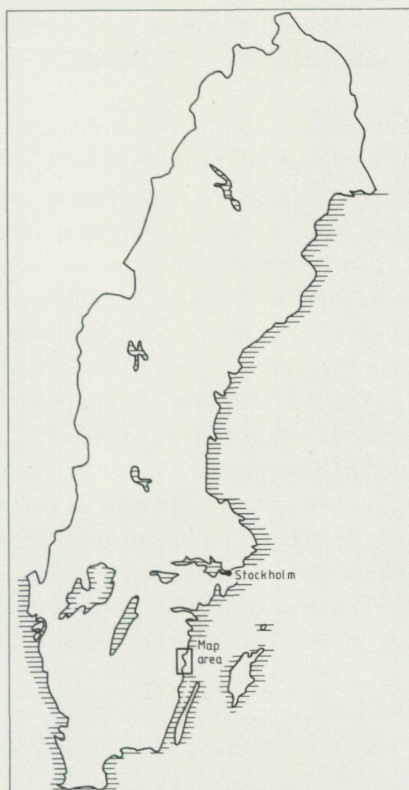


Fig. 1. Position of the map area.

1. PREFACE

The Västervik area as defined in this paper is situated on the south-eastern coast of Sweden, Fig. 1.

The present investigation was initiated by a field trip in 1948 under my guidance and with a number of advanced students in geology from the University of Stockholm. The excursion program was a copy of a previous excursion guided by my predecessor, Professor Quensel. He, on the other hand, had received this program from my father, Axel Gavelin, who at that time was Director of the Geological Survey of Sweden. Axel Gavelin did his doctor's thesis on material from an area north-east of Västervik, the Loftahammar area. Afterwards, however, he extended his field investigations towards the south and had a thorough knowledge of the areas around and south of Västervik. When he was appointed Director of the Geological Survey he had to give up his scientific work on these areas. In spite of the many interesting and illuminating geological features which were known to be involved in the Västervik area, no

further systematic investigations were carried out over the next decades. The geology of the area and the general problems were sometimes commented on in various papers dealing with more regional aspects. These will be referred to later on in this paper.

When I was first confronted with the Västervik area, I had been working with regional geological mapping in Northern Sweden (Västerbotten County), where the genetical problems of metamorphic supracrustal rocks, gneisses and granites, were one of the main scientific objectives. The Västervik excursion just mentioned made it clear to me that here, in the Västervik area, we had an outstanding opportunity to study in the field the relations between various rock types overtaken by high-grade metamorphism. Exposures along the shores of the mainland or islands in the archipelago are absolutely free from overburden and lichens. Frequently, the outcrops have been polished by the inland ice, making it possible to study structures in great detail. It is also often possible to follow very closely all kinds of primary or metamorphic transitions between contrasting rock types. For these reasons the area is particularly well suited for excursions aimed at studying genetic problems involved in the development of granites and gneisses. When excursions in Sweden were planned for the XXI International Geological Congress in 1960, it was decided that the Västervik area should be included in one excursion under the heading "Granites and gneisses".

The available geological maps covering the Västervik area were, however, very old. They gave a very unsatisfactory idea of different rock types present, their stratigraphic distribution, and tectonics. In order to be able to discuss the problems illustrated by localities to be visited, it was necessary to remap the area. After some preliminary field trips in 1957, a more systematic mapping was carried out during 1958—1960, covering some areas of immediate interest. This work was done with the assistance of some students and teachers from the Geology Department of the University of Stockholm. This part of the field work was financed by the Geological Survey of Sweden, which had taken the responsibility for planning the Congress excursions in Sweden. The Västervik area has after 1960 been used as an object for field courses at various levels for students in geology at the University of Stockholm. From the studies available up to 1960, it was evident that a more comprehensive presentation of the geology of the area would require much more extensive work. From 1965, systematic field work was started again, now with economic support from the Swedish Natural Science Research Council.

The field work and also much of the work at the Geology Department was performed by me and a great number of co-workers (researchers, teachers, and students at various levels). The results of some of these studies have been published. There have been theses for doctoral and licentiate degree, in addition to other papers on special problems of the area. Most of these papers will be

referred to and commented on in the following text.

The published papers contain a large number of pictures of structural and textural characteristic features of the metasediments in question. In many cases, a good photograph gives a much better idea of the characteristics of such a rock than what could be presented in print. So that the reader will not have to refer to all these publications, even in this paper the most representative features are repeated in figures. In addition to the published papers, a large number of short manuscripts on various subjects have been prepared by students as one of the requirements for their undergraduate degree (the phil.cand.examination). In those cases, where the results of such investigations have been directly used in the present presentation the names of the co-workers have been given although they are not found in the list of references.

Chemical analyses have been performed at the Geological Survey of Sweden (SGU) under the supervision of Dr. A. Danielsson. Calculations of Niggli values and other ratios used in this paper were also performed at the Geological Survey using their computer programs.

2. INTRODUCTION

Originally, the aim of my investigation was to study the transformation of sedimentary rocks over gneisses into granitoid rocks. It was evident, however, that all discussions on these problems must rest on a general knowledge of the main stratigraphic and tectonic features of the area.

The northern metasedimentary areas were previously presented on four published map-sheets at a scale of 1:50 000 in SGU Series Aa, viz. No. 137 "Västervik" (Svenonius 1907), No. 126 "Ankarstrum" (Svenonius 1905), No. 147 "Gamleby" (Svenonius 1914), and No. 127 "Loftahammar" (A. Gavelin 1904). The metasedimentary rocks to the south were found on a map-sheet at a scale of 1:100 000, SGU Ser. Ac, No. 5 "Oskarshamn" (Svedmark 1904). On these maps the metasediments were coloured yellow. Symbols on the yellow base colour indicate a coarse subdivision into some different petrographical types. Clearly meta-arenitic rocks were denoted by black dots, the distinctly gneissic types with quartz-feldspar veins by red streaks on a yellow bottom. A special type of spotted gneiss was marked by red crosses on yellow. Amphibolites, where they represented a characteristic constituent of the metasedimentary units, were indicated by green streaks on yellow.

This choice of subdivisions, however, was found to be unsatisfactory if the characteristic variations of all the original sediments and their metamorphic forms were to be surveyed. In previous publications, the metasediments of the area in question have frequently been summarized under the heading "Västervik

quartzites". My first, preliminary studies revealed, however, that, although quartzitic metasediments are very common, there also exists a great variety of other kinds of metasediments, see p. 9 ff.

In addition, there is also a belt of volcanic supracrustal rocks (map-sheet "Ankarsrum") about 20 km west of Västervik. They represent mainly acid volcanics — metarhyolites — although intermediate and basic forms also occur. They have been assumed to belong to a group of rocks which are widely spread in the inner parts of south-eastern Sweden and which has been collectively grouped under the heading "Småland porphyries".

The metasedimentary sequences have been intensely folded, frequently displaying vertical or even overturned bedding, which sometimes makes stratigraphic interpretations somewhat uncertain. Since no fossils are available it was necessary to establish some kind of lithostratigraphy. Fortunately the meta-arenitic rocks often display distinctive cross-bedding, and sometimes even graded bedding, making it possible in these cases to determine the up-down-directions of the sedimentary sequences. During the mapping all kinds of primary sedimentary structures were thoroughly recorded. From such information it was in certain areas possible to establish the positions of contrasting metasedimentary units and determine the main tectonic structures with a fairly high degree of accuracy.

As can be seen on the map (Pl. 1), the metasedimentary rocks occupy several separate areas which are, at least in part, separated by extensive masses of granite of various kinds. Within the areas of metasedimentary rocks, the structural pattern may vary considerably in complexity. When stratigraphic and tectonic features are discussed in a following chapter (p. 75 ff), we therefore start by describing those areas where conditions are particularly simple and unambiguous. Basic rocks, mainly amphibolites, are common in the metasedimentary rock sequences. They represent basic magmatic rocks in most cases. This basic magmatism is of great importance in considering the general geological evolution of the area.

The granites, which in part occur in the central parts of metasedimentary areas and in part delimit the more thoroughly mapped areas, represent various ages of emplacement. Classification of the granites into generations of different ages turned out to be more difficult than it was thought to be at the start of the investigation. Generally, my own studies of the granites have been restricted to the border zones between granites and metasediments (including paragneisses), whereas the inner parts of the vast granite massives have been studied only superficially. Peter Kresten, on the other hand, has devoted more time to study the granite areas on a broader scale. His contributions will be referred to in the chapter on the granites.

The map, Pl. 1, requires some special comments. Restrictions of time and money for the mapping work have not allowed for a perfectly uniform recording

of outcrops and various structures over the whole area. Since the first step of our investigation was intended to present a provisional picture of the main geological features within those areas where the localities of the 1960 Congress excursion (see S. Gavelin and P. H. Lundegårdh 1960) were situated, these central areas were studied first. At that time, the main field work was concentrated to shore belts around islands and well exposed localities on the mainland. Poorly exposed inland localities were sometimes recorded in a more superficial way.

Later on, when the field work was extended over the whole area (included in the map, Pl. 1,) certain parts were studied in very great detail, while others were characterized by a more sparse net of observations. All these differences with respect to frequency of observation points will be commented on in connection with the treatment of individual sub-areas.

For the most part, field data were recorded on maps from the so-called Swedish "Economic map" series at a scale of 1:10 000. However, there exist many islands or smaller areas where certain geological features are marvellously exposed and where certain genetical problems can be clearly evidenced by field data. In such cases detailed mapping on still larger scales was necessary. Several such investigations have been performed by my co-workers. There still exist, however, many objects suitable for further detailed field studies, which, at least sometimes, may serve as a background for geochemical, petrological or mineralogical problems of more general significance.

Owing to the reduced scale of the geological map, 1:100 000, it has been impossible to present the positions of the numerous localities necessary for the construction of the map. For the same reason, only a restricted number of observations of strike, dip and fold axes have been given. Additional data can be found in the provisional maps on the scale 1:50 000 which have been stored up in the archives of the Geological Survey of Sweden together with a selected number of hand specimens and thin sections as well as the author's field note books and a great number of field maps on the scale 1:10 000.

3. DESCRIPTION OF ROCKS

3.1. SURVEY OF THE METASEDIMENTS AND THEIR PRESENTATION ON THE MAP.

As was mentioned above, quartzites are quantitatively the most important metasediments within the area mapped. They may sometimes be fairly pure quartzitic rocks. Those in and around the town of Västervik have frequently been taken as examples of typical representatives of the "Västervik quartzites". More micaceous and/or feldspathic compositions also occur within the areas that have

been characterized as "quartzites" on the map. The quartzites have been denoted by light blue colour on the map. An increase in the mica content has been indicated by the use of black streaks on light blue.

Several other kinds of metasediments were discovered during the field work, where we recognized three additional main groups. Each group was recorded by its own colour on the provisional field maps. One group consists of red or pink meta-arenites which contain considerable potash feldspar but fairly little biotite. Generally, these rocks are very restricted in areal extent. However, in the northern part of the published map two areas appear where they form larger continuous rock units. Megascopically, they have a very characteristic appearance and were therefore recorded with a specific colour — darker blue. On the basis of their mineral compositions they would be classified as meta-arkoses, assuming the composition represents primary epiclastic sediments.

A second main group is characterized by an alternation between reddish and grayish bands, both rich in quartz and feldspar. The grayish bands show a higher biotite content. In many respects, this is a very heterogeneous group, as will be seen from the more detailed descriptions below. The rocks, however, are easily identifiable and often play an important role in lithostratigraphic considerations. The group has been called the red-gray metasediments and is presented with light gray on the map.

The third group of metasedimentary rocks has been called the gray metasediments, a name which simply refers to their appearance in the field. The gray metasediments have been indicated on the map by dark gray. The rocks are composed of meta-arenites as well as meta-argillites. Mineralogically, the metamorphic argillitic portion of the metasediments is now represented by such characteristic minerals as cordierite, andalusite, and/or sillimanite. During our provisional mapping, I believed that the meta-arenitic members represented a graywacke suite and that the meta-argillitic members corresponded to graywacke-argillites. Later, however, it was found that gray meta-arenites frequently are decidedly potassic. In addition, rocks of the gray metasediments still contain such minerals as, for example, cordierite in appreciable amounts. Analyses of these so-called gray metasediments show that, chemically, the rocks can hardly be classified as graywackes since potassium dominates over sodium. We will return to this question in a later chapter. The red-gray, the red, and the gray metasediments may frequently occupy the same lithostratigraphic position. Laterally, one rock type may continuously pass over into another. In some instances, one of these three types may form very similar-looking rock sequences over wide areas. Ordinarily, the boundary between these types and quartzites, as presented on the geological map, does not involve any serious complications. There are of course cases where gradual transitions occur. As can be seen on the map, quartzites often form very large homogeneous bodies. There are several areas, however, where pure quartzite occurs as sharply delimited, fairly narrow beds

within sequences made up predominantly of potassic meta-arenites.

Units which originally were argillaceous now appear as micaschists with cordierite, sometimes with andalusite and/or sillimanite. Sometimes these rocks form thin intercalations in micaceous quartzites. In some cases such beds have been taken to characterize a certain lithostratigraphic unit. They may be followed laterally over large distances in spite of the fact that they are only 2—20 dm thick. On the map they are denoted by dark gray lenses on light blue with black streaks. In the chapter on the sedimentary evolution I will comment these patterns more thoroughly.

The main characteristic features of the sedimentary sequences can be summarized as follows.

The primary sediments were originally mainly arenites. These arenites were in part — and perhaps mainly — fairly pure quartz sands, which means that they represent a fairly mature sedimentation. However, there also occur a lot of feldspathic arenites, which would indicate non-mature sedimentation. Argillaceous sediments are on the whole subordinate. We never find wide areas on the map which can be classified as true meta-argillites.

Conglomerates are extremely rare. They have only been found in the southernmost part of the area. Only in one case has a true conglomerate been recorded. Generally the only tendency towards conglomeratic development is indicated by scattered pebbles in micaceous quartzites. In all cases the pebbles have been derived from adjoining sediments, which means that the conglomeratic forms must represent very local formations.

A noteworthy feature is that calcareous sediments seem to be almost totally absent. These general characteristics of the sedimentary column will be discussed later on in connection with an attempt to survey the sedimentary evolution (p. 90 ff) in the area.

3.2. DESCRIPTION OF THE METASEDIMENTS

3.2.1. QUARTZITE AND MICA-QUARTZITE

If the chemical compositions of the Västervik quartzites are surveyed (Table 1), it is seen that very often they fall within the group defined as orthoquartzites by Pettijohn (1957, table 49, p. 198). The orthoquartzites in Pettijohn's table vary between 93 and 99.5 % SiO_2 (with one exception 83.8 % SiO_2). A fixed boundary between "orthoquartzite" and "protoquartzite" may be a question of definition (or taste). If one sets the limit at 85—90 % SiO_2 , the following analyses represent true orthoquartzites in the Västervik area: nos. 1, 2, 3, 4, 5, 6, and perhaps 7 (Table I). From Russell (1969, p. 281, table 1) we may add his analyses nos. Z92, S70, S34, perhaps A26 and Z86.

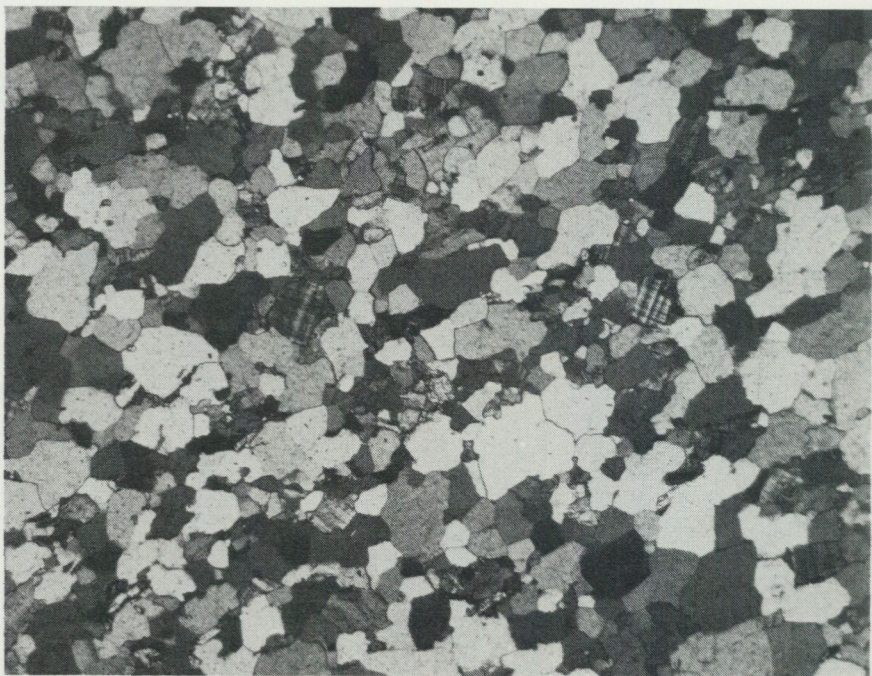


Fig. 2. Fine-grained orthoquartzite. + nic., 32 \times . Old water tower, Västervik city. Map-sheet Loftahammar SV (0a).

Protoquartzites would be represented by analyses 8 and 9 (Table 1) from the southern part of the map-sheet Västervik, 1: 50 000. Analysis 8 is from some intensely cross-bedded micaceous quartzites on the island Tallskär (north of Eknö; cf. Fig. 5). Analysis 9 is from the arenaceous beds of the "tidal flat sediments" on the island of L. Äppleholmen (north-west of Eknö; see Fig. 21). From Russell (1969, p. 281) we may add his analyses nos. Z91, A29 and A22.

The purest quartzites are always white. In hand specimens, however, one can discern two main types. One type is represented by the quartzites in and around the town of Västervik (cf. p. 9). Hand specimens look "granular", evengrained, and homogeneous. Fig. 2 shows the texture in thin section. The other type is very coarse. Fresh rock surfaces display almost conchoidal fracture. Hand specimens may sometimes give the impression of having been derived from a coarse quartz vein. During our provisional mapping we called this type "glassy quartzite". Its geological occurrence shows that such forms always appear in high-metamorphic areas. They certainly represent recrystallized, coarse-grained equivalents of the more fine-grained quartzites. Fig. 3 gives an example of their texture (to be compared with Fig. 2). It is interesting to note that even in such strongly

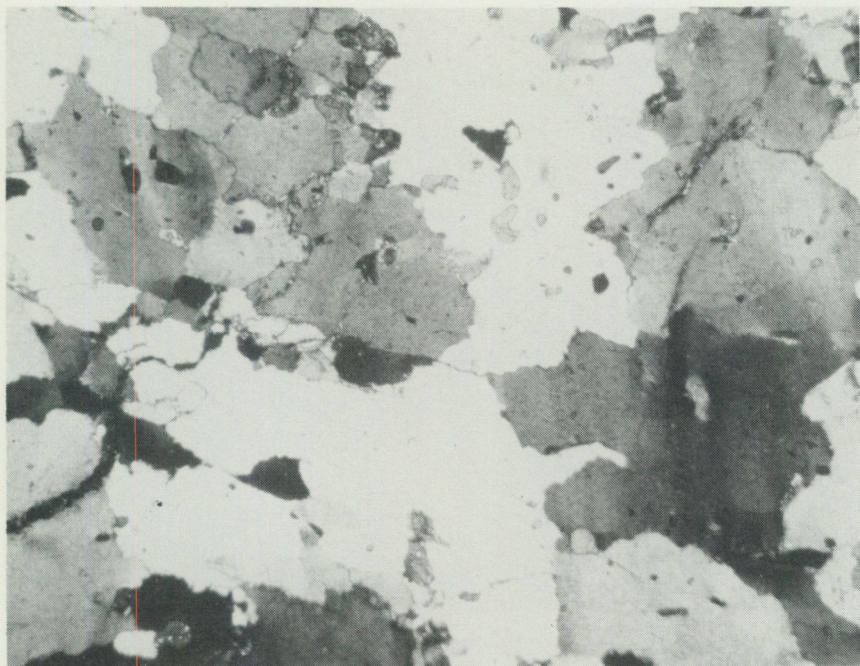


Fig. 3. Coarse-grained recrystallized orthoquartzite. + nic., 32 \times . Skjortö, north-western shore. Map-sheet Kråkelund NV (7a).

recrystallized quartzite cross-bedding may be preserved.

Worth mentioning is a very interesting observation from the north-eastern shore of the island of Långö (c. 11 km south of Västervik). Here, both the "granular" and the "glassy" forms occur together, with fairly sharp contacts between the two types. The coarse quartzite is found to penetrate and in some respect brecciate the granular type. Such a pattern indicates that recrystallization was accompanied by hydrothermal solutions and probably some migration of silica. If this is the case, then it would be in perfect agreement with our experience with respect to the gneiss- and granitoid-forming process, which will be discussed more thoroughly in a following chapter.

Several primary sedimentary structures are visible in the meta-arenites, especially in the micaceous or argillaceous forms. They have been described in some detail by Gavelin and Russell (1967). For this reason, these phenomena need only be treated briefly here. Cross-bedding is most common among primary structures. It appears in various forms and dimensions. Figs. 4—6 give examples of the most common patterns.

One also finds other primary sedimentary structures which may make it



Fig. 4. Cross-bedding in quartzite. Almviksnäs. Map-sheet Västervik SO (2h). Photo Th. Lundqvist.

possible to establish paleocurrent directions and to characterize the environmental conditions during sedimentation. Ripple marks have been noticed at several places (see Gavelin and Russell 1967, fig. 9). Graded bedding is not common but has been seen at some localities, see Fig. 7. Erosion channels have sometimes been observed. The eroding sand is always unlayered when it cuts more distinctly layered meta-arenite (Fig. 8 and Gavelin and Russell 1967, fig. 11).

Fig. 9 shows an example of "overtuned cross-bedding". According to some authors, this indicates that the foresets in a sedimentary sequence were deformed soon after the sand beds were deposited. In addition to those examples given by Gavelin and Russell (1967), Figs. 10—14 from a locality found after 1967 serve as very instructive examples of both primary structures and deformation patterns. The structures are found in a band of mica-schist with arenaceous inlayers, about 0.5 m thick, occurring in stratified quartzite. The author wants to draw a special attention to the deformation patterns since they are similar in appearance to those found in certain veined gneisses, where rock masses with highly contrasting physical properties are affected by kinematic metamorphism. These matters will be further discussed in connection with the development of veined gneisses.

The mineral composition of the rocks presented on the map as quartzites can

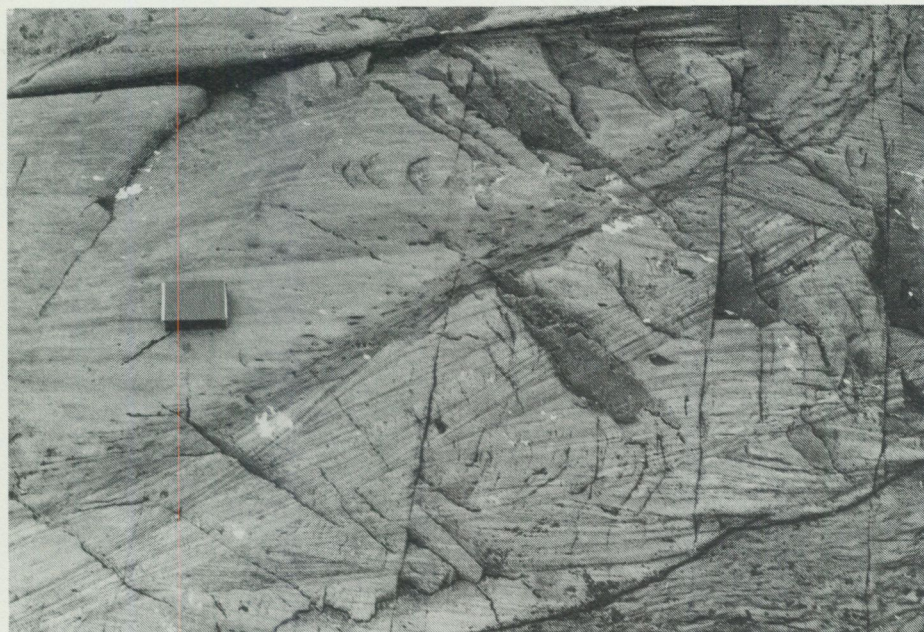


Fig. 5. Cross-bedding in quartzite. North-eastern shore of Tallskär, about 300 m N of Eknö. Map-sheet Kråkelund NV (7b). Photo S. Gavelin.

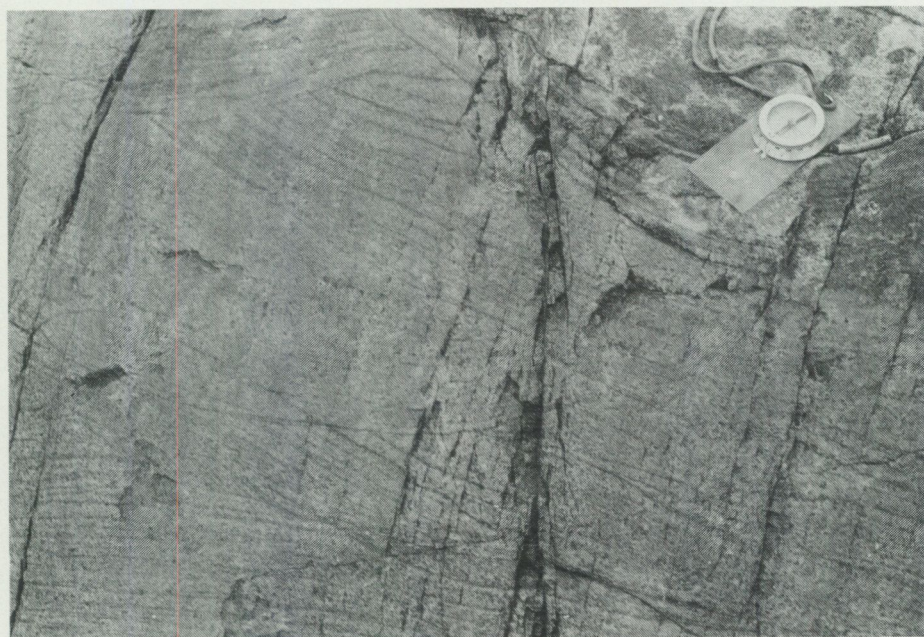


Fig. 6. Lenticular cross-bedding in coarse quartzite. Skjortö, western shore. Map-sheet Kråkelund NV (7a). Photo P. H. Lundegårdh.

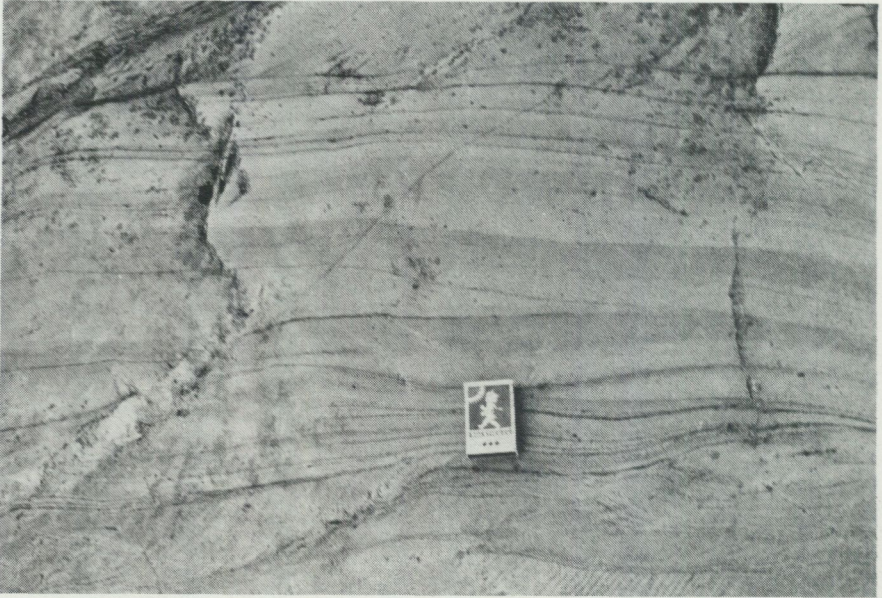


Fig. 7. Graded bedding. North-eastern shore of Tallskär, about 300 m N of Eknö. Map-sheet Kråkelund NV (7b). Photo S. Gavelin.



Fig. 8. Erosion channel. Small island NW of Vistingsö, 7.5 km SE of Gamleby. Map-sheet Västervik SO (2i). Photo S. Gavelin.



Fig. 9. Overturned cross-bedding. Almviksnäs, south-western shore. Map-sheet Västervik SO (2h). Photo Th. Lundqvist.



Fig. 10. Bedded metasediments, "intruded" by flowable argillaceous matter. Ripple marks, somewhat deformed, are seen in the upper parts of the picture. Western shore of Eknö, 2.1 km S of the Ormö island. Map-sheet Kråkelund NV (7a). Photo S. Gavelin.



Fig. 11. Rolled load cast (cf. Gavelin-Russell 1967, fig. 22). This pattern can be considered as a further step of the same movements as are indicated in Fig. 10 from the same locality. Photo S. Gavelin.

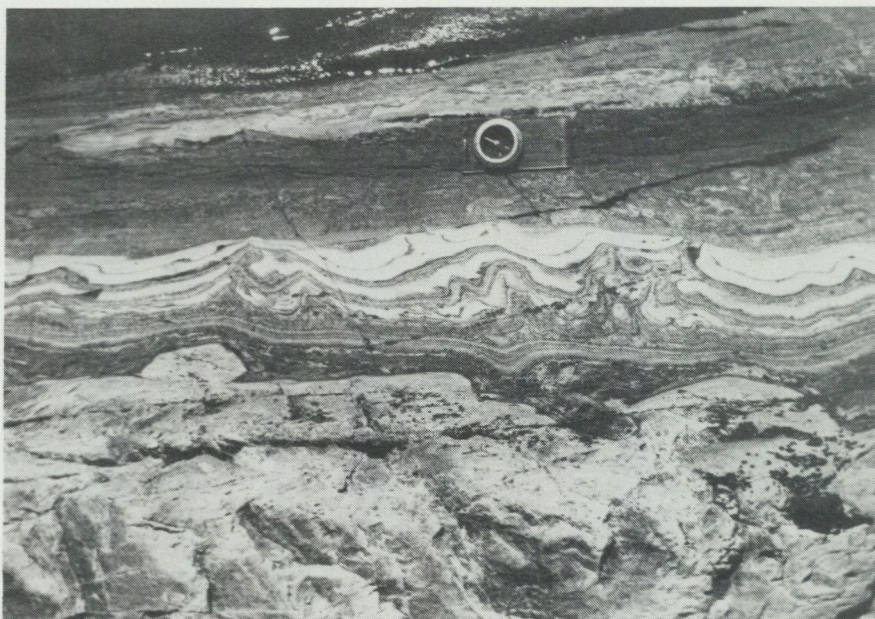


Fig. 12. Flow of argillaceous matter deforming arenaceous beds. The same locality as Fig. 10. Photo S. Gavelin.

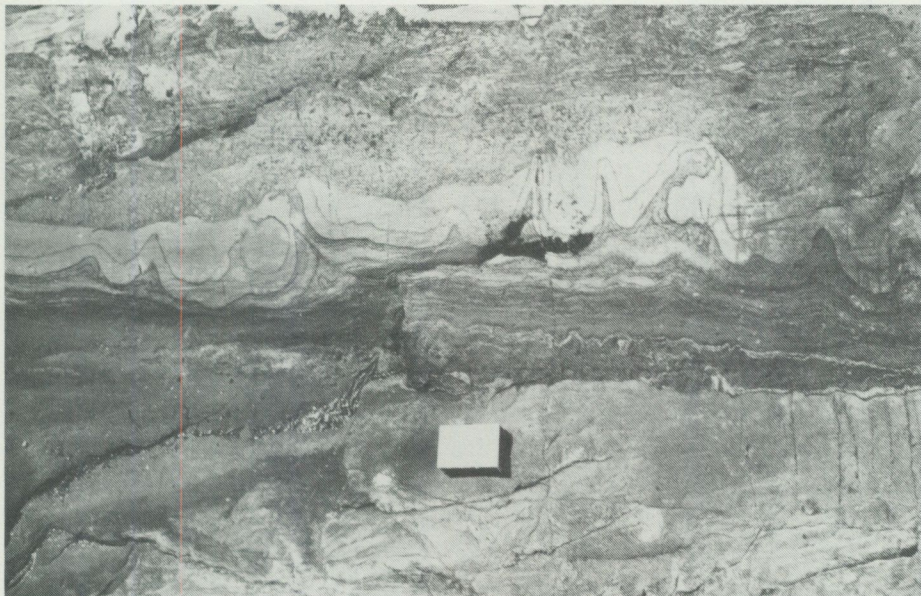


Fig. 13. The same as in Fig. 12, with somewhat different patterns. Locality as Fig. 10. Photo S. Gavelin.

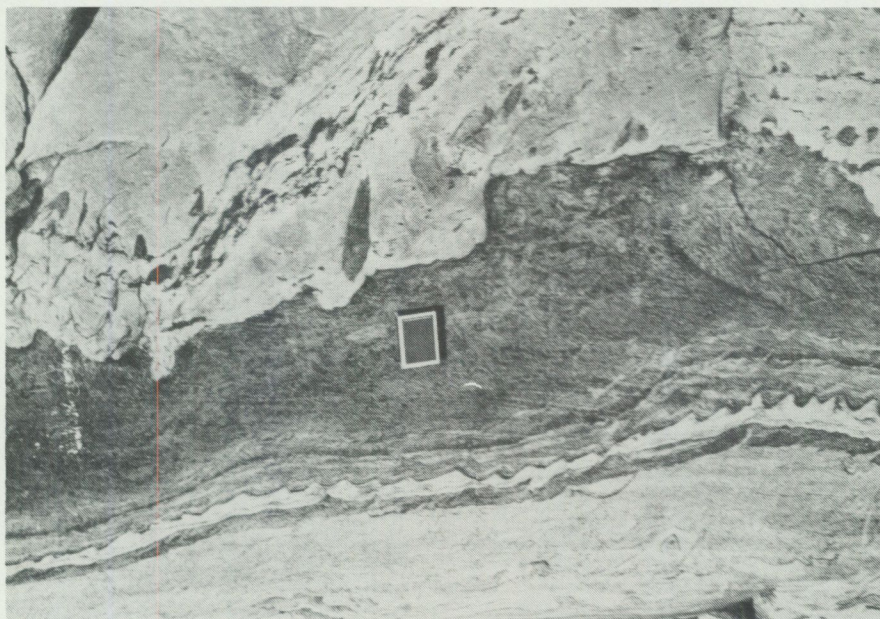


Fig. 14. Arenaceous bed with fragments of meta-argillite indicating that mud beds have had an opportunity to dry, fracture and be broken up before the next invasion of sand. In the lower part of the figure occurs a narrow bed of meta-arenite with beautiful ripple marks, somewhat deformed. Locality as Fig. 10. Photo S. Gavelin.

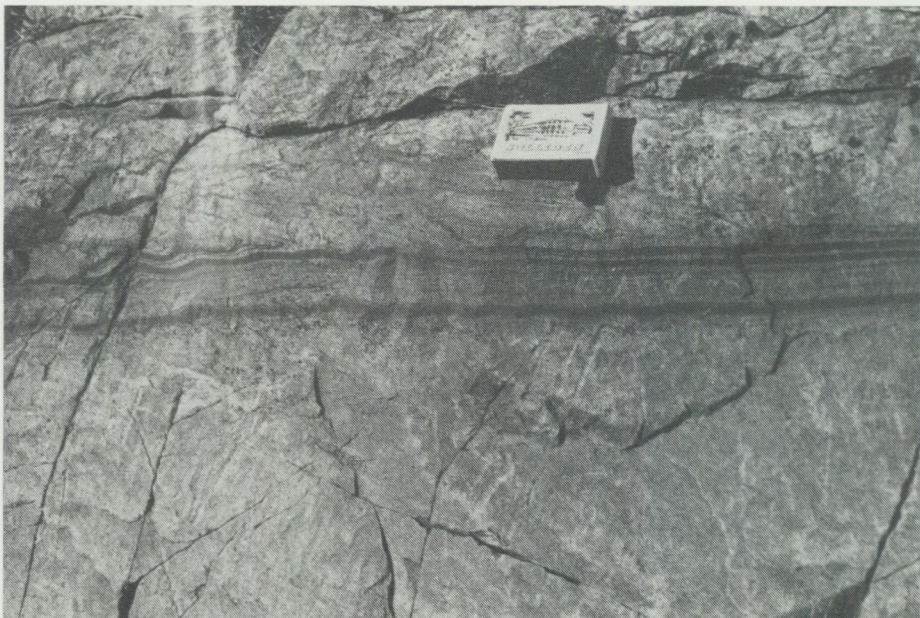


Fig. 15. "Black sand" layers in quartzite. Koholmen, 500 m NW of Hamnö. Map-sheet Kråkelund NV (6a). Photo S. Gavelin.

be treated fairly briefly. In addition to quartz, which of course dominates, the rocks contain potash feldspar and (generally) to a lesser extent plagioclase. These feldspars appear as very small individuals filling the interstices between the larger quartz grains.

Muscovite and biotite are present in varying amounts. As the mica content increases, the "orthoquartzites" pass over into "protoquartzites". Generally, an increase in mica is accompanied by an increase in feldspar. With increasing feldspar content, especially potash feldspar, the rocks grade into arkosic meta-arenites. If the quartzitic meta-arenites originally contained a significant amount of clayey material, minerals such as sillimanite and/or andalusite, and cordierite may occur.

It seems probable that heavy minerals have been considerably concentrated in the quartzites. In general, the percentages are not very high, however. At some localities layers of "black sand", a few millimetres thick, have been observed in layered protoquartzites, Fig. 15. These beds are composed mainly of iron oxides, but also display a marked enrichment of zircon. In addition to iron oxides and zircon, rutile, titanite, apatite, tourmaline, and monazite (tentative) are found in varying proportions.

The feldspar content of the orthoquartzites is believed to represent primary

TABLE 2. Volumetric analyses in % of protoquartzites (and orthoquartzites) in a section through quartzites SW of Gamlebyviken.

Quartz	Feldspar (mainly K-fsp)	Muscovite	Biotite	Opaque minerals
90.2	0.4	7.4	—	1.6
66.9	4.5	21.6	5.6	0.6
62.0	2.8	19.9	14.6	0.1
76.8	5.8	13.6	3.4	0.1
77.2	7.3	11.3	3.8	0.2
63.7	12.4	15.3	7.9	—
68.3	6.4	16.0	8.4	0.5
73.9	11.4	13.0	1.2	0.3
81.5	7.1	9.0	4.2	0.1
81.4	4.9	8.9	3.8	0.6
89.7	—	7.5	1.7	0.8
78.7	3.7	9.7	7.5	—
91.5	—	6.4	1.3	0.5
88.0	1.0	9.4	0.2	1.1
78.8	8.3	7.0	4.6	0.8
86.4	2.9	8.9	1.3	0.4
91.1	—	5.0	0.9	2.5
61.5	9.0	17.8	10.4	0.1
80.8	—	12.1	2.9	3.9
74.8	6.1	13.9	3.9	1.0

clastic constituents in the original sediment, at least in most cases. On the other hand, we know that regional metamorphism very frequently leads to metamorphic differentiation with the migration of certain chemical elements over various distances. These questions will be treated more thoroughly in the chapter on metamorphism (see p. 107 ff).

There are several localities where the problem arises as to what extent the feldspar content of the quartzites is the result of a secondary feldspathization. It has been proved that the large bodies of plagioclase-quartz rocks along the border of the Loftahammar granite belt in the north-east are the result of a metasomatic feldspathization of more quartzitic rock types. Mrs. Helgi Lindewald made a number of pointcounter modal analyses of micaceous quartzites belonging to stratigraphic unit 5 (see p. 77 ff and Pl. 1) which occupies a position in the center of the main Gamlebyviken syncline. The samples were taken about halfway between profiles 3 and 4 in Pl. 1 and cover a cross-section of 1 500 m on the map. The results are presented in Table 2. They may serve as an example of the variations to be found within a fairly narrow section of arenaceous metasediments.



Fig. 16. Red meta-arkose. + nic., 32 \times . S of Borgö. Map-sheet Loftahammar SV (0a).

3.2.2. META-ARKOSE (RED METASEDIMENTS)

Typical representatives of this group are pink, fairly fine-grained rocks. They are generally massive and then display no or very indistinct fine-bedding. However, even in these rocks cross-bedding has been observed at some localities.

The red colour is caused by red potash feldspar, the marked red tint of which is due to a fine powder of iron oxide, probably hematite. Plagioclase also occurs. The proportions between quartz, potash feldspar, and plagioclase may vary considerably also within small areas, which is evidenced by the six analyses of red meta-arenites (analyses nos. 10—15, Table 1). Biotite, muscovite and chlorite are additional constituents but are generally found in smaller amounts than in the micaceous white and gray quartzites. In types closely related to gneissic areas, sillimanite and andalusite have been observed. Fig. 16 is a microphoto of a typical representative of this group.

It has been suggested sometimes that the high content of potash feldspar could have resulted from an invasion of potassium from potassic granites or pegmatites. This is apparently not the case, since rounded pebbles of the red meta-arkose are sometimes also found in white quartzite. This is a clear evidence that the red colour is a primary feature.

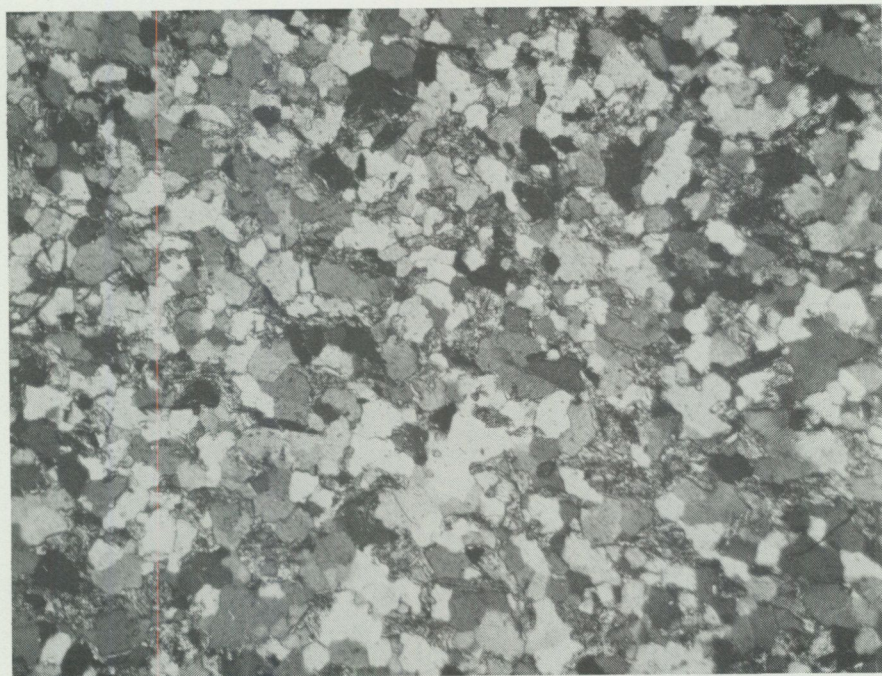


Fig. 17. Micaceous arenaceous member of the gray metasediments. + nic., $32\times$. Fiskholmen. Map-sheet Kråkelund NV (8b).

3.2.3. GRAY METASEDIMENTS

Gray meta-arenites are encountered in several places. They are generally fine-grained and may or may not display visible bedding. Where more micaceous layers also occur, graded bedding has been observed. Where the rocks grade into typical argillaceous metasediments they show an increase in mica content and the occurrence of such metamorphic minerals as cordierite, andalusite and/or sillimanite. Meta-argillites with true clay compositions are fairly rare. Using the contents of SiO_2 , Al_2O_3 , and excess alumina (= t if Niggli values are considered), we can distinguish three main groups among the rocks analyzed (Table 1)¹. One group represents true clay sediments with the following Niggli values: $qz = 20$ to 102 ; $t = 25.3$ to 33.3 ; $k = (0.46) 0.71$ to 0.92 (analyses nos. 29—30, and Russell 1969, p. 281 nos. S 72, X 54). Another group consists of clayey meta-arenites: $qz = 137$ to 568 ; $t = 24$ to 37 ; $k = 0.61$ to 0.91 (analyses nos. 19—28). The third group (analyses nos. 16—18) represents true graywackes: $qz = 17$ to 30 (64); $t = -0.4$ to -13.2 ; $k = 0.09$ to 0.15 (0.29).

¹ The Niggli-values of qz have not been presented in Table 1 since these figures are used only in discussions on the chemistry of the gray metasediments. However, the values presented here can easily be verified from the other Niggli-values of the table.



Fig. 18. Gray mica-schist with abundant porphyroblasts of andalusite. Ljusterö, southwestern shore. Map-sheet Västervik SO (2j). Photo P. H. Lundegårdh.

Megascopically, it is often impossible to distinguish between metagraywackes and "clayey meta-arenites". They may sometimes have been interchanged on the map. In other cases the distribution of the two types could be recorded with certainty. Their bearing on the sedimentological evolution of the area will be commented on in the discussion of conditions of sedimentation.

The mineral composition of the gray metasediments can be treated briefly. In arenaceous forms quartz is the dominate mineral, the amount of quartz decreases towards the argillaceous end members, where micas and chlorite become more abundant. Feldspar and micas are additional constituents in the normal types. Fig. 17 shows a common form. In the true metagraywackes, such minerals as andalusite, sillimanite and cordierite are generally absent. In a few cases, small amounts of cordierite have also been observed. The meta-argillites and the "clayey meta-arenites" contain andalusite, sillimanite and cordierite as essential constituents. One, two, or all three of these minerals may occur together in varying proportions. Only in one case has almandite been observed. Fig. 18 shows an example of mica-schist with abundant andalusite and deformed arenitic layers. The feldspars are represented solely by potash feldspar in many of the "clayey meta-arenites". Sometimes also plagioclase is present. However, this

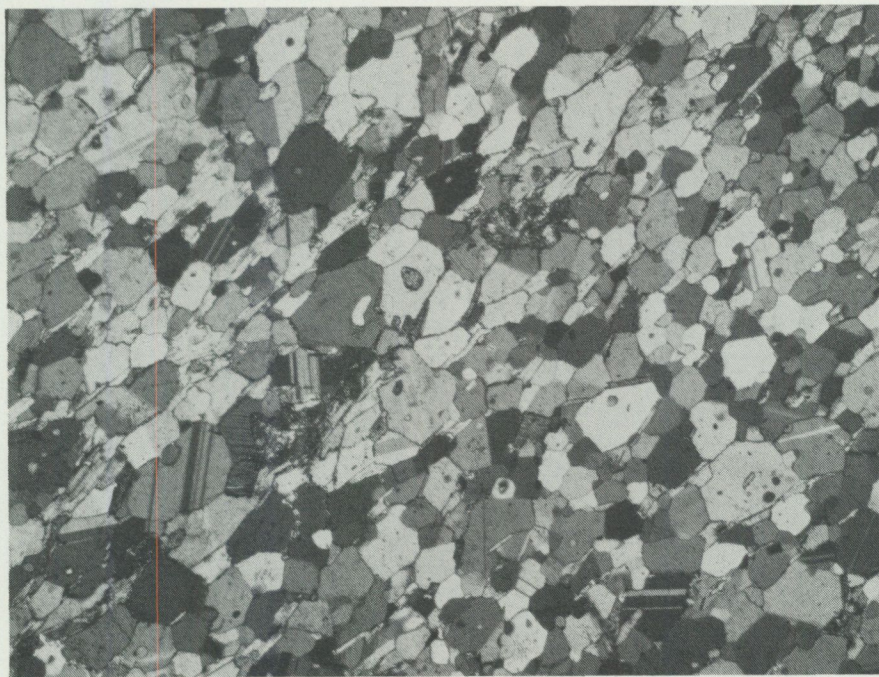


Fig. 19. Metagraywacke. SW of Tuvgölen. + nic., 32 \times . Map-sheet Vimmerby NO (8h).

mineral is subordinate to orthoclase. Small amounts of potash feldspar may or may not be present in the typical meta-argillites. Typical metagraywackes contain only plagioclase (oligoclase) and no potash feldspar. The amount of quartz may vary considerably between different types. This is clearly seen from the *qz*-values in the analyzed samples. Fig. 19 shows the structural development of a typical metagraywacke. Epidote minerals have been observed in some cases, although they as a rule are never found in appreciable amounts. An exception is seen in a specific rock type from Oxebo (about 7.5 km WSW of Gamleby). These dark, fine-bedded metasediments are believed originally to represent intermediate tuffites. Biotite is the predominating constituent. Quartz, microcline and subordinate plagioclase, as well as andalusite and some muscovite, are additional minerals.

3.2.4. RED-GRAY METASEDIMENTS

Red-gray metasediments is a field name used to denote several types of meta-sedimentary rocks which vary widely with respect to mineralogical and chemical composition. The feature they have in common and which is readily recognized in the field is a regular alternation between darker (grayish) and lighter (pink)



Fig. 20. Red-gray metasediments. Road-cutting at E 66, about 1.5 km NW of Gamleby. Map-sheet Västervik SO (4g). Photo S. Gavelin.

beds. The beds vary in thickness between 3 and 20 cm. The pink layers are often identical with certain pink representatives of the red metasediments, whereas the gray layers often correspond to arenaceous forms of the potassic units of the gray metasediments. The most common representatives of the red-gray metasediments contain abundant quartz, both in the pink and the gray layers. The silica content may vary considerably as can be seen from the analyses (nos. 36—41, Table 1; Loberg 1963, p. 17, table 2; Gavelin 1975, p. 58, analysis no. 1, table 1). From the analyses it is further seen that in most cases these metasediments are clearly potassic. Their mineralogical composition is simple. In addition to quartz, potash-feldspar is the most common mineral. Plagioclase occurs in varying amounts, generally quite subordinate to (but in some cases even dominating over) potash feldspar. Biotite, sometimes, partly altered to chlorite and muscovite, is of course more abundant in the gray than in the pink bands. Usually, muscovite is present as a main constituent. Such minerals as sillimanite and cordierite have been observed in two thin sections only. This indicates that the gray bands in these forms originally contained very little true clay components. Fig. 20 shows a typical section of the red-gray metasediments. The textures vary within the same limits as those seen in the red and the gray metasediments, Figs. 16 and 17.

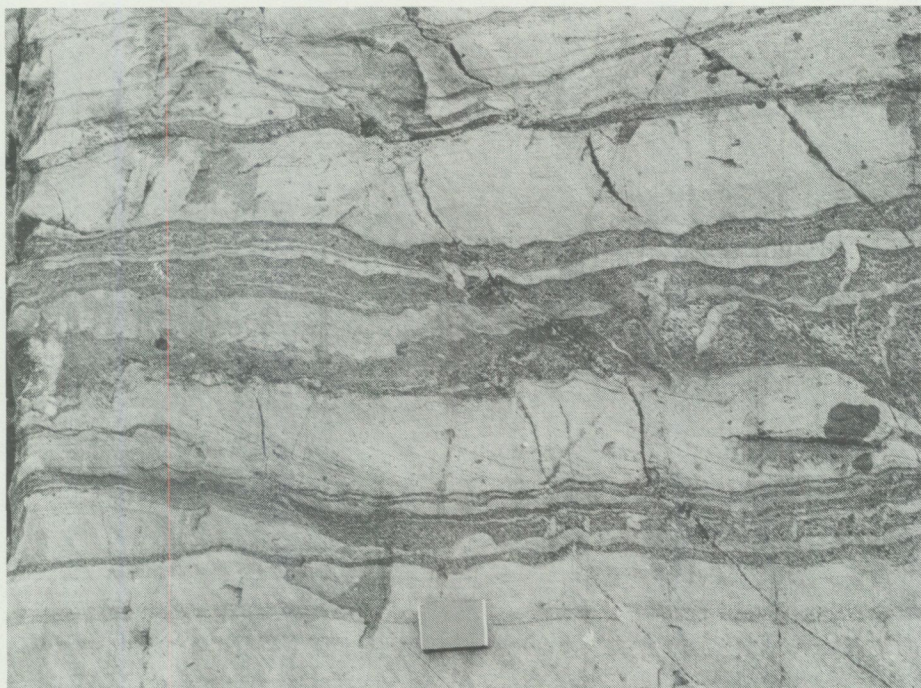


Fig. 21. Bedded metasediments with mud cracks and cross-bedding in the arenaceous beds. L. Äppleholmen, c. 700 m SE of Skjortö. Map-sheet Kråkelund NV (7a). Photo S. Gavelin.

There also exist banded sediments of partly quite different appearance, but which on the map have been denoted by the same colour. These rocks are characterized by an alternation between white, or slightly pink, arenaceous beds and mica-schist beds. The mica-schists represent primary mud layers which often contain sandfilled mud cracks, proving that the metasediments represent tidal flat formations. The pattern has been pictured and commented on by Gavelin—Russell, (1967, figs. 6 and 7). Fig. 21 gives an additional example where also cross-bedding can be discerned in an arenaceous layer.

Analyses nos. 29 and 9 give the compositions of dark and pink layers, respectively. It is seen that the dark layer represents a true clay composition. Biotite and sillimanite are the major minerals present. Muscovite, chlorite, quartz, some potash feldspar, and plagioclase are additional constituents. In the pink, arenaceous beds, quartz and potash feldspar are by far the dominant phases. Micas and chlorite occur in minor amounts. Arenitic layers often display distinct cross-bedding.

The banded rock sequence with mud cracks has a very characteristic appearance. During the mapping they were given a field name, "the Äppleholmen



Fig. 22. Conglomerate. Järsö Böte. Map-sheet Kråkelund NV (7a). Photo S. Gavelin.

series", and coloured separately. The only area, however, where they seem to form a continuous lithostratigraphic unit, is found on some islands in the southernmost part of the geological map Västervik (on L. and St. Äppleholmen), as well as some distance to the east of these islands. On a smaller scale, mud cracks have also been observed at several other places. This development is always associated with decidedly banded forms of the red-gray metasediments.

3.2.5. CONGLOMERATE

As was mentioned on p. 11, conglomerates are extremely rare or generally completely missing. Due to small extension, conglomerate has not been indicated on the map. Only at one locality, at the north-western point of Järsö Böte (c. 7 km east of Blankaholm), has a real conglomerate been found. The pebbles consist of various metasediments and massive metabasite in a quartz-micaceous groundmass. In this case the groundmass is strongly sheared (Fig. 22). A kind of conglomeratic development is also discernible in the neighbouring areas where the massive white quartzite frequently contains scattered, small, rounded pebbles of other metasediments, even the red ones.



Fig. 23. Breccia. The western point of Lökholmen, 2 km SSW of Händelöp. Map-sheet Kråkelund NV (8a). Photo S. Gavelin.

3.2.6. BRECCIA

At the western point of Lökholmen and on Marsö (map-sheet Kråkelund NV, 8a), on the southern shore of Brunnskär (250 m north of Eknö) and 400—500 m ENE of the latter locality (map-sheet Kråkelund NV, 7a) a type of rock is met with, the origin of which is somewhat obscure. The rock can be described as a breccia which is composed of light, elongated fragments in a dark groundmass (Fig. 23). Due to small extension this breccia has not been shown on the map. The rock was first thought to represent some kind of tectonic breccia. Through the mapping it was found that the unit is conformable with the bedding of the sedimentary sequence. In addition, it was seen that it has been cross- or shear-folded in the same manner as the metasediments. Since the crossfolding represents a late stage of the tectonic evolution, the breccia must have been formed in an early stage of deformation. The breccia has also been overtaken by a strong shearing deformation, causing a pronounced shistosity in the groundmass and a very regular E—W orientation of the fragments (see Fig. 23). This orientation coincides with the most prominent direction of shearing in this area. From other parts of the area, no evidence of early deformation has been re-

cognized which could have produced a breccia of the kind found here. Therefore, it is possible that some kind of activity closely combined with the very sedimentation could have been responsible for the structure in question. Bersier (1964) has described and pictured a phenomena from molasse sediments in Switzerland which seems to offer some analogies with the Västervik example. The rocks are quite different in the two cases. But they have in common that two contrasting rock compositions occur together, in Bersier's example, molasse sandstone contra marl, in the Västervik case mica-schist contra feldspar-bearing quartzite. Bersier presented an evolutionary model as follows.

Limestone and molasse sand were alternately deposited along a shore which oscillated in such a way that the accumulated sediments were sometimes brought above the sea level and eroded. Erosion channels were formed through alternating beds of sand and limestone. Because the coarse sand was more easily eroded than limestone, erosion preceded also below the blocks of limestone which were then broken up into separate pieces and tilted. The end result was a sedimentary breccia, the pattern of which has much in common with the breccias from the Västervik area.

The preferred orientation of the blocks in this latter case was certainly caused by later shear movements. If this comparison holds true, the light, eroded portion should represent the more clayey matter and the more resistant portion the sand beds. Similar contrasts have been found in many examples of pre-consolidation movements in sediments (cf. Figs. 10—14). The breccia should then be taken as a specific development of these previously exemplified deformations.

If one considers the chemical and mineralogical characteristics of the breccias, some complications with the above-mentioned explanation arise. The breccia on Lökholmen island has light fragments which are coarse-grained but not gneissic. They resemble neither the gneissic metasediments within other parts of the island, nor the preserved blocks of gray metasediment in the gneisses. The chemical composition of the groundmass is reported in analysis no. 42. The analysis shows that it is more sodic and more calcic than the normal micaceous metasediments in this area. The SiO_2 content is certainly somewhat too high, if the pure ground mass is to be considered, since the analysed specimen contains small pieces of quartzite.

On the diagrams, intended to demonstrate the chemical characteristics of the various metasediments (Figs. 24—25a, b), the analysis no. 42 falls outside the fields for the potassic, gray metasediments. In Fig. 25b it is seen to take an intermediate position between these metasediments, the graywackes and the metabasites. The difference between this rock and "normal" metasediments of the gray metasediments include higher c values and lower k values. This is reflected in the mineralogy, the breccia groundmass being richer in plagioclase and epidote than the adjoining gray metasediments. The same groundmass contains epidote as an essential mineral and also more plagioclase than is usual in adjoining meta-

sediments. Even the fragments seem to contain somewhat more plagioclase and epidote than the adjoining metasediments.

The last-mentioned results suggest an alternative explanation of genesis implying that the breccias might be the result of combined volcanic activity and normal sedimentation. Since it has been proved that basic magmatism occurred contemporaneously with sedimentation, such an interpretation cannot be considered impossible. In such a case the breccia would represent a combined volcanic-epiclastic sedimentary formation with quartzitic metasediments embedded in basic tuffites.

There is one additional factor that must be considered with respect to genesis. The light fragments of the Lökholmen breccia are clearly zoned. The centers consist of quartz and potash feldspar. In the margins, potash feldspar is replaced by plagioclase. This is exactly what occurs on a small scale as a kind of sodium-metasomatism between basic rocks and more or less feldspathic quartzites (p. 123 ff). Perhaps further finds will make it easier to answer these questions. On the whole, these interesting rocks have very little bearing on the main stratigraphic and metamorphic problems of the area.

3.2.7. CHEMICAL COMPOSITION OF THE METASEDIMENTS

In the descriptions of the four main types of metasedimentary rocks represented on the map, some of their most significant chemical features have already been mentioned. This presentation will be completed by some additional data which may have a bearing on the genesis of the sediments. Some characteristic features are visualized in three diagrams, chosen from a great number of possible graphical presentations but which for the metasediments in question are especially suited to illustrating variations between the different kinds of rocks.

It has been mentioned that a majority of the feldspar-rich metasedimentary rocks are decidedly potassic, although to varying degrees. The Niggli value k is therefore an important factor. Excess Al, expressed as t , is another significant variable.

Further factors which are found to vary significantly are alk and mg . I believe that the most significant features of the chemical variations in the metasediments can be expressed in the three diagrams to be presented here. If we look at the Q-Or- (Ab + An) triangle, Fig. 24, which is also used to demonstrate chemical features, connected with metamorphism (p. 125 ff) we find a great spread in the plots of red arenites. This is not unexpected in view of the observed great variations in quartz content. The red-gray metasediments also plot over a wide area of the diagram, although most of the analyses are concentrated towards the Q-corner along the Or-Q-side of the triangle. The most interesting feature, however, concerns those rocks which have been called the gray metasediments.

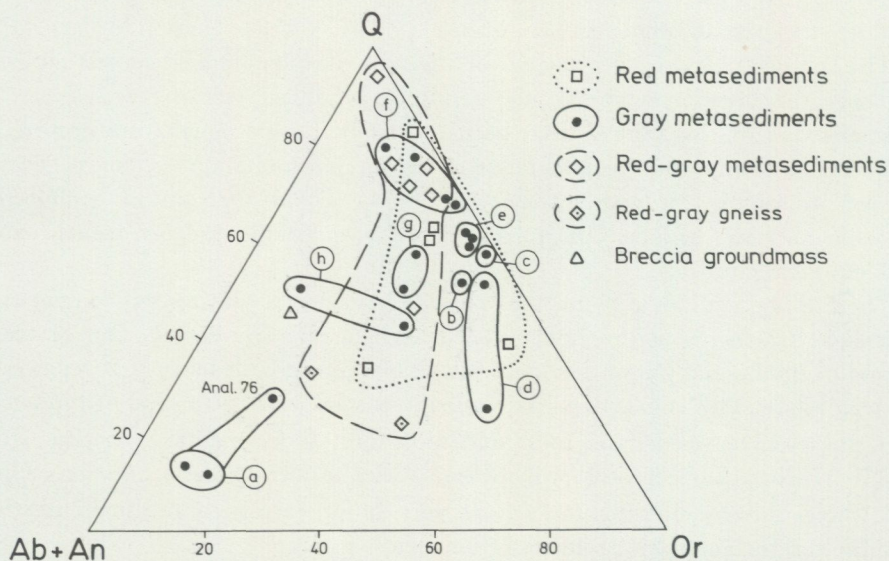


Fig. 24. Analyses of metasediments grouped according to their regional distribution. a = the Flugén area; b = Oxebo; c = 2 km SW of Gamleby; d = the archipelago L. Äppleholmen — Skjortö; e = the small islands S of Hultö; f = the Henriksnäs — Tullerö area; g = the Rummen area; h = metasediments from the Vetlanda area (Röshoff 1973).

It was stated before that most of the gray metasediments were surprisingly potassium-rich. Only rocks from the so-called Flugén area, represented by analyses nos. 16 and 17, are true graywackes and fall in the Ab+An-corner of the diagram. Analysis no. 18 may also be added to this group. Its position in the field associates it with the graywackes to a certain degree. Potassic forms of the gray metasediments also represent some different fields in the diagram. They are seen to take different positions when plotted. Nos. 19 and 20 are from the Rummen area; nos 26—28 are from the archipelago south-west of Hultö; and nos. 22—25 are from the Henriksnäs—Tullerö area. Consequently there must have existed some characteristic differences between the sedimentation in these areas.

Fig. 25a shows the ratio alk/mg . In this case, too, we find that the field for the red-gray metasediments covers a wide area. The field of the red metasediments agrees to a certain extent with the former, but is characterized by slightly higher alk values. But even in this diagram, the gray metasediments are split up and show approximately the same kind of grouping as in Fig. 24. True graywackes represent an area with high values for both alk and mg . Analyses from the islands south-west of Hultö form a quite isolated group, characterized by high mg and low alk . Analyses from the Henriksnäs—Tullerö area and the more distant Rummen area seem to be fairly closely related. Both groups show low

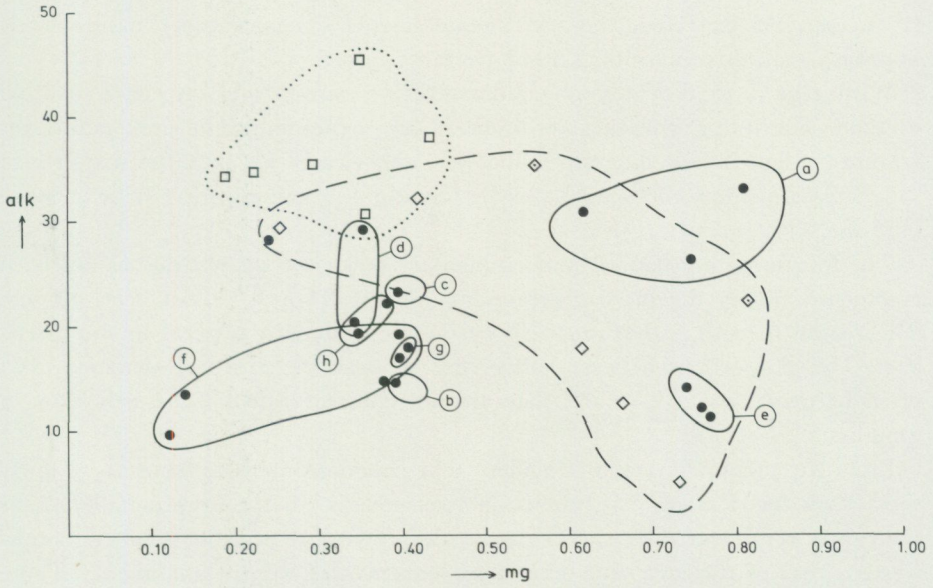


Fig. 25a. The main metasediments in an *alk:mg* diagram. (Symbols as in Fig. 24.)

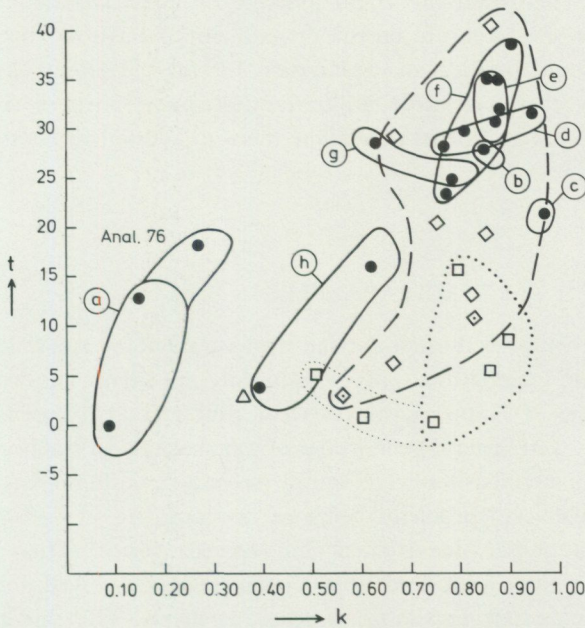


Fig. 25b. The main metasediments in a *t:k* diagram. (Symbols as in Fig. 24.)

values for both *alk* and *mg*. Fig. 25b represents two important variables, *t* and *k*, for the primary sediments. Here too, we find that the red-gray metasediments plot over a wide area in the diagram. Especially the variation in *t* (=excess Al) is obvious. As expected, the red metasediments (meta-arkoses) more closely approach granitic compositions and have low *t* values.

With regard to the gray metasediments, we can mainly discern a twofold division. The true graywackes are found in low *k* positions. The most significant feature evident in this diagram is that one can clearly see that the majority of the metasedimentary rocks are decidedly potassic — *k* values generally lie between 0.50 and 0.90.

The fourth main group of metasedimentary rocks, the quartzites, has not been commented on in the three diagrams mentioned. They have not been plotted. The reason for this is that quartz is by far the dominant mineral in the quartzites. The proportions between other very subordinate chemical elements must often be occasional. Therefore, they are not characteristic for the sediments in question.

From the present survey it is evident that chemical characteristics are a fairly weak basis for drawing conclusions on rock genesis. In the gray metasediments there is a very clear difference between the graywacke sediments in the southwestern part of the area and other representatives of the metasediments. There also exist differences between other representatives of the gray metasediments, for example in *alk* and *mg*. The grouping of analyses in the diagrams reflect geographical positions. They therefore could indicate different sedimentary environments. However, in the literature on recent sediments I have not been able to find any data that could provide an explanation for the variations observed. The above results may therefore serve a purely descriptive purpose. Further research on the formation of sediments may allow them to be used in interpreting sediment genesis.

3.3. METABASITES

Basic igneous rocks are common throughout the metasedimentary areas. In most cases they represent basic magmatites. They now mostly appear as amphibolites. Even in the initial stages of mapping, it was clear that several different types existed. Obviously, there were several generations of metabasites. In the beginning of our investigation, the metabasites were simply recorded, with no systematic study of their special geological problems being carried out.

Metabasites occur as dense, fine-grained and coarser forms. These could correspond to extrusive, hypabyssic and abyssic magmatites. In well-preserved metasediments, metabasites may appear as concordant sheets. The fine-grained types could thereby represent sills or intercalations in the metasediments. They



Fig. 26. Bedded basic metatuffites. Skavdö farmhouse, south-western Skavdö. Map-sheet Kråkelund NV (6a). Photo S. Gavelin.

may also form discordant dikes. In the north-eastern part of the map area there are massifs of metagabbro or metadiorite. These bodies are related in space to the Loftahammar granite which borders the metasediment belt towards the north-east. In metabasite dikes, fine-grained chilled margins have been observed in some places. Where the metasedimentary rock sequences have been subjected to intense shear- or flow-folding, for example in connection with the development of veined gneiss, the metabasites are always found to behave as highly competent units. They are then broken up and appear frequently as angular or rounded xenoliths in a more acid metasedimentary or gneissic rock mass.

From the field studies, it was evident that only in the southern, coastal part of the mapped area it was possible to determine the relationships between basic magmatism on one hand, and the development of sedimentation, folding and metamorphism on the other. Here it was found that some of the concordant fine-grained basic sheets were clearly bedded. Originally, they were basaltic tuffs, Fig. 26. Others are amygdaloidal and have been interpreted as basaltic lavas. These observations are very important since they prove that there existed a basic magmatic activity which was contemporaneous with the sedimentation. This activity can be classed as a primorogenic magmatism. Following the formation of these volcanic basites, the rocks were intruded by metadiorites or metagabbros.

These are also concordant with the sediments and were later folded together with them.

Mutual age relations between the various metabasites have been studied and described by Kresten (1972). He was able to recognize seven generations of basic and intermediate igneous rocks. The oldest metabasites are the synsedimentary ones mentioned above. The youngest dikes (rhyodacites) intrude even the oldest forms of the younger granites. Kresten (1972, Abb. 14) has also summarized the evolution of the Västervik area. From this presentation it is clear that there must have existed an intermittent basic igneous activity from fairly early stages of diastrophism — still connected with the accumulation of sediments — to the postorogenic stages manifested by the younger granites.

The mineral composition of the metabasites is generally simple. Plagioclase (andesine, sometimes labradorite), green hornblende, biotite in varying amounts, and variable amounts of quartz are the chief constituents in most types. In some cases, epidote and/or clinozoizite plus biotite replace hornblende. Therefore, this paragenesis seems to represent an alternative metamorphic grade. Kresten (1972) gives very little information on the petrography of the basic rocks. Only generation VI has been commented on. He refers to a previous publication (Kresten 1971b), where the metamorphism of the area was discussed. However, in this last-mentioned publication the mineral assemblages are referred to metamorphic grade and not to basite generation (op. cit. fig. 4, p. 751). Data on the mineralogy of the basic magmatites of the north-eastern part of the area mapped here has been presented by Elbers (1971). In his work, however, retrograde metamorphism which ends with parageneses containing such minerals as chlorite, pumpellyite, and zeolites was the main subject of discussion. This north-eastern area contains large massifs of gabbro and diorite which, in their central parts, display primary igneous textures and are characterized by such minerals as olivine, hypersthene and diallage instead of hornblende. This is a mineral association which otherwise is found within the mapped area only in the type VI metabasites of Kresten in the southernmost parts of the area. Ore minerals are sometimes present as essential constituents. Sphene and in some cases apatite are additional constituents. Some examples of the structural development of the seven main groups are given in Figs. 27—33.

In most cases the different metabasite generations form fairly distinct petrographical types. However, generation VII as interpreted by Kresten may differ considerably from one place to another. The locality where it can be shown to represent a young dike rock is in a road-cutting along highway E 66 (Norrköping—Västervik—Oskarshamn) north-west of Blankaholm where a black dike has intruded a granite which has been classified as belonging to the younger group (Kresten 1972, Abb. 7). In outcrops on the northern shore of N. Eknö, however, Kresten recognized a quite different type of generation VII rock (Kresten 1972, Abb. 5). Here, the generation VII dike is light gray. The

rock gives the impression of being more acid. This has been confirmed by petrographic investigations which show that the rock is fairly rich in quartz. The most characteristic feature, however, is that these dikes contain abundant lens-shaped dark xenoliths oriented obliquely to the dike walls (see Kresten 1972, fig. 5). Exactly the same type of dikes is found sparsely elsewhere, for example on the island of Ljusterö in the northern archipelago. This rock is represented by analysis no. 57, where it can be seen that in this case the name rhyodacite may be justified. An analysis of the outcrop on highway E 66 (analysis no. 56) gives a much more basic impression. Under the microscope, the rock is seen to be extremely rich in iron oxides (magnetite) and sphene. Point-count analyses of thin sections from the analyzed samples show a clear difference (see Table 3, which gives the main minerals). If analysis no. 56 is recalculated, assuming that sphene and magnetite are approximately equally abundant in both cases, the type of no. 57 still appears somewhat more acid. The difference, however, is no longer so prominent.

TABLE 3. Volumetric mineral analyses of thin sections of samples for analyses nos. 56 and 57.

	<i>Analysis no. 56</i>		<i>Analysis no. 57</i>
	<i>Real composition</i>	<i>Re-calculated</i>	
Quartz	18.0	21	41
Plagioclase	36.1	42	35
Potash feldspar	3.8	4.5	2.5
Biotite	27.0	31.5	20
Sphene	7.7	0.5	0.5
Magnetite	7.4	0.5	1.0

In the northern area, a very specific type of metabasite dike has been found at two localities. One locality is 1 km SSW of Lofta church at the Råberga farmhouse. The other is 2 km SSW of Lofta church, immediately south-east of the little Lake Pärlobogölen. These dikes are characterized by a coarse porphyritic central zone with feldspar phenocrysts up to 10×15 mm in size. Megascopically, the phenocrysts are conspicuously zoned with a gray or greenish kernel surrounded by a white or pink outer rim. Towards the contacts, the phenocrysts disappear and the dikes appear as normal even-grained amphibolites.

The southern dike could be followed for a distance of at least 300 m. Its average thickness of 2—5 m may locally be extended to 15—20 m. The dike discordantly cuts cross-bedded white quartzites. The southern dike is clearly schistose, whereas the northern is more massive. Both dikes contain abundant small, black, lens-shaped xenoliths which are oriented aprallel or somewhat obliquely to the direction of the dike. In this way, they resemble some types referred to as generation VII. On the whole, however, no definite arguments can be given in support of their assignation to any of the groups IV or VII. The chemical composition is shown in analysis no. 58.



Fig. 27. Amygdaloidal metabasite generation I. + nic., $12\times$. 250 m N of Skälö. Map-sheet Vimmerby NO (7j).

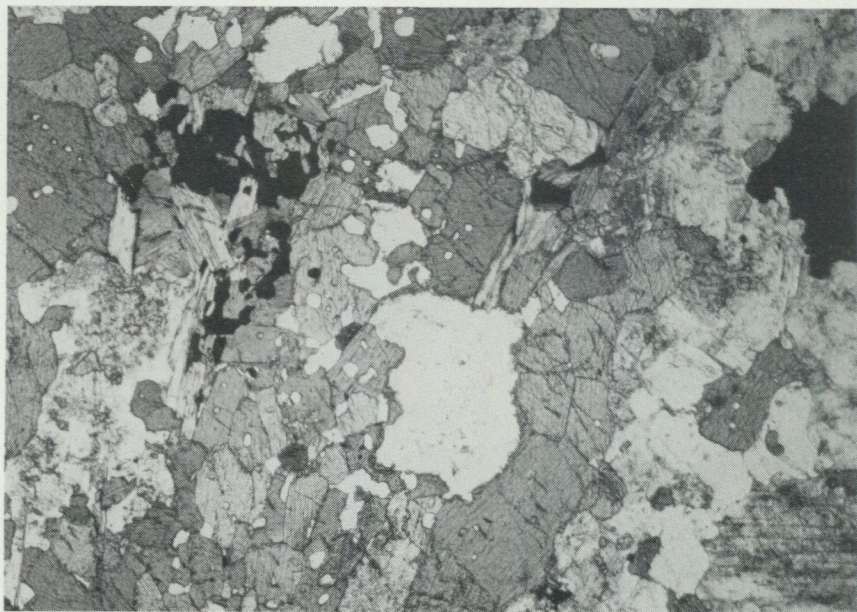


Fig. 28. Metabasite, gen. II. + nic., $32\times$, 900 m E of Skavdö farmhouse. Map-sheet Kråkelund NV (6a).

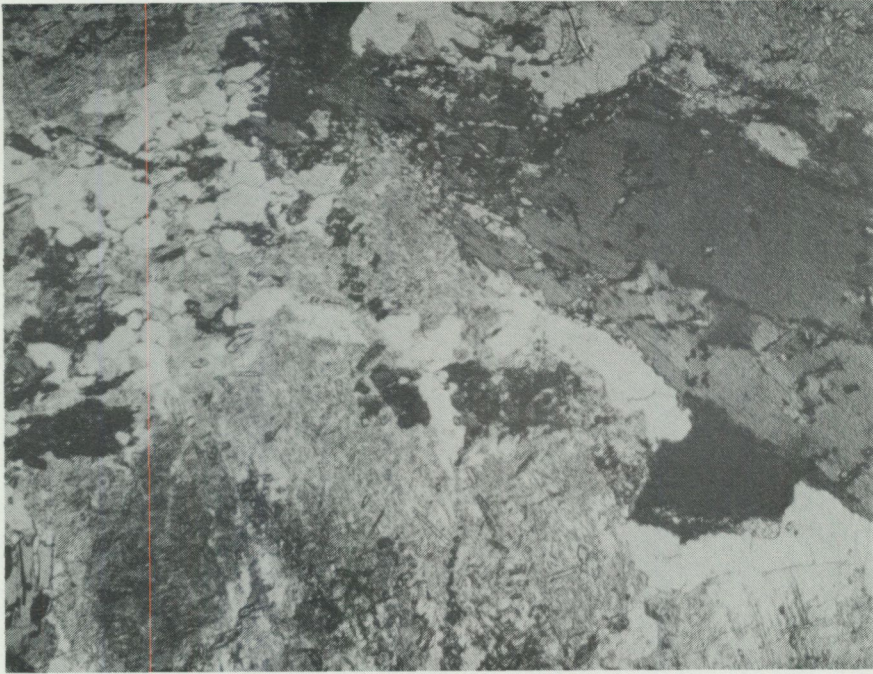


Fig. 29. Metabasite, gen. III. + nic., 32 \times . N. Eknö. Map-sheet Kråkelund NV (7a).

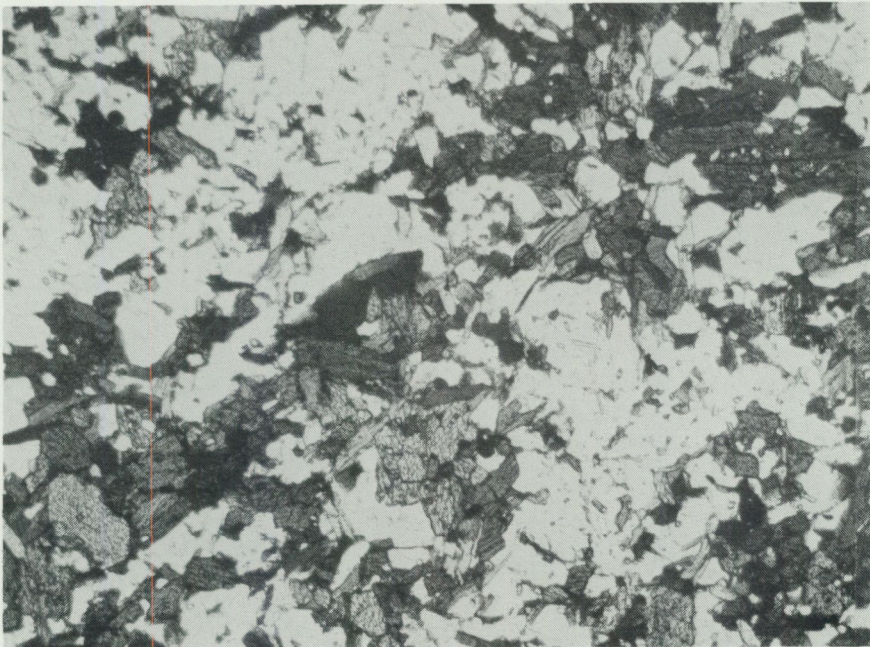


Fig. 30. Metabasite, gen. IV. + nic., 32 \times . S of Lake Maren. Map-sheet Västervik SO (1j).



Fig. 31. Metabasite, gen. V. + nic., 32 \times . N. Eknö. Map-sheet Kråkelund NV (7a).



Fig. 32. Metabasite, gen. VI. + nic., 32 \times . Lindskäret. Map-sheet Kråkelund NV (5a).

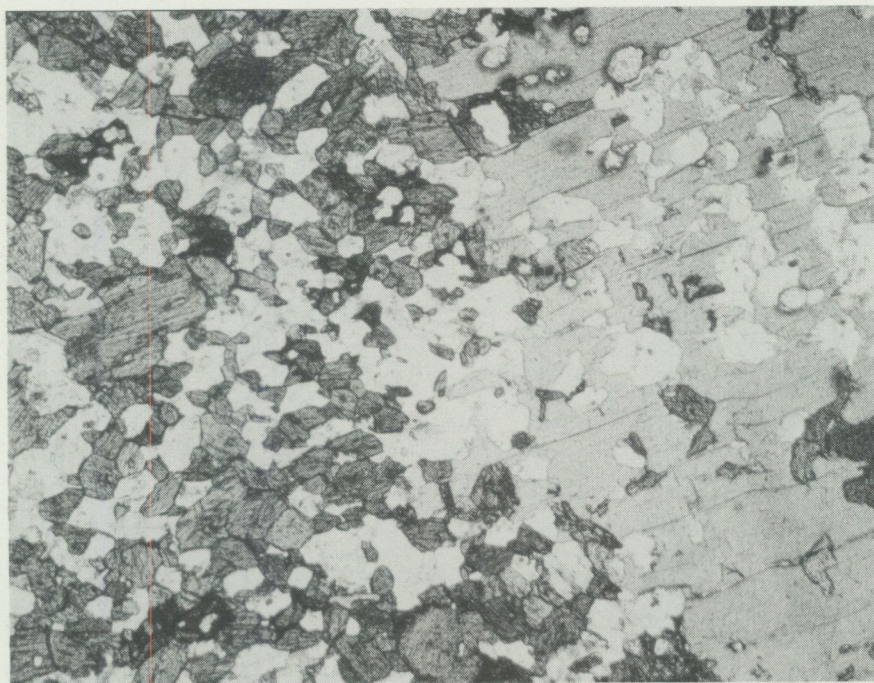


Fig. 33. Metabasite, gen. VII. + nic., 32 \times . N. Eknö, NW point. Map-sheet Kråkelund NV (7a).

A very interesting observation from the southern dike is particularly noteworthy. This dike contains a large angular xenolith of a coarse-grained, red granite. This is amazing since the nearest granite — the Gamleby granite — is 1.5 km away. The Loftahammar granite is about 4 km away. Since the Loftahammar granites have been found to underlie the metasediments where they meet, it would be most plausible to interpret the xenoliths as having been derived from the Loftahammar granite. In any case, the observations show that the basic magma penetrated granites and moved over considerable distances.

Under the microscope the matrix of the porphyritic forms consists of even-grained plagioclase (andesine), green hornblende and biotite. In addition, ores and biotite may be essential constituents. The phenocrysts, which macroscopically give the impression of being euhedral feldspar crystals, are found to consist of polycrystalline aggregates of plagioclase. The margins are intimately intergrown with fine-grained quartz, hornblende and/or biotite, giving the structure a myrmekitic or poikiloblastic appearance (Figs. 34—35). The outermost rims of the plagioclase aggregates are sometimes powdered with finely distributed quartz. Analyses nos. 43—59 provide examples of the chemical compositions of the basic magmatites as well as dikes with a more intermediate composition. Most of these

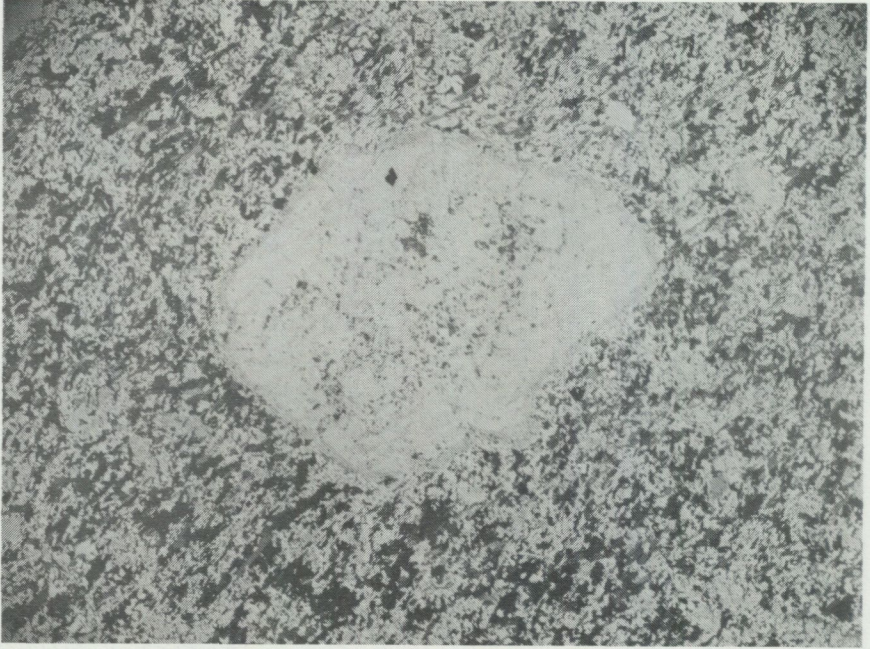


Fig. 34. Porphyritic metabasite. + nic., $6.7\times$. SE of Pärlobögen, 1.5 km E of Nygård. Map-sheet Västervik SO (4h).

rocks are seen to represent basaltic magmas. Analyses nos. 43, 45, 46 represent bedded tuffites and no. 44 an amygdaloidal lava, all belonging to generation I. Analysis no. 48 represents generation II, no. 49 generation III, no. 50 generation IV, no. 54 generation V, and no. 55 generation VI.

These analyses represent types which, by definition, can safely be ascribed to their respective generations. Analysis no. 47 is from the northernmost amphibolite gneiss area, where there is no definite indication of the position of the primary metabasite in the geological evolution. The fact that one sometimes finds traces of bedding in the metabasites makes it probable that they belong to the oldest basic volcanic rocks — generation 1. There is nothing in the chemical composition which would contradict such an assumption. However, one must keep in mind that the alteration which has affected these rocks may have caused some metamorphic differentiation. Analysis no. 51 is representative of the widespread metabasites seen on the map in the central areas around Gamlebyviken. The geological position of the metabasites can be compared with the concordant metagabbro-diorite bodies (generation II) in the southernmost archipelago. It is not impossible, however, that they are equivalent to the metabasites on the islands further to the north, which were assumed to represent generation IV. If analysis no. 48 is representative, these rocks seem to be most closely associated with gene-

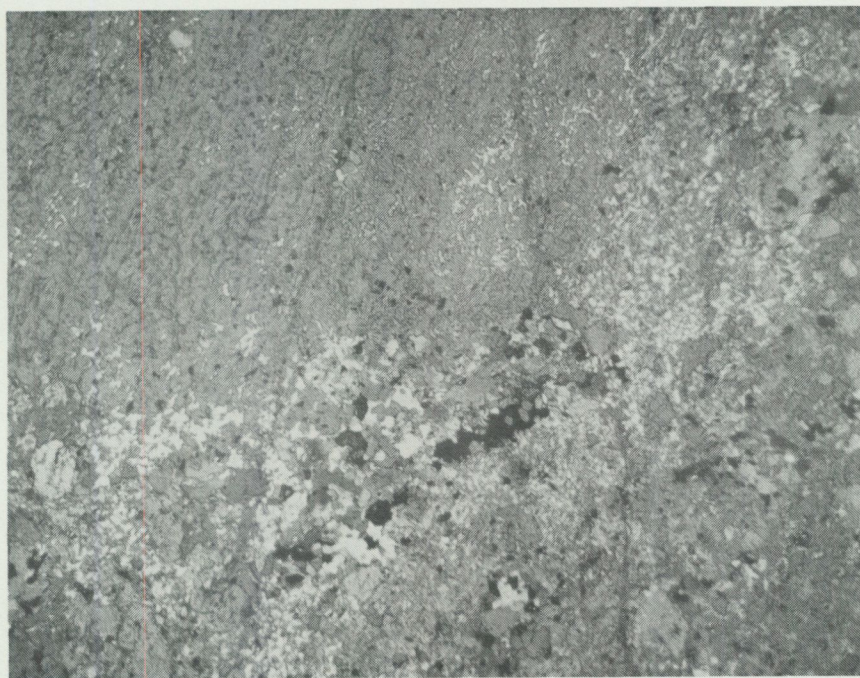


Fig. 35. Porphyritic metabasite. Fine-grained intergrowth of quartz and plagioclase as border zone around large plagioclase phenocryst. + nic., 32 \times . Råberga farmhouse. Map-sheet Västervik SO (4h).

ration IV. Analysis no. 58 is from the porphyritic metabasite described previously. There exist no indications whatsoever as to its age of intrusion. One could perhaps guess that it belongs to the most widespread dike generation, no. IV. Analyses nos. 49 and 54 represent the more sparsely found generations III and V, respectively. Analyses nos. 57 and 56 apparently represent generation VII. Analysis no. 59 could possibly belong to the same generation. It transects a deep quartzite. However, its chemical composition suggests that it belongs to generation VII.

In petrogenetic discussions, attempts have been made to classify the basaltic rocks into some main types: tholeiitic basalts, high-alumina calc-alkali basalts and alkali-olivine basalts etc. Some authors believe that these emanate from different levels in the earth crust and mantle. Barth (1962, p. 174) feels doubtful whether it is possible to perform such divisions consistently in all cases. He refers to an attempt by Murata (1960) to define two main groups, using a diagram with the content of MgO in per cent and the ratio Al_2O_3/SiO_2 as variables. Using Murata's diagram (Fig. 36) it is seen that analyses representing the group I, IV, and VII fall close to the boundary towards tholeiitic basalts, whereas groups II, V, and VI fall in or close to the alkali basalt field. Group III falls in the central field.

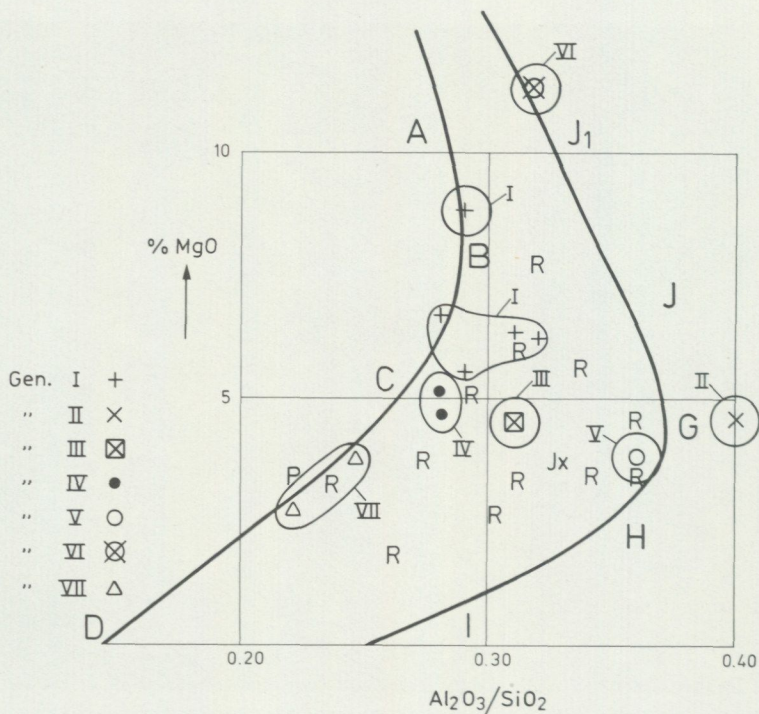


Fig. 36. Analyses of the metabasites projected according to Murata (1960). Tholeiite series: A-B-C-D; alkaline basalt series: J₁-J-G-H-I; porphyritic metabasite: P, analysis no. 58, J; analysis no. 109 from Jonuk's volcanite area 20 km west of Västervik (Table 1); R: analyses from Röshoff (1973).

Wilson *et al.* (1965) attempted to distinguish oceanic alkaline volcanic rock suites and orogenic calc-alkaline suites by using the Niggli values *alk* and *si* as parameters. A number of well-known representative rock analyses from various parts of the world were used. The above authors were able to draw a clear boundary line in the diagram between the two rock suites. Their investigation was made in order to examine the Precambrian volcanics of the Canadian shield. It is therefore of particular interest for the present problem. The same diagram has also been used by Röshoff (1973) for presentation of chemical characteristics of the Nömmen volcanites, situated about 100 km WSW of the Västervik area (cf. p. 138 ff).

The Canadian rock suites (Wilson *et al.*, op. cit.) all fall in the field for orogenic calc-alkaline suites, as would be expected. Both the analyses from the Västervik area and Röshoff's values fall mainly in the orogenic calc-alkaline field of the diagram, however, mostly very close to the boundary between the two fields. Some analyses also fall in the oceanic alkaline field, see Fig. 37. It seems that the orogenic calc-alkaline tendency for the Västervik samples is less pronounced

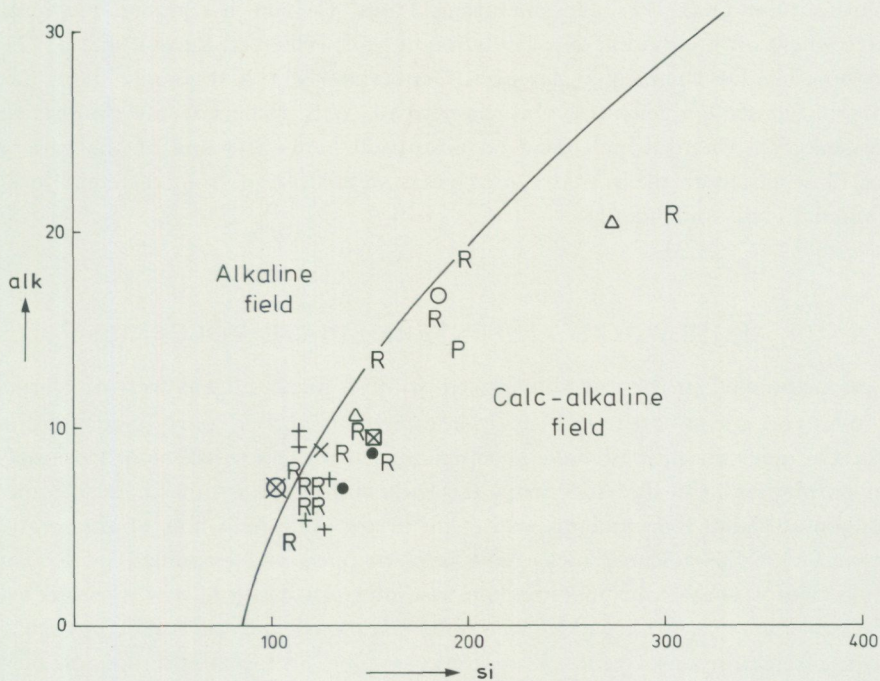


Fig. 37. Analyses of the metabasites projected according to Wilson *et al.* (1965). Symbols as in Fig. 36.

than in the examples from Canada presented by Wilson *et al.*

Analyses no. 55 (gen. VI) and no. 49 (gen. III) do not differ from the others as in Murata's diagram. The reason could be that this diagram is only intended to discriminate between high-alumina and low-alumina basalts.

A third way of characterizing basic volcanics on purely chemical grounds was presented by Rittmann (1962). In this scheme, the classical concepts of "Pacific", "Atlantic", and "Mediterranean" suites were used in forming a "suite index". Because Röshoff (1973) also used this classification, this grouping was also adopted for the metabasites from the Västervik area.

Both in the Västervik area and in Röshoff's Nömmen area the metabasites fall mainly in the Pacific group. A more detailed grouping according to the proposals of Rittmann is genetically meaningless. However, as evident from the four analyses of group I from the Västervik area, which occur close together, no. 43 (bedded metabasite, dense bed) is strong Pacific, no. 44 (amygdaloidal lava) weak Atlantic, no. 45 (bedded metabasite, dense bed) strong Pacific, and no. 46 (same locality, porphyritic bed) extreme Pacific.

If we compare the chemical characteristics of the seven generations of metabasites in the Västervik area, it is not possible to discern any general trend of

evolution with time. Possibly, generations I and II have a common magmatic source where differentiation or assimilation of sialic crust (cf. Barth 1962, p. 174) is responsible for chemical differences. Generation VII is definitely more acid and could indicate a general evolutionary trend. With respect to the comprehensive geological events which must be postulated between many of the generations, it seems more likely that the magmas were derived from different levels within the crust and mantle.

3.4. MAINLY ACID AND INTERMEDIATE VOLCANICS

It was mentioned in the introduction (p. 8) that about 20 km west of Västervik there occurs an area with acid, intermediate and in part basic volcanic rocks. On older maps, these have been assumed to belong to the so-called "Småland porphyries". On the older maps the rocks are found within an oval-shaped area about 10 km long and up to 2.5 km across. The long axis of the oval is east-westerly. The volcanic rocks have been mapped and examined by Roland Jonuks. Unfortunately, his investigation was interrupted before it was completed. It is hoped that his work will some day be completed and his results published. The main features are quite clear, however. The geological position of these volcanic rocks is so important for a survey of the geological evolution within the Västervik area that a brief presentation of his results to date is justified here.

3.4.1. MAIN GEOLOGICAL FEATURES OF THE AREA

(by Roland Jonuks)

Most of the volcanics can be classified as metarhyolites and meta-andesites. Metabasalts are subordinate. Metabasites in this group, however, could well be compared with the metabasites of group 1 in the present publication, which represents the basic volcanism of the southern part of the mapped area. Fig. 38 gives a simplified picture of the distribution of the various types.

The area which is best suited for a study of the mutual relations between metasediments and various types of volcanic rocks is the eastern part of the area in question. Here, the metasediments and the metavolcanics meet. Scattered observations of cross-bedding in the metasediments (quartzites, most probably belonging to Gavelin's lithostratigraphic unit 3) indicate that the metasediments underlie the volcanics. Some structural features in the volcanic metasedimentary rocks indicate the same thing (such observations are marked on the map, Fig. 38). Generally, however, the metavolcanic rocks are bordered by granites which frequently brecciate them and certainly belong to the younger granites, i. e. the Småland granites.

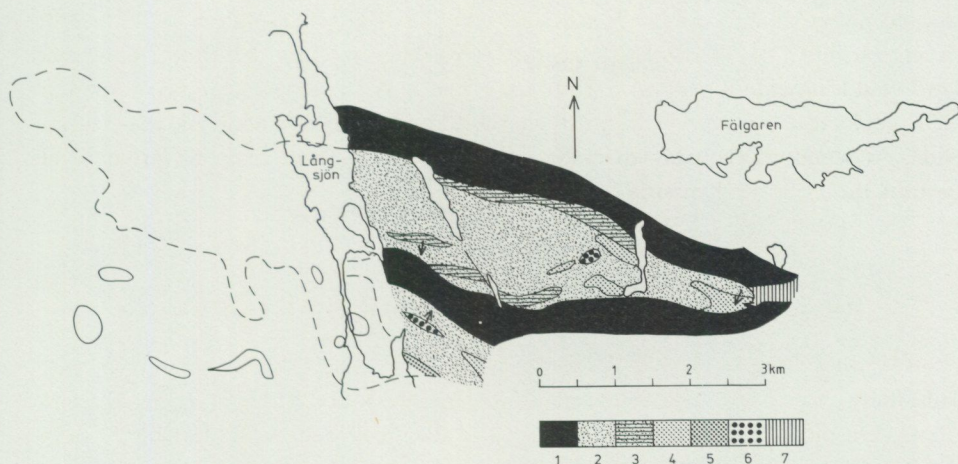


Fig. 38a. Generalized map of the volcanite area 20 km W of Västervik. Map-sheet Västervik SO (0-1, f-g). 1 = Granite; 2 = Metarhyolite; 3 = Acid to intermediate tuffs; 4 = Meta-andesite; 5 = Metabasalt; 6 = Conglomerate; 7 = Quartzite. Broken lines indicate the approximate westward extension of the volcanites.

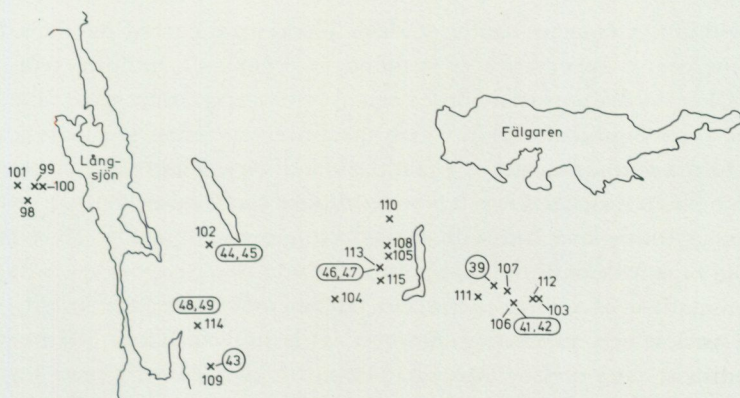


Fig. 38b. Position of analysed samples (Table 1: nos. 98—115) from the volcanite area 20 km W of Västervik. Encircled figures indicate position of Figs. 39 and 41—49.

The lowest members of the metavolcanic rock sequence consist of acid types such as metarhyolites. Generally, they are fairly coarse-grained and maintain a uniform appearance over long distances. Phenocrysts of feldspar and quartz are common. Along the highroad east of the northern part of Lake Långsjön, varia-

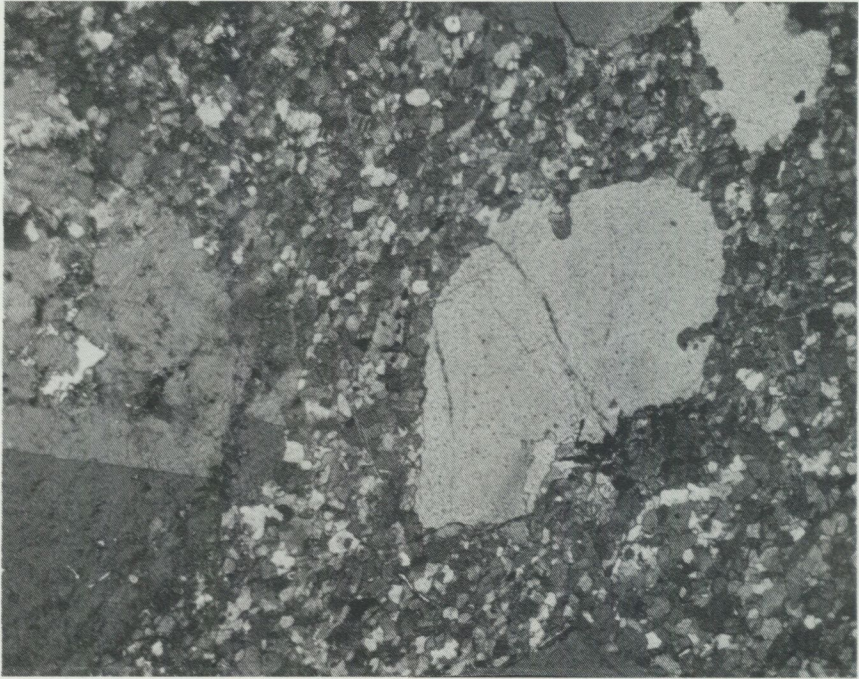


Fig. 39. Metarhyolite. Position, see Fig. 38b. + nic., 32 \times .

tions within the sequence can be studied. The central part of the metarhyolite has the same coarse appearance as is found to occur as a uniform type over large areas. Close to the northern border against younger granitic rocks, the metarhyolite has a dense groundmass in which there are very small phenocrysts. One kilometre to the south, the rock is again dark and very dense with almost no phenocrysts visible to the naked eye. These conditions could mean that we have a single, continuous, thick lava bed with chilled bottom and top. Fig. 39 is intended to exemplify the texture of the acid porphyries.

Intercalations of acid tuffites occur but are very rare. One locality (found by P. Kresten) is very interesting, however. It is situated about 400 m west of the southernmost part of lake Mösjön, just north of the small road towards Stormandebo. Here one finds a light gray bedded rock, where individual beds are clearly graded. The dark bottom part of each bed (the heavier volcanic minerals), grades upwards into lighter upper portions. These rocks clearly show the top-bottom direction in the volcanic sequence.

In the eastern part of the volcanic area bedded sections have also been observed. They are situated on, or close to the top of the porphyry bed. For this reason, they may represent a mixture of volcanic and epiclastic sediments. Some layers appear to be arkosic. At some places, small fragments have been

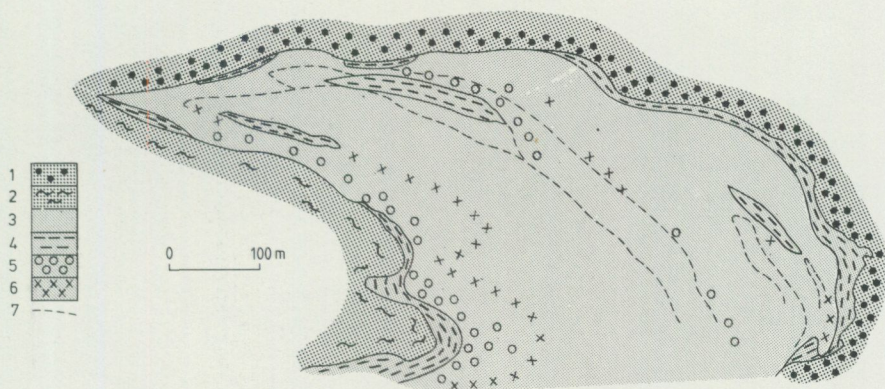


Fig. 40. Detail of the eastern part of the volcanite area 20 km W of Västervik (position, the south-easternmost meta-andesite area in Fig. 38a). 1. Coarse metarhyolite; 2. Fine-grained metarhyolite with fluidal structure; 3. Meta-andesitic lavas; 4. Meta-andesitic bedded tuffs; 5. Amygdaloidal meta-andesites; 6. Meta-andesitic agglomerates; 7. Continuous beds in the volcanic sequence.

observed in the porphyry. In addition, a weak fluidal structure is also observed, although such phenomena are on the whole very rare.

There also occur thick beds of red porphyry which chemically and mineralogically are very similar to those described above, but overlie them. There are also some dissimilarities, however, which are particularly obvious in hand specimens or in the field. Thus, the upper metarhyolites are more fine-grained. The phenocrysts are smaller and they are often characterized by a fluidal striation and small fragments. These features could indicate an ignimbritic origin.

The major minerals are quartz, potash-feldspar, plagioclase (An 30), biotite, muscovite, and sericite. Sometimes, spots of sillimanite occur. Accessories include zircon, apatite and opaque minerals.

The chemical composition of the metarhyolites is exemplified by analyses nos. 98—101.

On the whole, the andesitic and quartz-andesitic volcanics are much more variable than the red, acid volcanic rocks. An excellent cross-section through these rocks is found in the easternmost part of the volcanic area. This area has been mapped in detail, Fig. 40. Here, we find an intimate intercalation of lavas and tuffs or tuffites. In many cases, the sequence includes beautiful agglomerates with angular or rounded fragments of adjoining volcanics. A very instructive outcrop is found about 1 km west of lake Magergöl. Here, an agglomerate is seen to contain numerous fragments of the typical, coarse, red porphyry found to the north. This is a further indication that the top direction of the series is towards the south. Within the broad belt of andesites there are numerous lava beds which

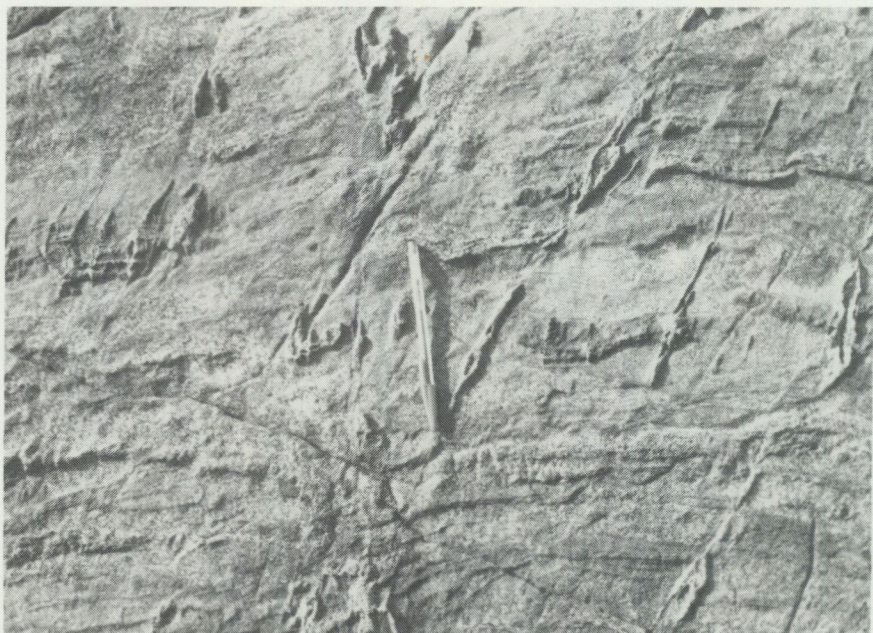


Fig. 41. Bedded andesitic metatuffites. Position, see Fig. 38b. Photo S. Gavelin.

differ in petrographical development. The rocks include dense lavas, lacking visible phenocrysts as well as lavas with well-defined phenocrysts of feldspars and even hornblende and amygdaloidal lavas with vesicles of quartz, epidote or garnet, etc. The tuffitic rocks are more or less clearly banded, frequently veined and often contain fragments of typical development. A large number of typical patterns are found which could possibly be used in the future to recognize the various beds in different parts of the volcanic area. Some of the characteristic patterns are shown in Fig. 41.

Sometimes, the andesitic lavas contain phenocrysts of plagioclase (An 30) and hornblende in a fine-grained groundmass of plagioclase, considerable biotite, hornblende and also some potash feldspar. Chemical compositions for the andesitic rocks are given in analyses nos. 104—108, 110—112. Fig. 42 exemplifies the texture of an andesitic lava.

True basic or basaltic members are rare in the area. Analysis no. 109 is the most basic rock analysed. Phenocrysts of hornblende occur in a matrix rich in plagioclase and hornblende. Fig. 43 illustrates the texture of this rock. Some of the darker volcanics, which could be said to represent chemical transitions between basalts and andesites, show well-developed amygdaloidal structures (Fig. 44). It is interesting to note that the very same bed of an amygdaloidal lava with-

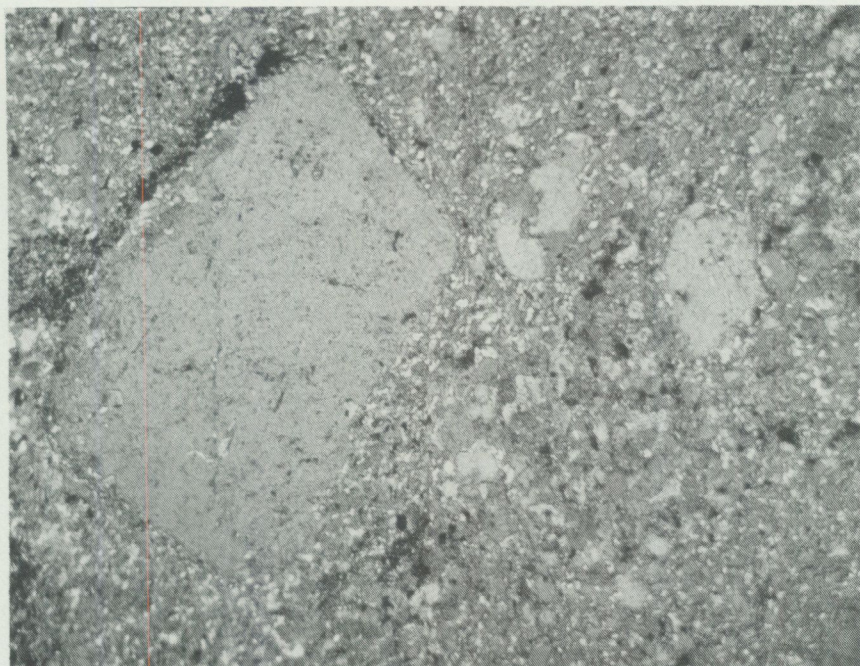


Fig. 42. Meta-andesitic lava. + nic., 32 \times . Position, see Fig. 38b.

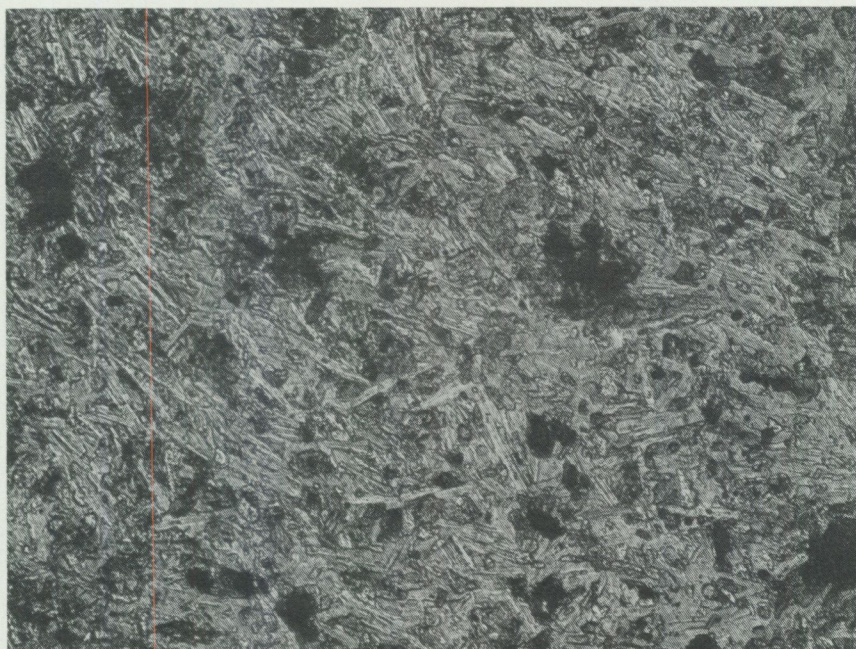


Fig. 43. Metabasaltic lava. + nic., 129 \times . Position, see Fig. 38b.



Fig. 44. Amygdaloidal lava. Position, see Fig. 38b. Photo S. Gavelin.

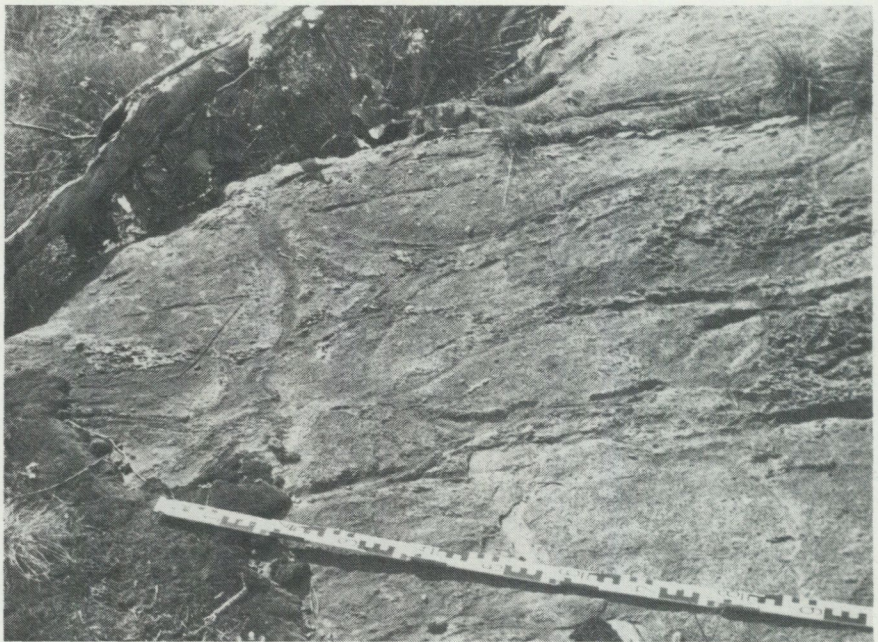


Fig. 45. Pillow lava. Position, see Fig. 38b. Photo S. Gavelin.

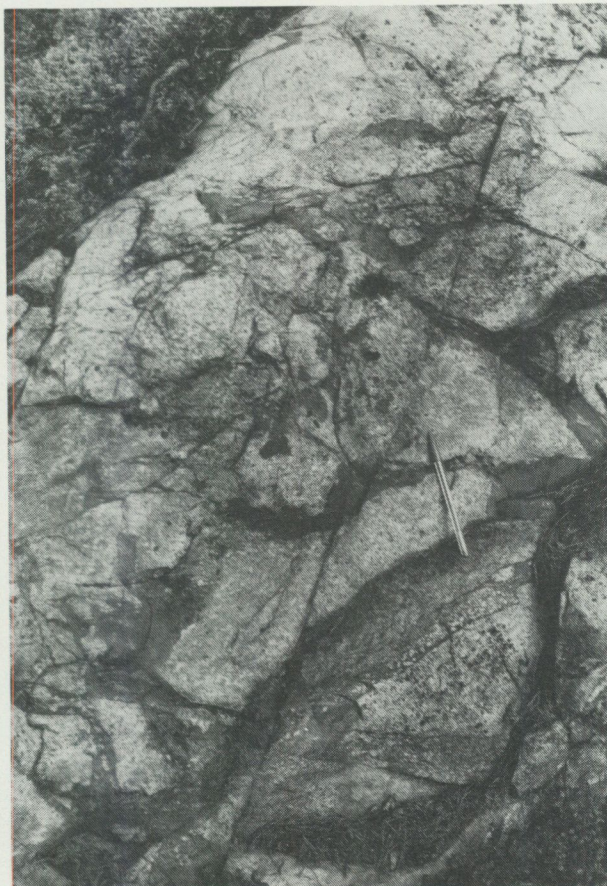


Fig. 46. Erosion breccia of coarse metarhyolite. Position, see Fig. 38b. Photo S. Gavelin.

in some few metres is exposed as a beautifully developed pillow lava (Fig. 45). Such observations confirm the general impression that sub-aquatic and supra-aquatic volcanism were intermixed, as is also evidenced by the relationship between sedimentation and volcanism.

In any discussion of the evolution of the volcanism described above, it is also necessary to consider some rock sequences which cannot be related solely to volcanic activity. About 1 km east of Stormandebo there is an area with conglomerates, surrounded by the same types of volcanites as those already described. Pebbles of the conglomerate consist almost entirely of metavolcanics. The bottom of the conglomerate has been studied in great detail. Sedimentation started by the formation of an erosion breccia composed of the red, coarse, lower metarhyolite, Fig. 46. This unit is overlain by conglomerate in which the pebbles are composed mainly of the coarse metarhyolites, Fig. 47. Next comes a more



Fig. 47. Polymictic conglomerate. Position, see Fig. 38b. Photo S. Gavelin.

polymict conglomerate, Fig. 48. Overlying these rocks are andesitic tuffs which correspond exactly to those found in the eastern area. These relationships show that there has existed a break in the volcanism. Uplift must have taken place followed by erosion before the next volcanic phase began. It is interesting to note that, within the area studied, there occur several indications of an unconformity between the lower, coarse acid volcanics and the andesites. Erosion breccias have been found on top of the metarhyolites. Arkosic layers are also seen in the metarhyolites close to the upper boundary. Everything fits in with the general evolution of the area. It would of course be desirable to be able to follow this stratigraphic discontinuity. This would require additional work in the field.

It has been stated that, within the well-exposed areas discussed previously,



Fig. 48. Polymictic conglomerate. Position, see Fig. 38b. Photo S. Gavelin.

there are consistently facing directions from the north towards the south. About 1.7 km south of Västatorp, just west of the road, there are some exposures which represent the southernmost part of the volcanic belt. The volcanics are surrounded by granites, see Fig. 38, p. 47. Here again we find a very beautiful polymict conglomerate, Fig. 48. It is bordered towards the north-east by layered, gray metasediments containing well-developed cross-bedding, Fig. 49. Dark layers in the rock consist of iron ore minerals (see analysis no. 114). Cross-bedding shows that these metasediments overlie the conglomerate. The metasediments in turn are overlain by the same type of fine-grained acid porphyry that was found previously to represent the uppermost part of the volcanic-sedimentary sequence.

Below the conglomerate, there is a narrow zone of banded andesitic tuffites



Fig. 49. Cross-bedded metasediment in the metavolcanics. Position, see Fig. 38b. Photo S. Gavelin.

and below them the coarse acid porphyry. We have consequently the same stratigraphic sequence as before — lowermost, coarse acid porphyry, followed by some andesitic tuffite, conglomerate, fine-grained metasediment and uppermost, fine-grained acid porphyry. The fact that facing or top direction of sedimentation in this case is towards the north indicates that the volcanic belt on the map represents a synclinal structure.

In summary, we can conclude that the volcanic activity started with a slightly acid volcanism. This phase was followed by vertical movements which resulted in combined volcanic and epiclastic sedimentation. The next phase was characterized by andesitic (possibly basaltic) volcanism. The final phase was one of acid, in part ignimbritic, volcanism.

The chemistry of this Västervik volcanic area can be visualized by analyses nos. 98—101, which represent acid lavas; nos. 102 and 103, acid, bedded tuffs; nos. 104—108, intermediate to basic lavas; no. 109, metabasalt; nos. 110, 111, intermediate agglomerates; no. 112, intermediate tuff; nos. 113—114, "sediments"; and no. 115, an intensely sericitized acid porphyry, which however, has no bearing on the original composition of the volcanics.

Fig. 50 shows the Niggli values t and k for these rocks. As would be expected, the lavas form a group around the line for $t = 0$. The two values from agglom-

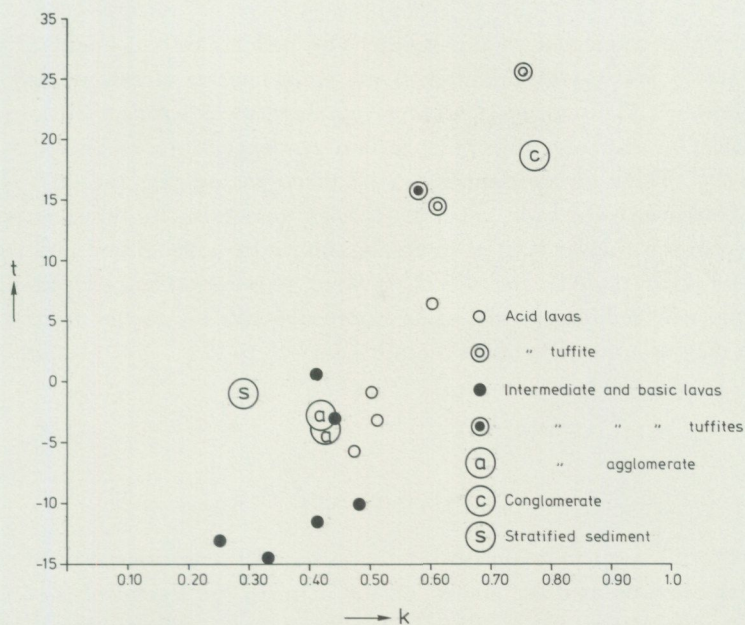


Fig. 50. Analyses of the metavolcanics and metasediments of the volcanite area 20 km W of Västervik, plotted in a $t:k$ diagram.

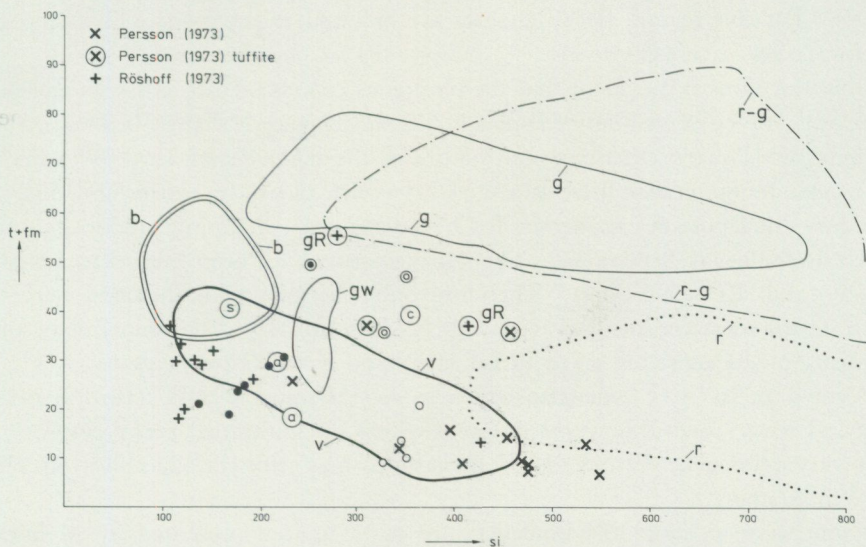


Fig. 51. Analyses of the metavolcanics and metasediments of the volcanite area 20 km W of Västervik, plotted in a $si:t+fm$ diagram (cf. Gavelin *et al.* 1976, fig. 20, p. 30, and its references). Symbols of the Västervik map area as in Fig. 50. Fields of the main groups of metasediments of the map area are also marked: v = "red metasediments"; g = "gray metasediments"; gw = graywackes; r-g = "red-gray metasediments"; b = metabasites from the Västervik area; gR = metasediments of Röshoff (1973). The heavy line v represents the field of volcanites in the presentation of Simonen (1953), see Gavelin *et al.* (1976).

merates are also connected to this group. The bedded tuffs — acid as well as intermediate — and the groundmass of the conglomerate clearly display higher t values, however. This means that they represent rocks with an obvious excess of alumina. One can also discern a certain tendency towards higher k values in this group. These circumstances can be taken to indicate that the rocks in question contained a certain amount of clay minerals. In other words, the volcanic evolution was, at least at intervals, connected with erosion and weathering. During such periods, the volcanics were to some extent mixed up with normal epiclastic sediments. The same impression can be gained from Fig. 51, which is a diagram of the variables si and $t + fm$ (cf. p. 57).

3.5. GNEISSES

In this chapter I want to comment briefly on the characteristic features of those rocks which are presented as "gneiss" on the map. In the legend of the map two main types of gneiss are distinguished: "Flecky gneiss" and "veined gneiss". Both of these expressions refer roughly to the way the rocks look in the field. Flecky gneisses are particularly interesting since they frequently grade into veined gneisses. For this reason, flecky gneisses are believed to represent a first step in the formation of veined gneisses.

From the name it is evident that the most conspicuous feature in flecky gneisses is the appearance of well-defined spots in a homogeneous or slightly bedded meta-sediment with quartz, feldspars and biotite as the main constituents. The flecks are zoned. In the center there is a dark core with plenty of biotite and quartz. The core (melanosome) is surrounded by a light rim containing practically only quartz and feldspar (leucosome). The flecky gneisses have been treated by Loberg (1963) and Russell (1969). Therefore only one picture is included here to illustrate the most conspicuous type, Fig. 52. Descriptions of the mineralogy and chemistry of the rocks are given in Loberg's and Russell's publications.

"Veined gneiss" is a field term which in several respects lacks scientific stringency. It is very useful, however, in areas where the gneissified rocks were originally very heterogeneous and the gneiss patterns may vary considerably from one place to another.

If one were to adopt the nomenclature of migmatites presented by Mehnert (1968) the term "migmatite" would apply to most of the rocks which have been characterized veined gneiss. They are also often called phlebitis by Mehnert. If one wants to emphasize the veined pattern, in contrast to the typical flecky gneisses, it seems convenient to use the expression "veined gneiss" for gneisses where leucosome and melanosome appear in a conspicuously veined manner.

A very characteristic feature of the rocks called veined gneisses is that the



Fig. 52. Flecky gneiss. Mjödö, eastern part. Map-sheet Loftahammar SV (0a). Photo S. Gavelin.

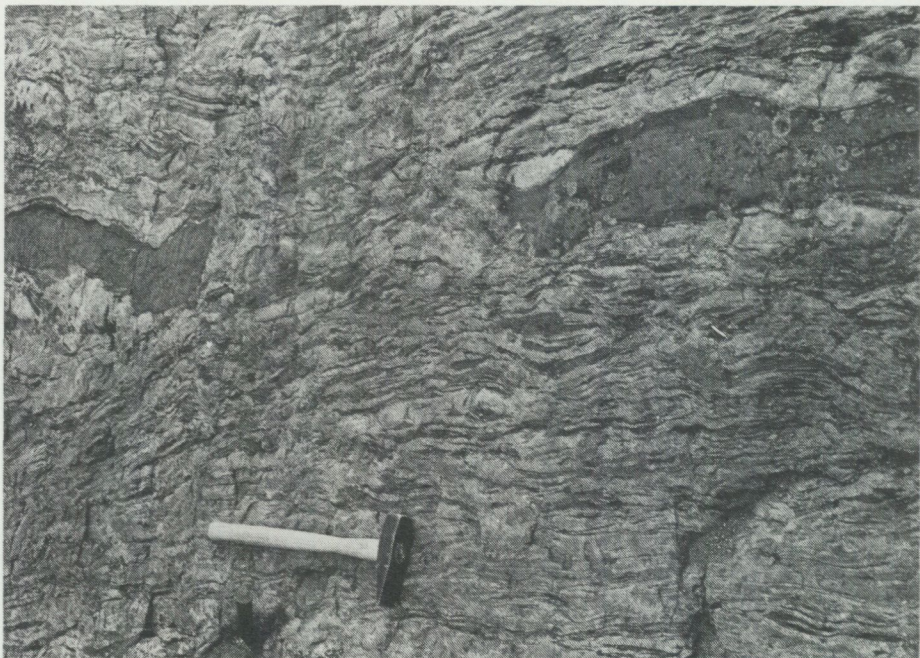


Fig. 53. Veined gneiss with broken-up sheets of metabasite. Shore west of the southern mouth of Spårösund. Map-sheet Kråkelund NV (9a). Photo B. Loberg.

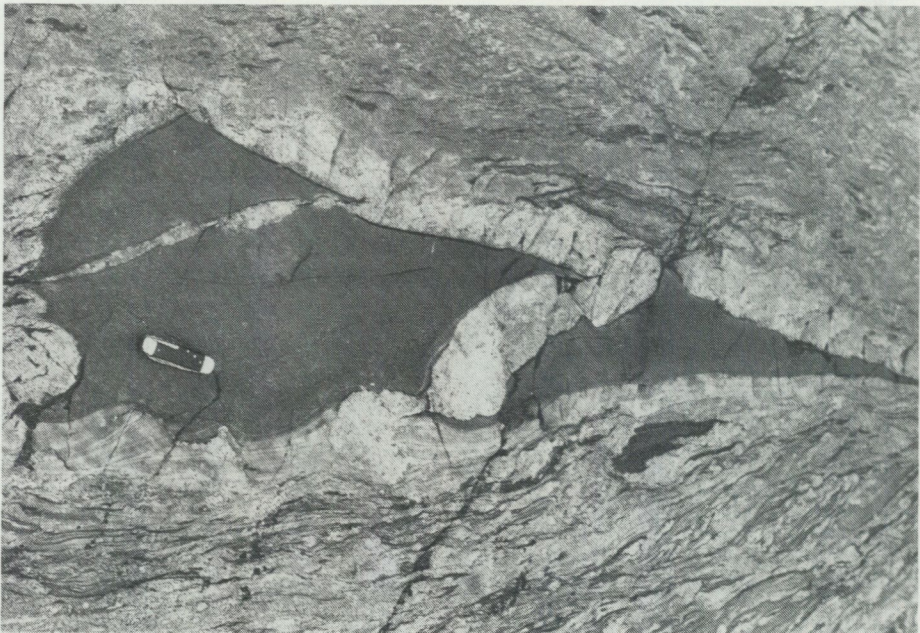


Fig. 54. Veined gneiss with broken-up fragment of metabasite. Mainland S of Borgö. Map-sheet Loftahammar SV (0a). Photo Th. Lundqvist.



Fig. 55. Veined gneiss with scattered fragments of better preserved metasediments. Locality as Fig. 54. Photo Th. Lundqvist.

whole rock mass has been affected by a very intense flow-folding. Xenoliths of various metabasites, quartzites and other more competent rocks are generally abundant.

The structural development of rocks which have been designated "veined gneiss" on the map is best illustrated by a number of photos from outcrops (Figs. 53—56). In general, one can discern two (sometimes more) components with different physical properties. Pure quartzites and metabasites are highly competent and break up into fragments in a more flowable mass which often has a pegmatoidal or granitoidal appearance. In the flowable portion of the gneiss we also find different kinds of "flowable" material. For example, although finely bedded micaceous metasediments may be plastically "flow-folded", they may also occur as broken pieces in more distinctly granitoidal parts of the rock. Sometimes, the flowable mass has been strongly granitized to the extent that certain parts can be characterized as granite while at the same time it is possible to discern sedimentary structures in the granitoidal material. Kretsen (1971a, b)

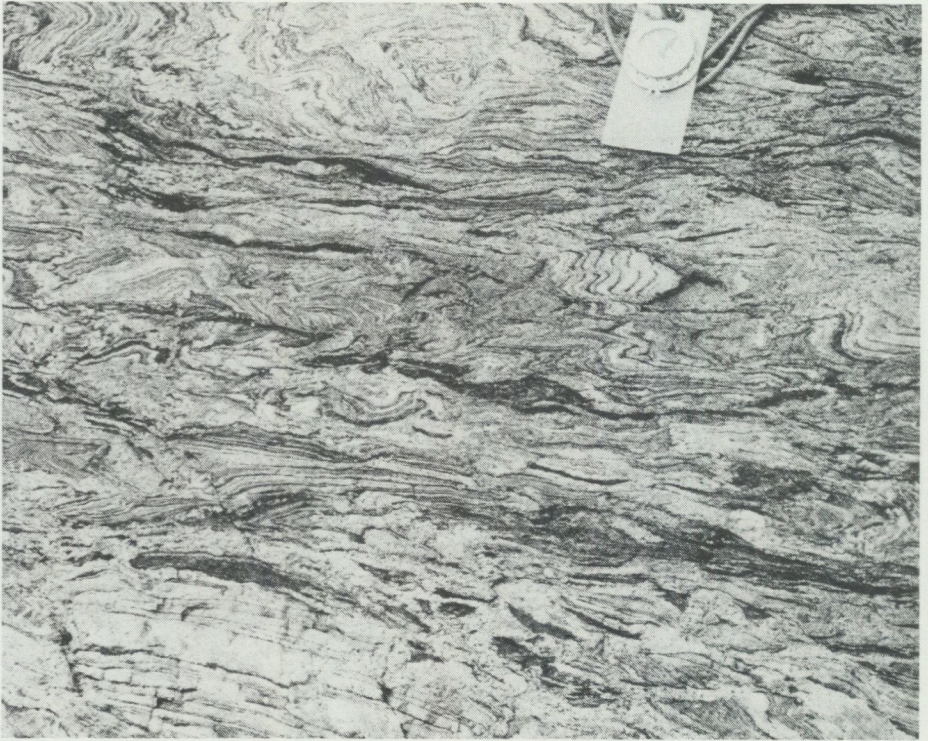


Fig. 56. Veined gneiss with remnants of crumpled, better preserved metasediments. Locality as Fig. 54. Photo Th. Lundqvist.

called these rocks "raft migmatite". A characteristic feature of "raft migmatites" is that the flowable granitoid contains a larger number of xenoliths than elsewhere. Some xenoliths represent well-preserved, fine-bedded, gray metasediments which were folded prior to their inclusion in the granitoid (Fig. 57). One also finds xenoliths of various metasediments and metabasites which are more or less resorbed and display gradual transitions to the granitoid (Fig. 58). These types of gneiss are best developed in the south-easternmost part of the map area.

The mineralogy of the veined gneisses is of course very heterogeneous. The light portions have granitoid or pegmatoid compositions with quartz, feldspars and some micas as essential minerals. Andalusite, sillimanite and cordierite may occur, but as subordinate constituents. When present, they are enriched in the dark portions of the gneiss. The origin of the gneisses will be discussed in the chapters on granitization. The chemistry of the rocks characterized as gneisses will be treated in the chapter "Origin of gneisses and granitization", where the analyses of gneisses in Table 1 are used.



Fig. 57. Folded metasediment xenolith in granitoid groundmass. Tvarö, northern shore. Map-sheet Kråkelund NV (5a). Photo S. Gavelin.



Fig. 58. "Raft migmatite". Tvarö, northern shore. Same locality as Fig. 57. Photo S. Gavelin.

3.6. GRANITES

3.6.1. PRESENTATION OF GRANITES ON THE MAP

On Swedish maps of areas which were previously characterized as Svecofennian, Gothian or Karelian, (conceptions which are now taken to represent roughly contemporaneous rock sequences of different lithological facies) two main granite groups have been recognized. The oldest one has been called "urgranite" or "gneiss-granite" in Central Sweden, or with reference to tectonic events, pre- or synkinematic granite. Younger granites were given local names such as Stockholm granite, Malingsbo granite, Örebro granite, etc. They were generally summarized under such headings as "younger granites" or "late-, in part postkinematic granites". A third group could sometimes be added, being a clearly postkinematic granite. The rapakivi granite is the most characteristic representative of this third group. Two criteria for the determination of the relative age of a granite were generally used. Firstly, the older granites, which had been affected by early folding and regional metamorphism, were frequently schistose and recrystallized, resulting in a granoblastic texture seen under the microscope. Younger granites, however, displayed a more "primary" granitic texture. These textural requirements must be taken with some caution, however. Central parts of large, older granite massifs, for example, might have escaped more intense deformation subsequent to the primary consolidation of the granite.

The second feature used for a characterization of the two granite generations was seen in the fact that the older granites were intruded by basic dikes (metadolerites), which were in turn always found to predate the younger granites. Even this criterium is sometimes of little value, however, if metabasite dikes are lacking in the area under investigation.

In the Västervik area, two main granite generations were recognized by A. Gavelin (1904, 1910). The most representative form of the older group is the so-called "Loftahammar granite", which forms a large mass bordering the metasediments towards the north-east. Rocks which are similar in appearance have also been found at several other places within the map area. Younger granites have been summarized under the heading "Småland granites". They have their major extension to the south and east of the metasediments. As typically developed, these two granite generations are in accordance with the definitions given above. The Loftahammar granites are generally gneissic and often display a conspicuous preferred orientation of micas. The Småland granites are massive and display no or very weak schistosity (no s-planes). The Loftahammar granites are frequently cut by metabasite dike swarms, rocks which are always brecciated by typical Småland granites.

On these grounds, it would be possible to distinguish the two granite generations by different colours on the map. There are, however, serious complications when one attempts to perform such a two-fold division consistently. It is evident from the general names of the granite groups (i.e. synkinematic and late- to postkinematic) that the relationship of granite emplacement and tectonic evolution should also be taken into account. Folding and various kinds of metamorphism have occurred after the *mise en place* of the older granites. They first grew schistose. Following stages of metamorphism led to the formation of veined or flecky gneisses in the metasediments. This formation also affected the older granites and may then have remobilized them in part. As a result of these processes the metabasite dikes were more or less broken up. This means that the same metabasite may occur both as a dike and as xenoliths in the same granite (cf. Figs. 74, 75, see p. 105). In general, such mobilized older granites have been recrystallized a second time, with the result that both in hand specimen and in thin section they give the impression of being a younger granite. Sometimes, one finds granite massifs where one part has the appearance of being a gneissic older granite while another part is more massive and non-gneissic. Both types may grade into each other fairly abruptly, but form comparatively similar-looking types over wide areas. In the more massive granites of this kind, the previous gneissic structure has apparently been more or less obliterated by the recrystallization accompanying the formation of veined gneisses. The problems concerned with these processes will be discussed in some detail in the chapter on metamorphism.

From what has been mentioned above it is clear, however, that it is impossible to maintain a clear distinction between two granite generations. Therefore, although it might be reasonable to maintain a general two-fold division, one must remember that in each group granitic matter must have migrated during several stages. For example, the last intrusions belonging to the younger granites are definitely postkinematic. They show straight granite veins cutting all fold structures. Such types are clearly massive and non-schistose. But there also exist types where weak s-planes are visible, due to preferred orientation of biotite. One also finds veins of type "younger" granite which cut across minor folds in a veined gneiss but are themselves plastically folded as a result of later stages of movements during the formation of veined gneiss, Fig. 59. Differences in the tectonic behaviour of the granites on a larger scale may perhaps be the best way of distinguishing between older and younger granites.

Generally the older granites are semiconcordant with respect to the metasediments. They form large massifs and are mainly found to underlie the metasediments (for example the Loftahammar granite to the north-east, the small granite massif near Falsterbobruk, etc.). The granites characterized as younger may, to a certain extent, follow the main structural pattern of the metasediments, especially the earliest granites within the younger group. Other, perhaps later generations, appear on the map as clearly discordant bodies with respect to the major

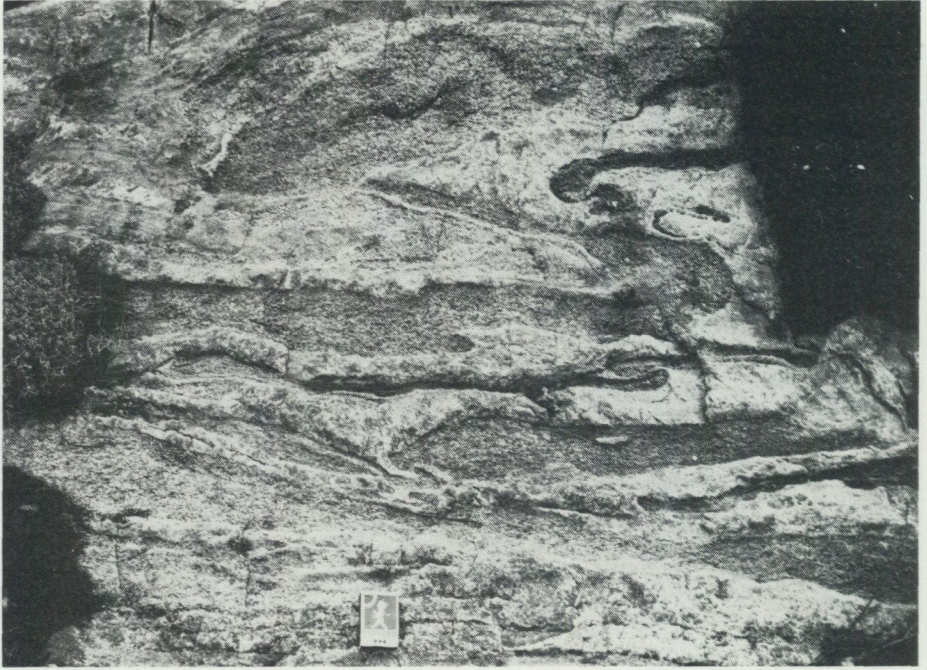


Fig. 59. Plastically folded vein of granite of the "younger type". S of Vida farmhouse 5.5 km N of Gamleby. Map-sheet Västervik SO (4h). Photo S. Gavelin.

fold pattern (see for example the granite massif in and around the village of Gamleby). The large massifs of younger granites frequently display contacts which are both concordant and discordant with respect to the metasediments. From the relationships described above, it is evident that in a two-fold division of the granites there must be cases where it is a question of definition what a certain granite shall be called and which colour should be chosen for its presentation on the map.

During the initial field work, granite areas were given only a superficial attention since the metasediments and their metamorphism were the primary aim of the investigation. Kresten has done a detailed study of the granitoids and presented a map which shows his conception of these rocks, their distribution, various types, and age grouping. (On my map the distribution of older granodiorite follows in the main Kresten's presentation.) Together with Chyssler (Kresten and Chyssler 1976) he has also described a small massif south of the map area, the Götemar massif. This granite represents a third age group of younger granites which is clearly postkinematic.

On the map, granites which megascopically and under the microscope clearly display gneissic structures and textures are marked with deep brown colour.

This denotes that they belong to the older group. Granites which are non-gneissic and connected with veined gneiss formation are given a red colour, indicating that they are younger granites. Areas with non-gneissic or weakly gneissic granites which gradually grade into gneissic forms and form continuous massifs together with the gneissic types are marked by paired dashes on deep brown on the map. This indicates that they are believed to represent recrystallized and mobilized parts of the previously gneissic granite. The same kind of symbolization is used for granites which contain metabasite dikes that have been broken up, and are now seen as xenoliths in mobilized older granite. This last-mentioned pattern indicates that the old gneissic granite has not only been secondarily recrystallized but that it also has been mobilized and subjected to partial secondary flow.

It must be remembered, however, that a presentation according to the principles sketched above cannot be performed absolutely consistently. Even within areas which are shown on the map as merely older granites, the rocks can show signs of having flown plastically. Sometimes, where the old granites are porphyritic, some of the porphyroblasts appear to be clearly postkinematic. They show no effects of the deformation leading to schistosity. From the data available, it is generally impossible to make any statements as to the degree of secondary deformation. The presentation on the map of transitional forms between older and younger granites is only intended to show cases where such forms are clearly evidenced by field data. In summary, one can say that the division of the granites into two main age groups has been founded firstly on the structural and textural developments of the granites, secondly the relations between granites and intrusive basic rocks and thirdly the tectonic behaviour of the granite, both in detail and in the patterns seen on a larger scale on the map.

In an attempt to present a survey of the total genetical history of the granites, some additional features are also worthy of consideration. In some cases, one finds vast granite areas where the rocks are very uniform. This may also hold true for massifs where one part exhibits characteristics normally associated with the old granite, while another part is recrystallized and has the appearance of a younger granite (for example the massif in the northern part of the map, north of Lake Billsjön). In other cases, even small massifs may contain a large number of structurally and mineralogically different types. An excellent example of this phenomenon is the small massif along the highway E 66, 16 km south-west of Västervik. Here, rocks form a mixed association of coarse porphyritic Loftahammar granite, fine-grained gneissic granite, massive red granite with broken up metabasite dikes and recrystallized granite of a younger appearance, etc., see Fig. 60.

Another feature which may contribute to the characterization of a specific granite is the content and composition of xenoliths. Many massifs are built up of granite containing abundant xenoliths with characteristic shapes and composi-

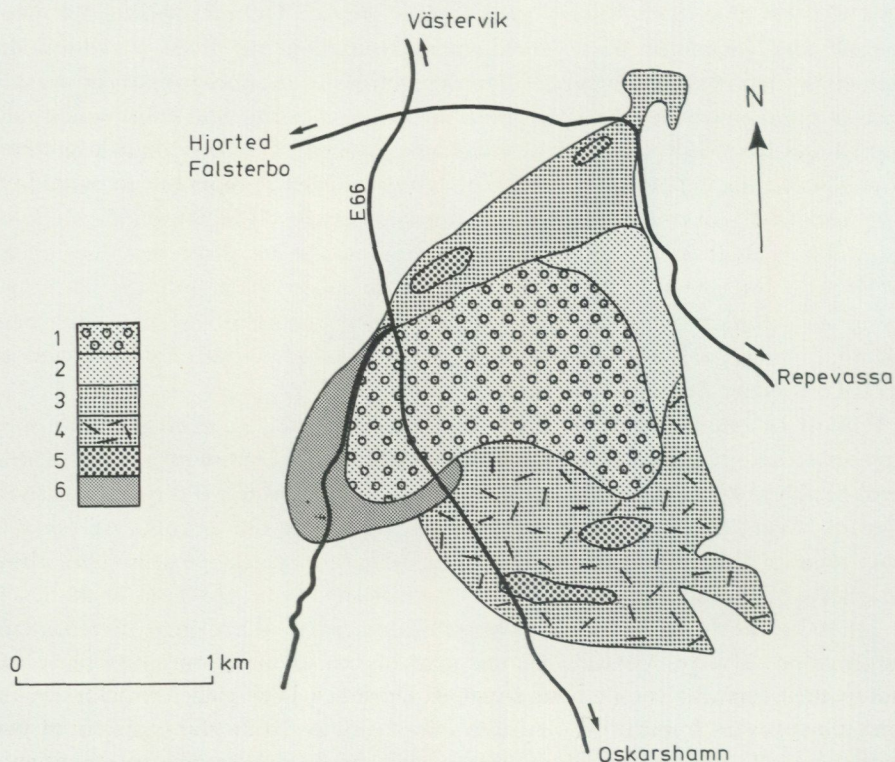


Fig. 60. Composite mass of older granite around highway E 66, about 16 km south-west of Västervik. Map-sheet Vimmerby NO (8h). 1 = porphyritic granite, Loftahammar type; 2 = fine-grained red granite ("border type"); 3 = even-grained red granite, sometimes with "younger" recrystallization; 4 = type 3, but frequently with broken-up metabasite dikes; 5 = even-grained granite with younger texture but with visible remnants of an older structure; 6 = typical younger granite.

tions. Others are absolutely free from any kind of xenoliths. The importance of these characteristic features in the formation of granite genesis will be discussed in the chapter on metamorphism and granitization.

With respect to the great variability among granitoid rocks within the map area, it would have been possible to propose several additional types between the younger and the older granites. However, there also exist transitions between metasediments, i. e. metasedimentary gneisses and granitoids. Generally, such transitional forms are fairly local in extent, for example the granite on Lammholmen in the southernmost part of Plate 1 (Kresten 1971a) and the Judö granite south of Borgö. In the south-eastern part of the map area, however, there is a belt of rocks which has to be marked on the map as "raft migmatites". These rocks can be described as pink granitoids which in a hand specimen could definitely be called granite, but which at the same time show signs of primary

sedimentary bedding when larger outcrops are studied. These granitoidal masses also contain large numbers of xenoliths of different kinds, including quartzites, various bedded meta-arenites or meta-argillites, and metabasites, etc. These rocks have already been described in the section on gneisses, pp. 61—63 and Figs. 57 and 58. On the whole, this rock development shows a very characteristic pattern. It also forms an important link in the transition from metasediments with preserved sedimentary primary structures into homogeneous granitoids.

3.6.2. OLDER GROUP OF GRANITES AND GRANODIORITES

The most well-known representative of this group is the Loftahammar granite which mainly borders the metasediments to the north-east. This granite was described by A. Gavelin (1904) where the main mineralogical and structural features were presented. Torbjörn Hahn has investigated the border zone between the Loftahammar granite and the metasediments within the mapped area.

Typically, Loftahammar granite is a coarse, porphyritic rock, generally with a marked schistosity, which is particularly obvious in the micaceous forms, the biotite then forming conspicuous s-planes. During a later stage of deformation, these planes were frequently plastically folded (cf. p. 102). Hahn discerned two main types. The main and dominant type is fairly rich in biotite. Additional major minerals are quartz, microcline and oligoclase. Some hornblende is also present. According to Hahn the border zone towards the metasediments is more acid. Hornblende is lacking and biotite is less frequent.

During the mapping it was found that the "normal Loftahammar granite" extends towards the north-west and curves around the north-westernmost parts of the metasedimentary areas. The same granites are also found south-west, south and south-east of Västervik as fairly large massifs. Within these areas, the older granitoids are frequently developed as granodiorites. The mutual relations between these older granodiorites and the "true" Loftahammar granites are not clear. In places, there seem to exist continuous transitions between the different forms. At other localities, however, the change from one type to another is abrupt. For example, south of Händelöp there occurs a narrow belt of typical Loftahammar granite, 300—500 m wide and over 5 km long. This granite joins an older granodiorite, which, however, is massive and differs clearly from the Loftahammar type.

A still more surprising occurrence of typical Loftahammar granite is found in a small massif about 2.5 km north-west of Rummen. On the map it appears as a small lens, about 1000 m long and 250 m wide. It is interesting to note that this small granite mass more closely resembles the typical Loftahammar granite

to the north-east than it does the large masses of older granite found closer to it towards the south-west.

There are also some other small massifs of older granite which differ from the main type. The small massif south of Lake St. Flugen, 17—18 km WSW of Västervik, consists of a special type of granite which, on account of its relation to metabasites and its tectonic position, must be classified as belonging to the older group. It is a fine-grained acid granite dominated by quartz, microcline and oligoclase ($\sim 25\%$ An), with subordinate biotite, chlorite and sericite. The chemical composition of the rock is given in analysis no. 85, Table 1. In this case the granite looks very similar throughout the massif. The small granite massif around and east of highway E 66, about 16 km south-west of Västervik, (see p. 68) is quite different. Here, within a small area, we find representatives of true Loftahammar granite, as well as several other types. The geological relationships between different types makes it clear that they belong to a single, common age group.

A third very important type of older granites has been described by Kresten (1974). The massif in question is situated about 25 km SSE of Västervik, and is called the Hamnö granite. Contrary to the Loftahammar granite the Hamnö granites often look very "fresh" and unaffected by mechanical deformation. For this reason, they were classified originally as belonging to the younger granites. Kresten's investigations, however, showed indisputably that they are older than the metabasites of group 4, and that they therefore must be referred to as older granites. According to Kresten, the massif is composed of three main types. These are arranged in a zonal manner. The central one is the most basic zone. The outermost zone is the most acid. Average values for these three types have been included in the diagram of this paper, Figs 83—85 (see pp. 131—134).

In summary, we can say that within the so-called older granites and granodiorites there are several distinctive petrographical groups or types which even in their field behaviour appear differently. For this reason, it is also possible that within the group the rocks may have slightly different ages.

The proportions between the major minerals quartz, microcline, plagioclase, and micas may vary over short distances, or in other instances the rocks may show very homogeneous compositions over wide areas. The variations in chemical and modal composition can best be exemplified by analyses nos. 77—84 (from Hahn, the Loftahammar massif proper), analyses from the Hamnö massif (Kresten 1974), further the analysis no. 85 and granodiorite analyses nos. 86—88 from the map area in Plate 1. Fig. 84, p. 132, was intended to illustrate some of the problems on granitization. The older granites are also included here. In the figure, we see that Hahn's Loftahammar granites form a well-defined group characterized by low c and high alk values. The Hamnö granites (KH) form a separate group. Analysis no. 85 of the acid Flugen granite, represents the most alkaline form.

3.6.3. YOUNGER GROUP OF GRANITES AND GRANODIORITES

From the map one can see that granites characterized as belonging to the younger group appear to the west and the south of the metasediments. It was stated previously that older granites usually are schistose, whereas the younger are non-schistose. It was also mentioned, however, that even younger granite may sometimes display a weak schistosity and that some granites which for other reasons must be classified as older are completely massive. On the whole, typical younger granites are characterized megascopically by a more clear granular appearance. Plagioclase and sometimes microcline, too, occur as rectangular individuals with reflecting crystal surfaces. On the whole, however, even such diagnostic features are insufficient for distinguishing between the two groups. Frequently, only the geological occurrence and general features over vast areas can be used as diagnostic criteria. Analyses nos. 89—96 give a survey of the chemical compositions of various representatives of this group. Analysis no. 97 represents a granodiorite which is believed to belong to the younger group.

3.6.4. TRANSITIONAL FORMS BETWEEN THE OLDER AND THE YOUNGER GRANITES

In the chapter of the subdivision of granites (3.6.1) it was mentioned that transitional forms are marked on the map only when they occur in larger bodies and are intimately related to typical older (Loftahammar) granites. Megascopically, they are massive and display well-defined feldspar individuals with reflecting crystal faces. It is possible that they represent older granites which have been secondarily recrystallized in connection with the formation of veined gneisses. Such rocks are best displayed north of Lake Rummen; however, similar phenomena have been observed in other areas. The classification of older granites containing scattered fragments of metabasite dikes may be a question of definition. Should they be presented as true older or as transitional types? Even masses classified as younger granite may be questionable if their structural-geological behaviour is considered. On the map, the large lobe of younger granite north of Henriksnäs—Skälö has the appearance of a resistant block towards the folded metasediments. Its general structural and textural behaviour, however, is in accordance with the younger granites.

3.6.5. SPECIAL MINERALOGICAL, CHEMICAL, STRUCTURAL AND TEXTURAL FEATURES OF THE GRANITOIDS

From the preceding brief descriptions of the granites, it is evident that the different groups show no significant differences with regard to mineralogical composition which can be used to identify them. Fig. 83, p. 131, which is intended

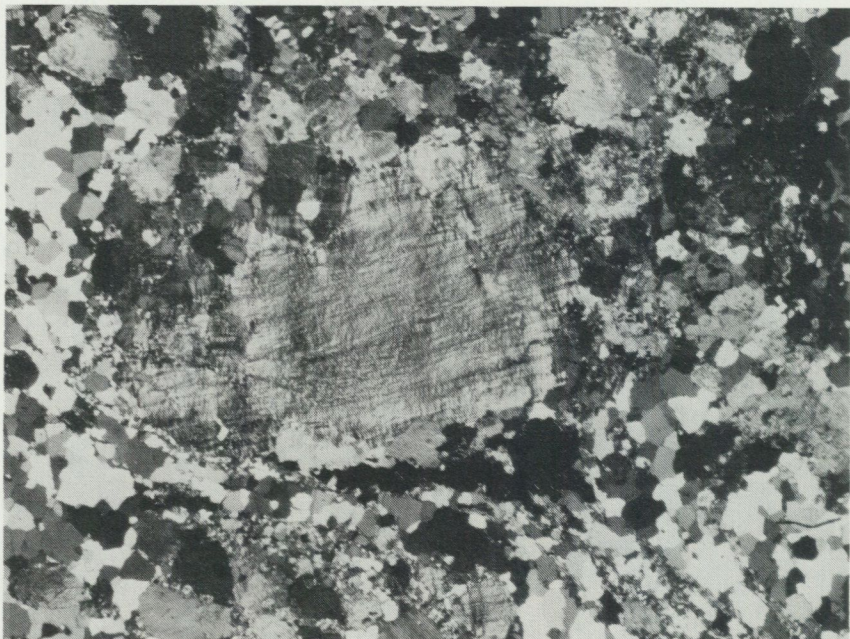


Fig. 61. Loftahammar granite. + nic., 12 \times . Svärdsöholmarna. Map-sheet Loftahammar SV (2a).



Fig. 62. Younger ("Småland") granite. + nic., 12 \times . 3.5 km N of Hjorted. Map-sheet Vimmerby NO (8f).

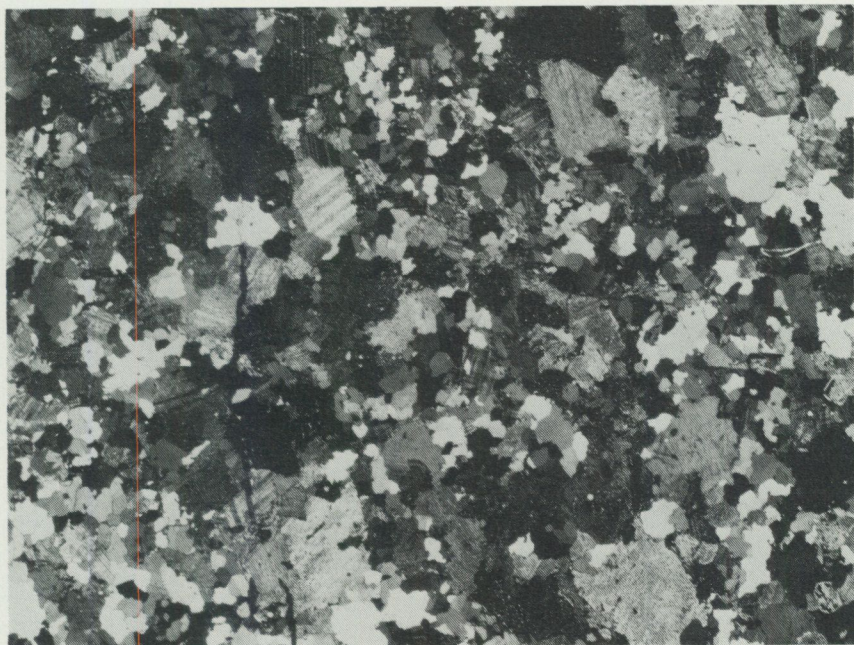


Fig. 63. Older granite. + nic., 12 \times . N of Lixtorp. Map-sheet Västervik NO (5f).



Fig. 64. Götemar granite. + nic., 12 \times . Map-sheet Vimmerby SO (4j).

to demonstrate the granitization of the metasediments, also shows the field of older granites. The older granites coincide fairly well with the field for younger granites. The older granites have also been plotted in the c — alk diagram shown in Fig. 84, p. 132. It is seen that no general trend of dissimilarity between older and younger granites exists. It is noteworthy, however, that different larger massifs disagree significantly. The Loftahammar granites proper (T. Hahn) are characterized by high alk and low c values. The Hamnö granites (Kresten) have higher c and lower alk , while the most acid form, the Flugen granite, is also the most alkaline type. The younger granites display a spread of approximately the same order in the diagram. It is interesting to note that older and younger granites from the same area coincide in the diagram fairly closely.

With regard to structures, one would expect that the older granites should display signs of more intense cataclastic deformation in thin section. This seems to hold true in an overall judgement of the samples examined. Kresten (1974) stressed that in the Hamnö granites, fine-grained crushzones surrounding and penetrating larger feldspar individuals are common. He believed this to be the most characteristic feature for distinguishing between older and younger granites. Unfortunately this does not hold true in every case. In other words, crushzones are often found even in the younger granites (even in granitic rocks characterized as younger by Kresten), although on the whole they are somewhat less frequent there and not so pronounced. This is understandable if one remembers that early forms of younger granites were sometimes plastically folded (cf. p. 65). Moreover, a general study of the older granites gives the impression that mechanical deformation of the granites was irregularly distributed through the rock mass. This is evidenced by the fact that shear zones may act as local foci for movements in the granitic masses (cf. Figs. 74—75, p. 105). This means that flow and late plastic deformation in the old granites are a selective process.

From the above it is clear that in thin section it is not possible in every case to distinguish between older and younger granites. As a general impression I would like to suggest that grain size and grain form are more irregularly developed in the older than in the younger granites, and that lamellar twinning in both plagioclase and microcline are clearer and better developed in the younger granites. But on the whole it is evident that many of the younger granites have been affected by mechanical deformation. It was mentioned previously that just south of the map area there is a granite massif that is definitely postkinematic, the Götemar granite (Kresten and Chyssler 1976). Under the microscope, this rock discloses a very "fresh" granitic structure with well-defined individuals of plagioclase and potash feldspar. It is evident that the structural dissimilarities between the Götemar granite on one hand and the younger granites of the map area on the other are far more conspicuous than the differences between older and younger granites on the map.

Figs. 61—64 show some selected examples of various structural types seen in

the granites of the map area. Generally the identification of some granites as transitional forms between older and younger granites has been based on textural characteristics. It has been thought that recrystallization of older, perhaps schistose granites may obliterate schistosity and give the rock a younger appearance. It is important to keep in mind, however, that older granites frequently have been remobilized and flowed. This phenomenon can be recorded with certainty only in such cases where the granite has contained more competent rocks — for example metabasites — which are broken up. These phenomena will be discussed further in the section on the basement problem.

3.7. TRICLINICITY OF POTASH FELDSPARS

No systematic investigation of the triclinicity of potash feldspar over the whole map area has been performed. However, the result of some restricted studies may be quoted here. A. J. Budding (1968) made an investigation covering mainly the rocks around Västervik and the south-eastern parts of Gamlebyviken. He found a very large spread in Δ -values — from 0.0 (monoclinic) to 0.99 (triclinic). Low-metamorphic gneisses had low to intermediate values, the granites high (0.75—0.99, generally 0.88—0.95). Some gneisses close to the granites and feldspathic xenoliths of metasediments had also "granite" values.

Two additional investigations by students (not published) confirm, on the whole, Budding's results. These are Per-Arne Melkerud: the Hamnö granite, and Bengt Nilsson: the Hamnö granite, the younger granites to the south-west and the metasedimentary rocks west of the Hamnö granite. In the last-mentioned area, however, we find in some derivatives of the metasediments potash feldspars with high triclinicity (granitic values) — so, too, in the raft migmatites, in some of the flecky gneisses and in the Tullerö gneisses.

Budding explains the differences with respect to triclinicity by assuming that "recrystallization and solid-state reactions have taken place down to lower temperatures in the granites than in the quartzites and gneisses". He thinks that this may reflect a higher water content in the granitoidal materials — an explanation that is in agreement with my own ideas on metamorphism and granitization (cf. pp. 119 and 135).

4. STRATIGRAPHY AND TECTONICS

4.1. METHODS

So far, no signs of organic materials have been found in the metasediments of the Västervik area. A research group from the University of Lund has been

able to identify some microfossils in a Precambrian metasedimentary series about 100 km WSW of Västervik (the Vetlanda group, which has often been correlated with the Västervik rocks). According to personal information, these investigators could not find similar microfossils in the Västervik rocks. Therefore, results reported here are founded on lithostratigraphic observations only.

In the previous surveys of the Västervik area (Gavelin and Lundegårdh 1960; Gavelin and Russell 1967; Russell 1967) it has been shown that a large part of the metasedimentary sequence represents a large delta formation. The rocks are shallow water accumulations, in part even tidal flat sediments. It has also been proved that the sediments frequently display many primary sedimentary structures which make it possible to identify facing directions within the rock sequences.

In a folded sedimentary rock sequence where the strata may be vertical and even overturned, and the folds often are isoclinal, it is generally an intricate task to determine the facing directions of the sediments (i. e. the question of what is up or down stratigraphically). Fortunately, cross-bedding is a very common feature in the arenaceous metasediments of the Västervik area. Even other primary sedimentary structures have been found to be suitable for a determination of facing directions. Such structures are of course most easily interpreted where outcrops are clean and where they display structural features in great detail. For this reason, the shore lines of the islands in the archipelago were first chosen for a close study. In the beginning, field work was concentrated in the south-eastern part of the geological map-sheet Västervik (1: 50 000) and the islands in the area Händelöp—Marsö—Flatholmen—Eknö—Kälmö. Cross-bedding is abundant in the area. However, preliminary mapping showed that the tectonic style is here very complicated. The primary fold pattern has been drastically deformed as a result of a later deformation phase which has led to the formation of steeper fold areas. These patterns will be discussed more thoroughly later.

South of the area in question, i. e. in the north-eastern part of the geological map-sheet Oskarshamn, 1: 100 000 (Henriksnäs, Skälö, Järsö, down to Hunö), the tectonic pattern is simpler and for this reason suitable for stratigraphic considerations. A well-defined, regular syncline could be established, which is strongly compressed at both ends, but which still permits an analysis of the stratigraphy over wide areas. To the west (Blankaholm) and south (N. Uvö—Vinö), tectonic patterns are again more complicated. The least complicated picture of individual lithostratigraphic rock units and of their mutual stratigraphic relations is seen in the area around Gamlebyviken—Gudingen (on the geological map-sheet Västervik). North-west of Gamleby it is again more difficult to establish fixed lithological units, although certain correlations have been attempted. It seems convenient to start the presentation of stratigraphy and tectonics by describing examples where relationships are most unambiguous and from there extend the discussion

into more complicated areas. Consequently, we will begin by giving an account of conditions within certain "key areas". These results provide a basis for the most reliable interpretation of the three-dimensional structure, which in turn can be used for genetical considerations.

A look at the map shows that — on the whole — the metasediments are bordered towards north-east by the Loftahammar granites along a line Idö—Torrö—Malmö—Björkö—Bjursund—Syrån—Storsjön. Towards the west there occur older and younger granites from Överum—Ämtén—Hunsala—Hallingeberg—Ankarsrum—Falsterbo—Lebo—Solstadsström. Younger granites also form the southern boundary of the metasediments. However, even within the major sedimentary areas there are granitic belts which divide the metasediments into sub-areas, with each sub-area showing a somewhat special style. Thus the widespread metasediments around Västervik, which have a wide extension towards the north-west, are limited towards the south by a belt of older granodiorites, granites and younger granites (at Äldersbäck—Nävelsö) which widens towards the west.

The rocks in the archipelago south-east of Västervik (Idö, Spårö, etc.) are separated from the metasediments of the archipelago south and south-east of Händelöp down towards Eknö. The southern area forms a separate section which is difficult to correlate with the northern areas. Part of the problem lies in the fact that both areas have their own special structural patterns. To a certain extent, the southern area is divided into two separate parts by a lobe of younger granite. The southernmost of these metasedimentary areas has been regarded as a "key area". Certain correlations between the two areas have been possible, however, although outcropping islands are sparse in the boundary zone between them. This makes combinations on the map uncertain.

Present interpretations of stratigraphy and tectonics are presented here in a number of profiles (Pl. 1). The choice of profiles is intended to summarize data as far as possible and thus give the reader a three-dimensional picture of the geology. For this reason, the profiles do not appear as straight lines on the map but are frequently curved, usually in such a way that they are roughly perpendicular to the axial planes of the first stage of folding. The profiles also represent sections where observations of strike, dip, fold axes, and facings are particularly numerous and unambiguous. The directions of the profiles and their relative spacings are therefore a consequence of the local tectonic-stratigraphic conditions within the area to be discussed. These circumstances are particularly evident within the southern part of the map area where a strong secondary folding of first-phase fold axes and axial planes has occurred (see Profiles 9 and 10, Pl. 1).

In the profiles, six different lithostratigraphic units have been recognized. They are numbered 1—6 in the northern area and 1a—4a in the southern area. It is impossible to correlate the northern and the southern areas with certainty, but certain conspicuous similarities between individual units and also sequences may

justify the use of the same main unit-figures in the north as in the south. The various units are:

Northern area	maximum thickness	Southern area	maximum thickness
6. Pure orthoquartzite	> 300 m		
5. Protoquartzite with intercalations of mica-schist	650 m		
4. Mostly red-gray metasediments sometimes substituted by gray metasediments In profile 2 also red metasediments	c. 750 m c. 300 m	4a. Mostly red-gray metasediments	c. 500—600 m
3. Mostly orthoquartzite	> 2 000 m	3a. Mostly orthoquartzite	∞ 3 000 m
2. Red-gray and gray metasediments	c. 1 200 m	2a. Red-gray and gray metasediments (here including "tidal flat deposits")	∞ 400—500 m
1. Orthoquartzite and plagioclase quartzite	c. 500 m	1a. Mostly orthoquartzite	∞ 500 m

Since the thickness of the individual unit beds varies greatly laterally (some units wedge out and disappear, for example units 2 and 4) maximum values are presented above. Even these figures cannot be considered as definite.

4.2. GAMLEBYVIKEN—GUDINGEN AREA

On both sides of Gamlebyviken, one finds broad belts of quartzites of the types which are considered typical for the Västervik area and which, for example, are found within the town of Västervik proper. On the map they may attain a width of several kilometres.

Some sections, however, may represent repetitions of strata due to folding. Along the shores of the bay and in part on islands and peninsulas in the bay continuous belts of the gray-red or gray metasediments occur, frequently developed as flecky or sometimes veined gneisses.

The most continuous section of strata (Profile 3, Pl. 1) is at the north-western end of Gamlebyviken (Tjust Motell—Kasimirsborg—Gudingén at Saltmarsudd). The bay, Gamlebyviken, marks the axis of a syncline, both limbs of which consist of the red-gray and red bedded metasediments in which flecky gneiss development is common. These rocks are underlain by units of fairly pure quartzite. Looking out over the bay at Tjust Motell, one gets a fine panorama

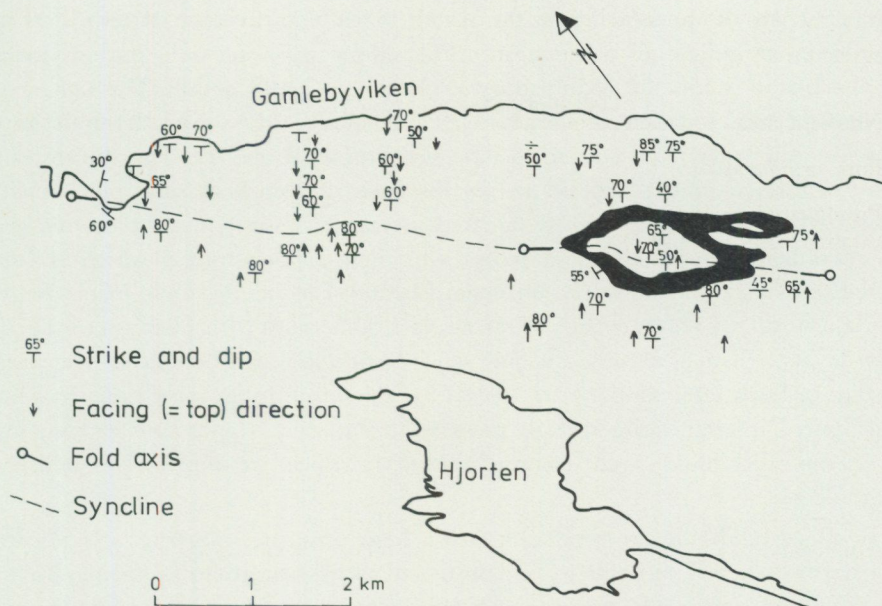


Fig. 65. Survey of the main structural features around the Gamlebyviken syncline. Meta-basites black. Map-sheet Västervik SO (0-4, g-j).

of the geology. The wooded hills between Gamlebyviken and Gudingen represent a quartzite anticline where dips and facing directions turn about half-way between the two bays (see Profile 3). The very similar-looking quartzites attain a thickness of 2 000—2 500 m (base not possible to determine). This great thickness of meta-arenites indicates that sedimentation was accompanied by subsidence within the basin which roughly balanced the accumulation of sediments. On both sides of Gamlebyviken, the dominating central parts of the two quartzite belts are composed of fairly pure quartzites in which bedding is only occasionally well developed. In most cases there are sufficient primary sedimentary structures to enable the identification of facing directions in the rock sequences with fairly great certainty. Towards the boundary between the beds of typical red-gray metasediments and the quartzites, the quartzites grow more micaceous and feldspathic. Cross-bedding is much better developed, which means that structural patterns can be studied in detail. It is thus clearly evident that Gamlebyviken constitutes a continuous syncline, oriented NW—SE, and that here the red-gray metasediments overlie the quartzites. The main fold axes plunge moderately towards the north-west in the south-eastern part but turn and pitch towards south-east in the north-west part. Consequently, there is an axial depression in the centre of the bay, where the uppermost strata of the entire sedimentary column are exposed. Fig. 65 illustrates how the structural pattern can be determined within the central part of the syncline. Here, one must keep in mind that every

sign of strike, dip and facing on the sketch is really an average of tens, perhaps hundreds, of individual observations. The simple main tectonic pattern makes it possible to study the sedimentary evolution in some detail. Through these studies the total sedimentary column was divided into six lithostratigraphic units, nos. 1—6 in order from bottom to top, (see Profiles 3 and 4). The thickest and most continuous unit is represented by the quartzites on both sides of Gamlebyviken, rocks which have been designated as unit 3. Unit 4, the typical red-gray metasediments overlie these quartzites. On these follows unit 5 which is composed of feldspathic and micaceous meta-arenites. Frequently, these meta-arenites contain distinctly separate beds of mica-schist, sometimes with plenty of cordierite. The layers, which generally are only 0.5—2 cm wide, can be traced over large distances. Such intercalations are typical for this lithostratigraphic unit. In general, "pure" quartzites are rare in these sequences. The uppermost section, unit 6, on the other hand, again contains quartzites which are very low in feldspars and micas.

If one extends the cross-sections shown here over the quartzite belt towards the north-east, it is difficult to find sufficient clear indications of facing. In the south-eastern part of the zone to the north-west, however, one finds unambiguous sections. The north-east end of Profile 3 cuts the land between Gamlebyviken and Gudingen north-west of Segersgårde and the south-eastern point of the peninsula Saltmarsudd. Here, there are almost continuous outcrops with facings in the quartzites always to the south-west up to a point about half way between Gamlebyviken and Gudingen. Beyond this point, the bedding turns over and a similarly consistent facing to the north-east begins. The rock's dip is about 55° — 70° NE. In other words, the section represents a large and symmetrical anticline (see Profile 3). This pattern is continuous over the north-westernmost bay of Gudingen and on the peninsula Saltmarsudd. On the little island of Hanholmen in the bay and on the peninsula itself the facing is reversed. This means that the bay marks the position of an isoclinal syncline, slightly overturned to the south-west. This was the first instance in the mapping where a systematic recording of cross-bedding disclosed anticlines and synclines where simple observations of strike and dip would have failed. Further to the north-east in the profile, the structural pattern is more uncertain. The syncline with red-gray gneisses (unit 4) pictured above the present erosion level in Profile 3, right part, is projected tentatively from areas north and north-west of the profile plane. On the map, unit 4 is represented by exposures west of Vinö, a small village situated c. 3 km east of Saltmarsudd. Between Syrsan and Utrikeviken (Gudingen) there are wide areas of the gray and the red-gray metasediments. According to the fold axes, these rocks underlie the quartzites of unit 3. The gray and red-gray metasediments have here been called unit 2. In the profile, this unit forms a sort of anticline which is bordered to the east by the big massif of Loftahammar granite.

South-west of Gamlebyviken, the quartzite belt of unit 3 gives no clear evidence as to fold structures. Cross-bedding is fairly sparse and often not so unambiguous as in the rocks further to the north-east. Contrasting facing directions are sometimes found. On the whole, one gets the impression that only minor repetition of beds has occurred through folding. It is evident, however, that the south-western part of the profile is better documented than the north-eastern part. The main pattern to the north-east is probably correct. In detail, however, the boundaries between contrasting rocks may be somewhat erroneous.

Profile no. 4 is situated about 8 km south-east of no. 3. It runs through the area where an axial depression has been established. There exist both similarities and dissimilarities between the two profiles. The main syncline is still visible but is much more compressed, slightly overturned to the north-east, and the limbs are much more asymmetrical than in Profile 3. One of the new features is the occurrence of a metabasite which in part forms concordant intrusions. On the map, one part of the metabasite appears as an oval-shaped body. Geometrically, it seems to represent a highly compressed lopolith. The quartzites belonging to unit 3 are very thin in the south-western limb but very thick in the north-eastern limb. However, layers to the north-east may have been repeated due to folding. Above the quartzites follows a sequence characterized by micaceous meta-arenites with abundant inlayers of mica-schist. Where the red-gray sequence, called unit 4, occurs, it is found to underlie the micaceous quartzites. For this reason, the latter have been called unit 5. Pure quartzites overlie unit 5. These quartzites represent the central part of the syncline in the axial depression. Consequently, they represent the highest lithostratigraphic level in the column.

In the south-western limb of the syncline, the typical rocks of unit 4 have wedged out and passed over into unit 5. The quartzites of unit 3 are underlain by a new formation of red-gray gneisses which are called unit 2 and which could correspond to unit 2 in the northern part of Profile 3. In Profile 4, unit 2 is underlain by quartzites — called unit 1 — which is bordered by granite to the south-west. Unit 4 is also absent in the north-eastern limb of the syncline where the profile has been drawn. However, at a short distance to the north-west these rocks occur. Their probable and approximate position in the profile has been presented through projection according to probable fold axes.

The thick belt of quartzite (unit 3) in the north-eastern limb of the syncline is very poorly exposed. No structural observations have been available. It is therefore quite possible that this limb contains fold patterns which cannot be visualized in the presentation.

The north-eastern part of Profile 4 is based on observations from the islands of St. and L. Rätö, Vinökalv, Hultö, and others. On the islands mentioned, the development of rocks is quite different from the areas treated previously. Meta-arenitic rock types dominate. For the most part, they are fairly pure white quartzites, although together with them several representatives of the red metasedi-

ments occur which properly should be called meta-arkoses. In part, the boundaries between the two types are distinct and sharp. Sometimes, however, one finds successive transitions. On the whole, the white types appear to dominate, even if sometimes it is possible to follow typical red beds over large distances. The areas in question have been investigated by Dutch geologists (Sijperda 1968, Westra *et al.* 1969, Elbers 1971, Hoeve 1974). These authors have dealt mainly with metamorphic and structural phenomena. On Elbers' map no attempt was made to distinguish between metaquartzites and meta-arkoses. A separation of white quartzites and the red meta-arkoses on the map would require very thorough and detailed mapping on a large scale. I have chosen to present these rocks as a single unit, called 3 α . My interpretation is based on several sections across the big islands. In addition to the meta-arenites mentioned above, there also occur representatives of the gray metasediments — in part mica-schists. Such forms, however, seem to be rare and of no lithostratigraphic importance. It is worth mentioning that this type of rock development, i. e. clearly delimited beds of red and white meta-arenites, has never been met with in other parts of the Västervik area.

The structural pattern is somewhat obscure. Individual observations indicate fairly intense small-scale folding which can hardly be visualized in the profile. A general trend is that fold axes dip between 30° and 60° to the north-west. Close to the Loftahammar granite there seems to be a small syncline of red-gray metasediments (unit 2) bordered by an anticline where feldspathized quartzite (unit 1) occurs.

One additional profile to the south-east (no. 5) gives some additional information on the Gamlebyviken structure. The dominating synclinal pattern is clear. The patterns and boundaries of the granite (Judö granite) in the centre are merely guesses. In this profile the direction of the main fold axis has changed from NW—SE to E—W. In this section the quartzite of unit 3 has disappeared. Based on the fold axes' directions it should be situated somewhere in the centre of the syncline but above the present level of erosion.

The northernmost profiles, nos. 1 and 2, complete the structural analysis of the northern areas. Profile 2 is seen to cut several belts of metasediments which are sometimes separated by older granites. To the south-west, there is an isolated area of metasedimentary rocks called the Oxebo area (named after the farms at Oxebo). The rocks in this area show features of great interest. The area is bordered both to the north-east and south-west by old granites which seem to "underlie" the metasediments. The metasediments dip away from the granites on both sides. In the centre of the area the dips are very flat. One gets the impression that the metasediments are here practically horizontal on the whole. In detail they are somewhat undulating. An interesting feature is that within this area there is a granodiorite which appears to be much less affected by stress than the older border granites are. The granodiorite has also been found to

truncate the schistosity of these granites. In general, the granodiorites are concordant with bedding in the metasediments, although discordant contacts have also been encountered. In several places, contacts between metasediment and granodiorite have been observed. These contacts are always very flat-lying. In every case, the granodiorite is found to overlie the metasediments. Often, the granodiorite is found on the top of the hills, which suggests that the small massifs of granodiorite on the map represent undulating sheets. In the profile I have interpreted their positions to represent two or three semiconcordant intrusions. It ought to be mentioned that, on a small scale, sill-like intrusions of granodiorite have been observed. They are often related to local feldspathization of the metasediments.

Further to the north-east in the profile, we find alternating belts of red-gray gneisses and quartzite. The quartzites can be followed to the ones in Profile 3 where they represent lithostratigraphic unit 3. The most probable interpretation for the stratigraphic position of the red-gray metasediments is that they overlie the quartzites. They would thus represent unit 4 and form two synclines, as pictured in the profile. If one looks towards the old granite to the south-west, this belt would also most probably represent an anticline, which means that the Oxebo metasediments also represent unit 4.

A glance at the map shows that the profile cuts in its central parts two belts of the red metasediments. These belts are the only places within the map area where this rock type forms larger, continuous masses. They border to quartzites, as illustrated in profile no. 3, where they are represented by unit 3. In the south-western part of the red area (NNW of Gamleby) cross-bedding is common, both in the red meta-arenites and in the adjoining white quartzites. These primary sedimentary structures clearly show that the red metasediments overlie the quartzites and would thus correspond to lithostratigraphic unit 4. The belt in question thus represents a syncline. Only a few cross-bedding structures have been found in the broad quartzite belt WSW of the red meta-arenites. Where seen, however, these as well as strike-dip observations clearly indicate that facing directions are sometimes reversed and that consequently there must exist repetitions of the same stratigraphic horizon within the section. Thickness estimates of the quartzite must therefore be exaggerated if based merely on outcrop width on the map, probably even to a higher degree than indicated in the profile.

In the centre of the anticline mentioned, the profile plane intersects a small granite massif, which has been interpreted as belonging to the younger group. Its extension in the profile plane is impossible to deduce. Therefore, the presentation of the granite in the profile is only meant to demonstrate the existence of granite in the surface plane of the profile.

The eastern area of red metasediments (around Lofta) is also bordered by quartzites. Since the red rocks look very much like those in the western area

one might expect them to occupy the same lithostratigraphic position. The profile plane cuts only the westernmost part of the belt, where facing observations are lacking. Within the central part of the area, however, several observations indicate that to the SSW the red metasediments underlie the quartzites. As these quartzites have been traced from Profile 3 as representing unit 3, the red metasediments here probably correspond to unit 2. Between the two areas of red metasediments, the profile is dominated by white quartzites. Sometimes the quartzites contain abundant granitoidal veinlets. The profile also cuts two belts of red-gray gneiss and red metasediments. In the profile, these have been considered as small anticlines, which is the best interpretation with respect to the small number of tectonic observations available. However, they could also represent inlayers in quartzite unit 3. In part, these quartzite sections are characterized by an alternation between dominating white quartzite and subordinate red meta-arenite. To a certain extent, the pattern resembles that which has been characterized as 3 a in Profile 4. In any case, the quartzite between the two areas of red metasediments contains several anticlines and synclines.

The Loftahammar granite appears further to the north-east. It contains two belts of metasediments, frequently in the form of strongly granitized gneisses. Their lithostratigraphic position is of course impossible to determine with certainty. In this presentation I have tentatively assigned them the position of unit 4, which means that they probably represent compressed synclines. The profile ends with amphibolite gneisses which border the mapped area to the north-east. We conclude our studies from the northern area with Profile 1 through Lake Rummen. From the map one can see that the central part of the profile is built up of quartzite, which thickens to the east and wedges out to the west. This quartzite can be traced to Profiles 2 and 3, where it is called unit 3. North and south-west of Lake Rummen, the quartzite is surrounded by gneisses from the red-gray metasediments, both veined and spotted forms. Several examples of cross-bedding have been found both in the quartzites and in better preserved parts of the gneisses, although they are fairly sparse and scattered. Local interpretation often leads to contrasting results. Therefore, it is surprising that adjoining values of strike and dip show that the low-competent bedded rocks have been intensely folded on a small scale. Combinations of different geological observations lead, however, to the interpretation that the red-gray gneisses overlie the quartzites and consequently should be equivalent to unit 4: a, in Profile 2 the same quartzite belt was interpreted as an anticline, b, immediately north-west of Lake Rummen bedding strikes NNE—NE and consistently dips W—NW, c, bedding in the red-gray metasediments just west of the southernmost bay of Lake Rummen dips very flatly (about 15° — 25°) to the south-west. This means that the red-gray metasediments overlie the quartzites.

As a result of these considerations, the picture as given in the profile seems very plausible in its main features. The extension of the young granite in the

profile plane is of course a mere guess — as was the case with the corresponding rock in profile no. 2.

4.3. THE AREA WEST, NORTH-WEST AND SOUTH-WEST OF EKNÖ

The Gamlebyviken—Gudingén area is considered to be the most informative one for studies on lithostratigraphy and tectonics within the mapped area. The next best "key area" is displayed by the south-westernmost part of Eknö and the adjacent islands to the west including the larger islands of Skälö and Hunö as well as the peninsula of Henriksnäs. We begin with Profile 9, Pl. 1, in its southern part, where the profile runs SW—NE. The map shows a lens-shaped area of spotted and veined gneisses representing the red-gray metasediments. Numerous cross-beddings show that these red-gray metasediments form a fairly open syncline, both outer limbs being represented by very large masses of quartzite. Here too, the central parts of the quartzites are fairly pure, whereas towards the red-gray metasedimentary gneisses they are more micaceous and feldspathic. So far, there is perfect agreement between the main synclines in Profiles 3 and 9. As the sediments in the two areas under discussion are not connected, it is not possible to compare them directly as lithostratigraphic units. On the basis of obvious similarities with respect to successions and petrographical development, I have chosen to refer to these new units as 3a and 4a, respectively.

The north-eastern limb in the profile is very well evidenced by cross-bedding. Here we find a continuous sequence of quartzitic deposits which must be 2500—3000 m thick. These values are about the same as found in Profile 3 for the corresponding rock unit. A particular feature in the profile is the occurrence of several concordant sheets of metabasite in the quartzite limbs. These metabasites represent volcanic formations and, consequently, indicate the existence of an early basic magmatism, contemporaneous with sedimentation. South-west of the syncline, we again find a broad belt (up to 2 km) of quartzite occupying practically the entire central part of the large island of Skälö. Along the south-western shore of Skälö there occurs a new type of gneisses, which have been traced to the north-west. These rocks could be interpreted as having been derived from gray metasediments with alternating darker (argillaceous) and lighter (more arenaceous) bands. The bands are broken. The gneiss gives the impression of being formed through a combination of both kinematic and mineralogical metamorphism.

The stratigraphic relations between these gray gneisses and the main quartzites cannot be established from observations close to the profile plane. On the map, the Skälö quartzites look at first hand like an anticline, the metabasites to the north-east and south-west would thus correspond to each other. But the metabasites to the south-west are metadiorites of group 2 (Kresten 1972), while

those to the north-east are metavolcanics of group 1. Therefore the extension of the metabasites cannot contribute to a solution of the stratigraphic problems here. If, however, we look at a profile about 2 km to the north-west (no. 8 of Pl. 1) and combine its main pattern in the vertical plane with the pattern of the map in the horizontal plane, it is possible to arrive at a final conclusion. In profile no. 8 the main syncline is very clearly evidenced. However, its central part in the horizontal plane is now occupied by micaceous quartzites belonging to unit 3a. These quartzites are underlain by a series of red-gray and gray metasediments in gneissic forms, although they are still identifiable as sediments. The red-gray or gray metasediments, which underlie the quartzites of unit 3a, should then properly be named unit 2a.

The peninsula of Henriksnäs is interesting in many respects. Along the eastern coast we find exactly the same rocks as those belonging to unit 2a on Skälö. Even though there is probably a north-southerly fault between Skälö and Henriksnäs, evidence from other parts of the map area shows that displacement between the different blocks cannot be of such an order that rocks on opposite sides of the fault should belong to quite different stratigraphic units. The peninsula of Henriksnäs is dominated by gneisses with relics of rocks which have been characterized as banded gray or banded red-gray rock sequences. Numerous intercalations of fairly pure quartzite are also present. To the south-west, these gneisses grade into forms which have been called the "Tullerö formation". Even here the metasediments contain beds of fairly pure quartzites. Between the south-western part of Skälö, the south-western part of Henriksnäs, and the islands of Tullerö—Storö—Marsholmen we find only water with no islands. The most plausible combination, however, between separate observations indicate that all these gray and red-gray gneisses belong to the same lithostratigraphic unit, i. e. 2a. On the other hand, on the Henriksnäs peninsula there are some features which could imply that the stratigraphic and tectonic patterns cannot be expressed simply in terms of the separate units 2a, 3a, and 4a. We will return to this question in connection with a stratigraphic and tectonic survey of the areas to the north-west. First, we will survey the most eastern and southern parts of the map area.

We have followed Profile 9 to the south-west from the south-western part of Eknö. Looking towards the north from Eknö, the profile has been drawn in a big bend, as shown on the map. West and north-west of the northern part of Eknö there is a number of fairly large islands — Lökholmen—Ormö—Flatholmen—Äppleholmen—Brunnskär—Skjortö—Långskär.

Profile 9 was followed to Western Eknö south of Lökholmen—Ormö. Further to the north-east, granite appears on the northern part of Eknö. On Lökholmen and Ormö we still find quartzites, although these islands are dominated by metabasites. The general strike of the metasediments has changed and runs E—W. This is also the direction of the axial plane. Further to the north,

on Skjortö—Långskär, the main strike and the axial planes run SW—NE. For this reason, the profile changes directions with a big bend as shown on the map. This presentation enables us to combine the lithostratigraphic units in the southern and the northern parts of the profile. The most uncertain part of the profile is that, which crosses Lökholmen, Ormö and western Eknö. Here, there are fairly large distances with island-free water. Further to the north, however, there are plenty of observations which make it possible to present the main fold pattern with a high degree of certainty. The meta-arenites are generally of the micaceous type with numerous cross-beddings. This area contains the best exposures of the red-gray metasediments with abundant mud-cracks — the so-called Äppleholmen series. These metasediments are unambiguously found to underlie the meta-arenites belonging to unit 3a and should therefore properly be called unit 2a. On the island of Skjortö the same lithostratigraphic unit is seen in quite another development. The metasediments could be characterized as the gray metasediments, frequently quartzose mica-schists with abundant andalusite. In places, they are slightly bedded but differ very markedly from the bedded metasediments containing abundant mud-cracks. If the latter are taken to represent tidal flat deposits, the sedimentary facies changes from the Äppleholmen to the Skjortö area might indicate a change from shore to off-shore deposits.

Profile 10, 1200—1500 m north-east of the northernmost part of Profile 9, completes our picture of the area under discussion. It cuts a large number of small islands where the quartzites contain abundant cross-bedding. Dips are almost always vertical, although facing directions change very rapidly. The general impression is that we have an almost isoclinal fold pattern of micaceous meta-arenites with numerous conformable metabasite units. The profile gives a fairly good idea of the main fold pattern. When compared with the style as shown in Profile 9 (northern part), no. 10 is seen to represent a much more intensely compressed rock sequence.

If we return to the southernmost areas, we see that the rocks exhibit more complicated structural patterns. In order to follow the lithostratigraphic units described previously it is convenient to start with unit 3a — the thick quartzite unit. The large islands of Hunö and Vinö are shown to be occupied almost entirely by quartzites. These often represent fairly pure quartz sands. Cross-bedding is observable only in a few cases. Observations give no one-directional facing, which gives the impression that the pure quartzites, too, have been intensely cross-folded. This is evidenced by conditions in the south-eastern part of Hunö, where concordant metadiorites have been isoclinally folded. This has been shown by detailed mapping of Kresten. The consequences of this structural style are very important, because they show that even the quartzitic rocks were apparently deformed in a fairly plastic state (see Profile 11).

The quartzites on Vinö are bordered to the south-west by veined gneisses

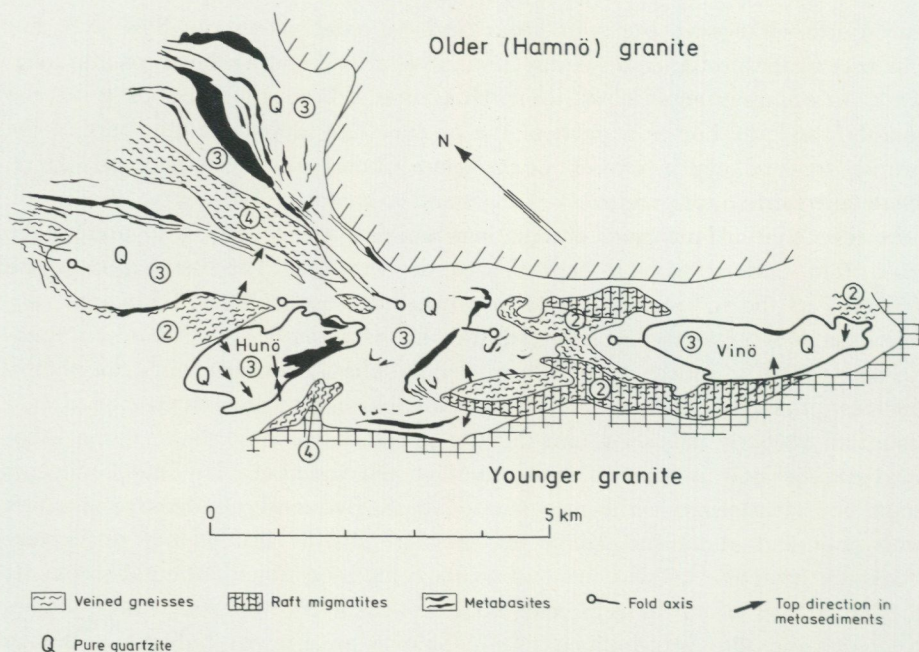


Fig. 66. Survey of the main structural features within the area Vinö-Hunö-(Skälö-Järsö). The encircled figures represent the different lithostratigraphic units. Map-sheets Vimmerby NO (6-7j), Kråkelund NV (5-7a).

which have been formed from the red-gray metasediments. In part, these gneisses grade into true granitoid rocks but with abundant xenoliths of various metasediments and metabasites. They belong to the same lithostratigraphic unit as the veined gneisses. The granitoid rocks, however, form a very characteristic metamorphic unit which has been given a special designation on the map. They are particularly well developed on Tvarö (earlier named "Tvärö"), although exactly the same types are also found on Lammholmen where the transitions from red-gray metasediments into granitoids have been discussed in some detail by Kresten (1971a). Facing observations show that here the red-gray metasediments underlie the Vinö quartzites. Therefore, it should be called unit 2a. Even along the south-eastern shore of Vinö gray metasediments are seen to underlie the quartzites. This means that Vinö represents a syncline with a main axial trend in SE—NW. The quartzites from Hunö can be traced to the south-east on N. Uvö. But here we find clear evidence of an intense cross-folding apparently representing a second stage of folding. The cross-folding leads to several axial depressions and culminations. Boundaries between the main rock units are therefore very irregular. Fig. 66 is a generalized sketch map of the area in which the main structural features are summarized. From this presentation, it is clear that the massive quartzites on Vinö are believed to correspond to those of Skälö and also on Hunö. The clear observations of facing from Hunö are presented on the map. It is seen

that to the north-west the up-directions found are constantly towards the SSW. Along the northern shore, however, we find facings both towards the north and south. It was mentioned above that the pattern of metabasites on the eastern part of the island clearly evidences an intense cross-folding. Therefore it is obvious that isolated cross-bedding observations cannot give a true picture of the detailed structural pattern.

Profile 11 cuts Hunö and the main syncline to the north-east. As is seen from the profile, this syncline is overturned to the north-east. On the northern and north-eastern parts of Hunö there occur red-gray metasediments which most probably underlie the quartzites and should consequently be called 2a. They would thus represent a compressed anticline. The Hunö quartzites would all represent a continuous sequence of 3a, although they have been intensely cross-folded, and individual layers are therefore often repeated in the map section. The gneissic derivatives of the red-gray metasediments on the mainland to the south-west would thus represent 4a. Moving towards the west and north-west, we find only gneisses formed from the gray or red-gray sequences in an area on the map from the mainland over Storö and Henriksnäs. North-west and west of Storö we again find fairly pure quartzites. A structural analysis of the area shows that these quartzites probably underlie the red-gray metasediments called 2a in Profile 8. In accordance with principles applied previously, they should be ascribed to unit 1a. However, there may exist another, and perhaps more plausible, explanation of the lithostratigraphy here.

The areas between Profile 6 and Profile 7 are illustrative. Alternations between rock sequences belonging to the gray and red-gray metasediments are common. Pure quartzites are rare or absent. Over large areas, the structure is dominated by moderate (or even horizontal) dips to the north-west or north (see the map, Pl. 1). This pattern is caused by cross-folding, leading to several repetitions of the same stratigraphic units, structures which in several cases have been verified in the field by cross-bedding. Small isoclinal folds with amplitudes between 1—3 m have sometimes been recorded. Profile 7 is an attempt to illustrate the general tectonic style of the folds which involves imbrications. The folds are seen to be overturned towards the south or south-west.

The westernmost profile, no. 6, is presented in order to exemplify a regular anticline where a massif of old granite appears at the center. Otherwise this profile adds very little to our general knowledge on the lithostratigraphy of the metasediments.

4.4. SUMMARY OF STRATIGRAPHY AND TECTONICS

The previous presentations were intended to be a survey of all facts on which a deduction of the evolution of sedimentation and folding must be founded.

In the discussion to follow, it is convenient to treat the stratigraphic and the tectonic problems separately.

4.4.1. STRATIGRAPHY; FACIES CHANGES AND THEIR IMPLICATIONS

The individual profiles presented above give a fairly good and correct picture of the stratigraphy and sedimentary evolution. Combined, they also provide information on changes in the depositional environments with time. If one were sure that the profiles and the maps were correct in every detail, it would be easy to make an analysis of the geological evolution during sedimentation. Our knowledge of course is restricted, however. Maps and profiles may be erroneous to some extent making it impossible to be absolutely sure of our premisses. However, if one assumes that the general picture is correct, one can make the following statements. There must have existed an alternation between fairly pure quartz sandstones and more micaceous and feldspathic sediments. Even these latter sediments were generally arenaceous. True argillaceous sediments were subordinate. If quartzites are taken to represent true delta stream deposits, the more argillaceous and "unsorted" meta-arenites could frequently represent deposits in "back water" basins which also explains why they are restricted laterally.

The pure quartzites are sometimes very thick. In connection with the discussion of Profile 11 (Pl. 1) it was mentioned that the quartzites, too, sometimes are intensely cross-folded, which means that the profiles do not necessarily reproduce the true thickness of the quartzite layers. However, there is one section where facing observations and other structural criteria are so numerous that no mistakes are possible, namely the Gamlebyviken area. In Profile 3 it was thus possible to estimate the quartzites of unit 3 to have a minimum thickness of 2000, perhaps 2500 m. In combination with Profile 4, this gives the entire sedimentary column a minimum thickness of about 5000 m.

At first, I attempted to "unfold" the sediments on both sides of the main syncline and to estimate facies variations from the thicknesses of various strata. Experience has shown, however, that in many cases the thickness read from the profiles cannot be taken to represent the thickness of a single lithostratigraphic unit. If we restrict our discussion to the Gamlebyviken area, the following general statements can be made.

The thick quartzites of unit 3 can be traced to the north and north-west, although very little is known about their original thickness there. To the south-west, from Profile 3, they seem to wedge out. (See Profile 4.) If we look at units 2 and 4, we find that unit 2 wedges out to the north-west, unit 4 to the south-east. One could say that the general trend is that of rapidly changing depositional environments, something that is in perfect agreement with our first assumption, namely that the sediments are mainly delta deposits. If the

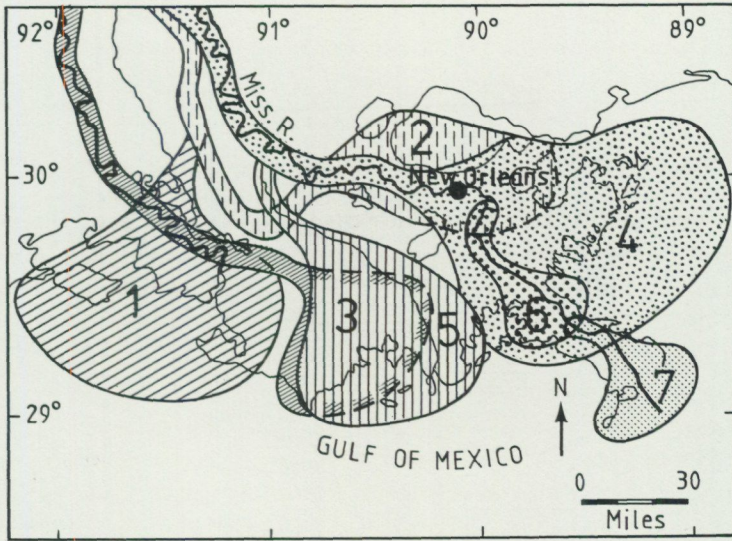


Fig. 67. Chronology of the Mississippi River lobate deltas. After J. P. Morgan 1967, p. 116, fig. 1. Figures 1—7 denote successively younger deposits.

quartzites are taken to represent a single continuous unit (unit 3), this unit must display very important lateral changes in thickness. This is also true for the other rock sequences.

Starting from the Gamlebyviken syncline, Russell (1967) attempted to analyse stream directions during the delta formation. In the north-western part of the investigated area he found a paleocurrent direction from north-west to south-east. In the southern part he found contrasting directions, a result which was interpreted as due to contrasting tidal streams in that area. The changes in lithostratigraphic units 2 and 4 could also be taken to indicate that an eroded land mass was situated to the north-west and that the shore line moved to the south-east with time. Such interpretations are of course very speculative. With the observation material available it is not possible to perform a reliable paleogeographic analysis.

In order to understand the stratigraphic and facial conditions presented in the profiles, it is instructive to make some comparisons with recent delta formations. The Mississippi delta is probably the most thoroughly investigated still growing delta. Very extensive geological research, using areal photographs, drilling, etc. has rendered a very good basis for an interpretation of its present state and of its historical evolution. The meandering course of the river during the preceding stages of evolution have been worked out in great detail. The mutual distribution between the deposition of the stream loads at the mouth

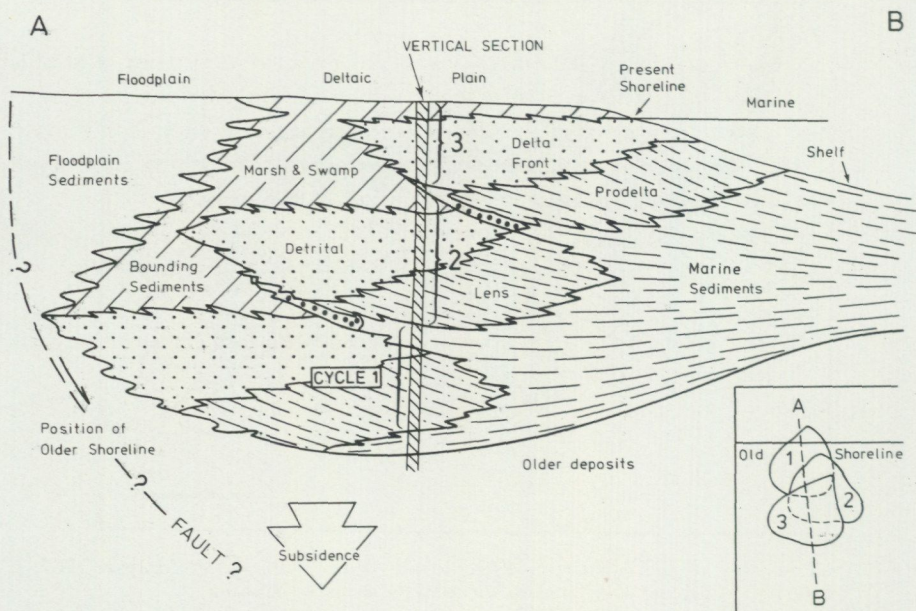


Fig. 68. Overlapping cycles in a hypothetical delta complex. After R. J. Weimer 1975, p. 84, figs. 11, 18.

of the river and the surrounding estuarine sediments during various steps of the evolution have also been established.

Fig. 67 is from Morgan (1967, p. 116, fig. 1). It shows the positions of the lobates of the river over a period of about 1000 years. Seven different lobates are shown, the centers of which cover a distance of 210 km at right angles to the main flow direction of the stream and 160 km parallel to the same direction.

Several cross-sections through delta deposits based on the results of drilling have been presented in recent papers. A simplified compilation of these studies has been given by Weimer (1975, p. 84, fig. 11.18; Fig. 68 in this paper). The pinching out of contrasting sedimentary facies, as demonstrated in the figure, is in good accordance with conditions found in the profiles from the Västervik area. As was stated above, the pure quartzite beds, as well as the more micaceous beds, are found to vary considerably in thickness when followed laterally. In addition, it is impossible to correlate petrologically similar beds in time over wide areas. The reason for giving petrographically similar lithostratigraphic units the same figures in the profiles is that they probably were formed under similar conditions — for example, unit 3 in the north and 3a in the south. They need not have been strictly contemporaneous, however. Taking the examples from the Mississippi delta into consideration one can easily imagine how the Västervik delta may have been formed.

4.4.2. FOLDING AND KINETOMETAMORPHISM

The general types of folding have been visualized by a large number of profiles from "key areas". These have been commented on in the previous paragraphs. In order to understand the final results of deformation it is necessary to more thoroughly review the various kinds of kinetometamorphism which have apparently been active during the geological evolution of the area.

All students of tectonics are aware that the patterns which can be studied in exposures or in maps and profiles are greatly dependent on the physical properties of the individual rocks being folded or otherwise kinematically deformed. One speaks of differences in folding competence — high-competent materials being harder and more resistant to flow movements. Low-competent rocks are more susceptible to plastic deformation and may even "flow". High-competent rocks react by fracturing. When dealing with simple and open folding, the thickness of the individual beds is also a decisive factor. This has been shown in many cases, both in the field and in laboratory experiments.

Within the areas under discussion here, we find a large number of rocks with contrasting physical properties. Among the metasediments it is common that high-competent arenaceous beds alternate with low-competent argillaceous beds. The pure quartzites are of course among the most competent metasedimentary rocks. Metabasites, which frequently form semiconcordant layers in the metasedimentary rocks, also behave as very competent constituents. Therefore, in a complex rock suite composed of meta-argillites, micaceous meta-arenites, pure quartzites and metabasites this order represents a sequence of increasing folding competence. This means that, if intensely folded and sheared, the last members of the series may fracture and break up into pieces, whereas the low-competent members may react by flow or flow-folding. Such conditions of course create very complicated patterns in the outcrops to be studied. Although much experimental work has been performed on the physical properties of rocks, it is often very difficult to apply the experimental results to geological problems in the field. There are many variables which cannot be determined — for example confining pressure or depth of deformation. Rocks or minerals which are brittle at low pressures may flow at high pressures. Examples of this are seen in limestone and, still more surprising, in quartz. For these reasons only relative properties are examined here, properties which can be determined from field observations.

Turning first to areas which have not been affected by gneissification or granitization, we find that pure quartzites break up in micaceous meta-arenites and that both rocks break up in meta-argillites. Metabasites behave in this respect as quartzites. But in my study on kinetometamorphism in the Västervik area (Gavelin 1960) I was able to show that during certain types of deformation quartzites were plastically deformed while at the same time metabasites reacted by fracturing. This process must have taken place in the presence of

volatiles and at considerable depth. Therefore, it is possible that this condition does not reflect altogether conditions existing during the earliest stages of deformation.

If high-competent rocks occur as large masses they may act as resistant blocks against folding. The large massifs of older granite are the most conspicuous example of this. But even thick beds of pure quartzites can, when folded to anticlinal domes or synclinal masses, act as resistant blocks in a later stage of folding against the more micaceous metasedimentary units. Even in the primary folding we must expect that different units will be more and less mobile within the deformed rock masses.

Contrasting physical properties of deformed materials become even more pronounced during stages of deformation connected to the formation of veined gneisses and granitization. In such cases, the veined material — micaceous and feldspathic rocks — is always found to be highly flowable. Pure quartzites and metabasites are brittle and react by fracturing. Therefore, they appear as "xenoliths" in the flowable mass. The pattern resulting from this type of deformation comes very close to what is generally presented as proof of magmatic intrusion. But when we find in the Västervik gneisses "xenoliths" of quartzite or metabasite, this *may* be due to a two-fold deformation, viz. a first stage of folding with no pegmatitization or granitization, a second with pegmatitization and highly flowable components. The pure quartzites and metabasites definitely behave as brittle materials even in the second stage of deformation. Therefore, xenoliths of these rocks in the flowable veined gneiss or granitoid material may be the result of both pre-gneiss and syn-gneiss deformation.

Folding and kinematic metamorphism did not only change the primary position of the sedimentary beds. These processes also affected the shape and thickness of the individual beds. In the southern area, for example, the main syncline has been intensely compressed at both ends (to the north-west or west on one hand, and to the south on the other). It seems very plausible that individual beds were either compressed or thickened by deformation. It is not possible to make an overall estimate of the effects of such deformations for the entire map area, which could be expressed by orientations and shapes of strain ellipsoids. However, in the gneiss area west of Västervik there are some localities which enable us to present a fairly sure picture of a strain ellipsoid. Fig. 53 (p. 60) illustrates a gneiss structure, where originally continuous competent metabasite sheets have been broken up and drifted apart in the flowable acid gneiss mass. From this separation of metabasite fragments one can establish that the axial ratio of the strain ellipsoid must be on the order of 2:1. This means that the shapes of the individual metasediments as seen on the map are sometimes different from the original beds. It also means that considerable mechanical transport of flowable material took place during the deformative processes.

If we look at the profiles we find that the major folds often represent open,

fairly symmetric folds with vertical axial planes (Pl. 1, Profile 3, south-western part, and Profiles 1, 2, 5, 9). Profile 10 shows more compressed isoclinal symmetrical folds, still with vertical axial planes. In several cases the profiles show folds with inclined axial planes, which means that they are overturned in a certain direction. In Profile 3 the main north-eastern syncline is overturned to the south-west. However, only 10 km to the south-east in Profile 4, the main syncline is definitely overturned in the opposite direction — to the north-east. In the southern area, the main syncline in Profiles 8 and 11 is overturned in the same direction with respect to the main orientation of the fold — to the east and to the north, respectively. South of Hunö, close to Profile 11, there is a tendency for overturning in the opposite direction, i. e. to the south-west. The fact that there is no consistent trend of overturning over the whole area may indicate that local resistant blocks to a certain extent influenced the distribution of stresses leading to folding. The same conclusion is drawn from a study of the main directions of the folds or axial planes.

Fig. 69 is intended to demonstrate the clearest and most important fold trends in the area, their spatial relation to granites and in addition the distribution of the larger masses of high-competent quartzites. In this figure we will consider three areas separately: the northernmost or Gamlebyviken—Rummen area; the southernmost or Vinö—Skälö—Blankaholm area; and the central or Nävelsö—Eknö area.

The northern area exhibits the most continuous and also most obvious fold trend within the entire map area. This is a syncline, partly in the central part of Gamlebyviken, which can be followed for 30, perhaps 35 km. The general axial trend is NW—SE; but in the easternmost part of the bay it turns to an E—W direction. This seems to be in accordance with the behaviour of the older granites. The massifs to the north and those to the south approach each other and are separated by a narrow strip of metasediments oriented E—W. The same thing seems to have taken place in the west where the identifiable anticline gives the impression of having been influenced by the bordering granites. We can therefore conclude that the massifs of old granites acted as resistant blocks during deformation and folding of the more mobile metasediments.

In the southernmost area, the most dominating feature is a clearly defined syncline. It can be followed for only about seven kilometres. Three main directions are apparent: approximately N—S in the central part, E—W in the north and E—W in the south. Here too, one gets the impression that the bordering granites influenced the main fold pattern.

To the south-east (on Vinö) the syncline attains a NW—SE direction which is parallel to the bordering granites. However, between Vinö and Skälö the rocks exhibit intense cross-folding which greatly affects the axial planes and also leads to sudden culminations and depressions of the fold axes, see Fig. 66 (p. 88).

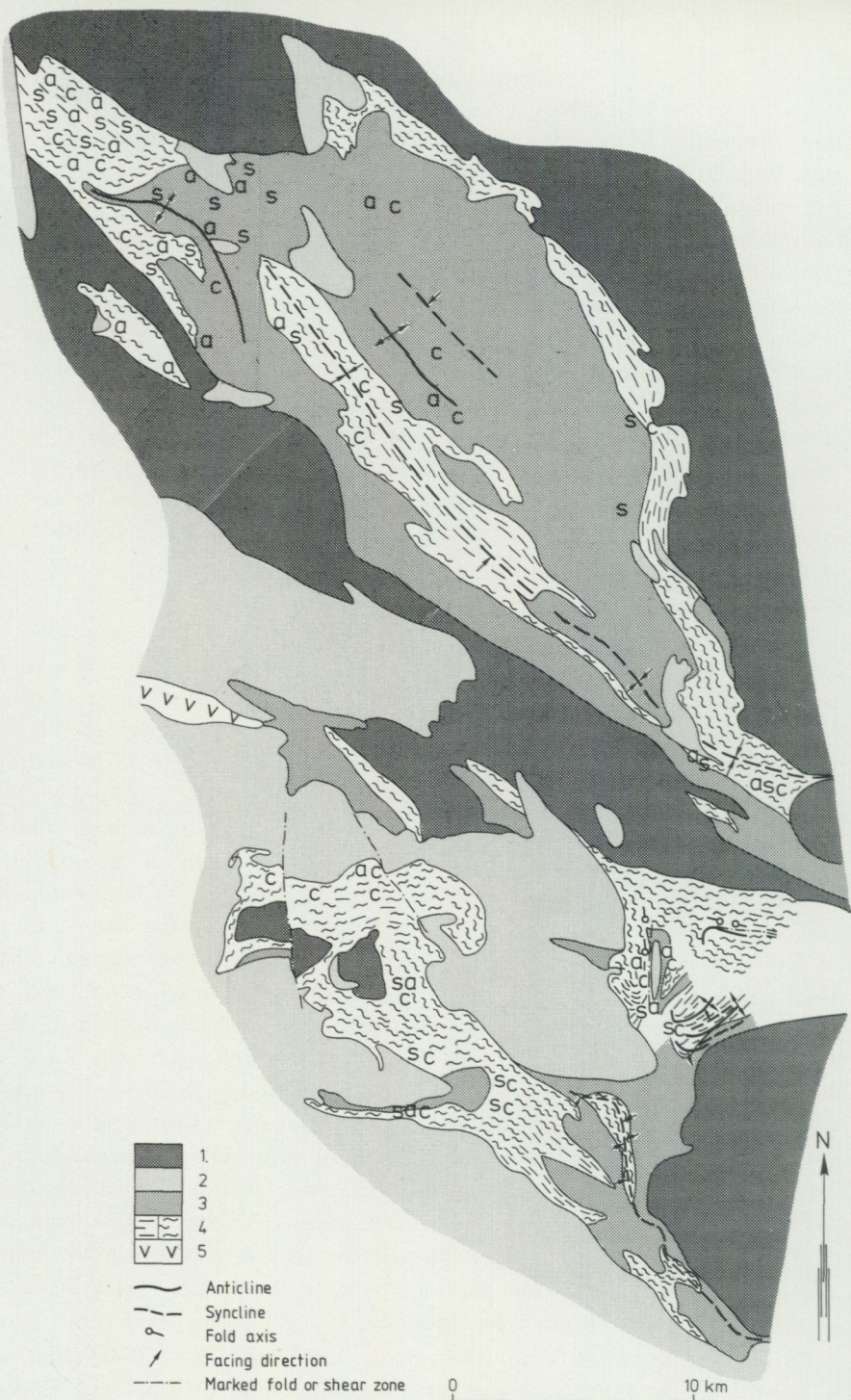


Fig. 69. Survey of the main regional structures of the mapped area and their relations to the larger massifs of granites and larger masses of quartzite. 1 = older group of granite and granodiorite; 2 = younger group of granite and granodiorite; 3 = high-competent metasediments (mostly massive quartzite); 4 = low-competent metasediments (bedded metasediments, left, and veined gneisses, right); 5 = volcanic area. Letters indicate the distribution of the main index minerals: andalusite = a; sillimanite = s; cordierite = c.

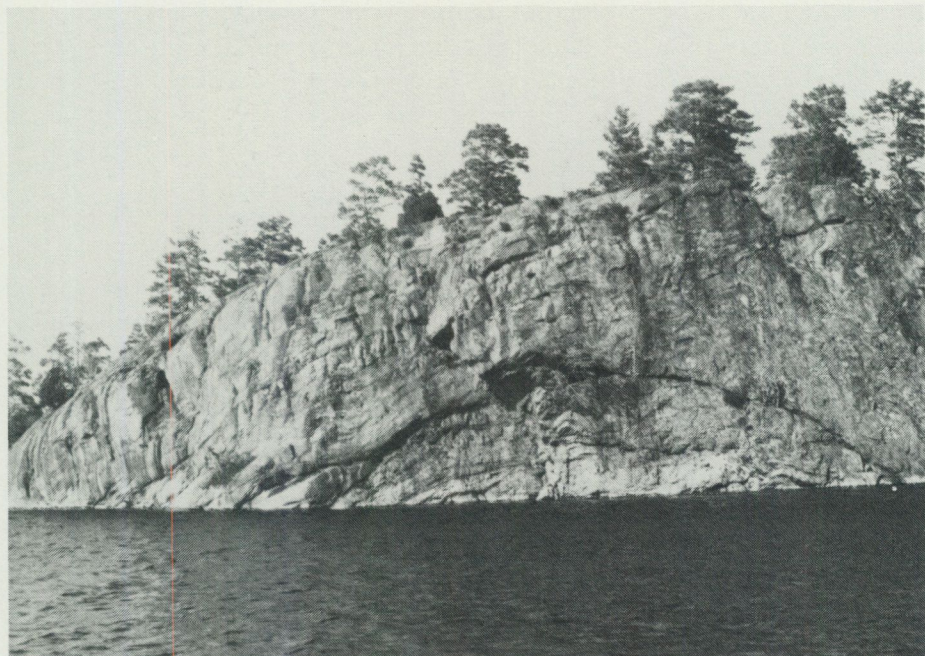


Fig. 70. Open anticlinal fold. Pipareholmen (9 km S of Västervik), seen from the south. Map-sheet Kråkelund NV (8a). Photo S. Gavelin.

The central area shows quite complicated fold styles. In the south there is a set of synclines and anticlines trending NE—SW or ENE—WSW. As they approach the bordering granite massif to the west they turn sharply to the NNW or even north. Further to the north, close to the large islands of Lökholmen and Marsö, we also find an interference between N—S and E—W directions of the axial planes. The fold axes are also quite irregular with contrasting directions, culminations and depressions. Some of the better defined directions have been marked in Fig. 69.

Close to the western granite there is a general trend of strike to the north, i. e. parallel to the main direction of the granite contact. Within this area there is a regular plunge of foldaxes 30° — 45° to the north or NNW. It is worth mentioning, however, that the folds within this area are open and gentle. A small island north of Långö, Pipareholmen (earlier named "Pipersholmen"), has a vertical wall towards the south, some 15 m high, where the foldpattern is clearly seen in the form of an open anticline, Fig. 70.

From the relationships described above it is clear that the tectonic evolution of the area is complicated. The final results cannot be explained by a single folding process. If one first tries to determine how the initial stages of folding occurred or how the pressures of the original folding were directed, it seems

most convenient to start with the Gamlebyviken syncline. This is the most continuous structure in the whole area and when compared with other areas, it is found to occur in the broadest belt of the folded metasediments, which are always bordered by granites. Let us therefore assume that the first phases of folding gave rise to folds NW—SE. That means there was a compression in SW—NE.

As a working hypothesis, let us start by assuming that the primary folds were oriented NW—SE. Deviations in the Gamlebyviken—Rummen area could then be explained by the proximity to bordering granites. The easternmost part of this syncline also gives the same impression. Where the oldest granites occur the folds tend to follow their margins. It has been assumed that folding started before the emplacements of the older granites, but that the granites, too, were affected subsequently by the deformation and probably also folded in the later stages of deformation. Consequently, after their emplacement the older granites behaved as resistant massifs. But even the thick masses of pure quartzites behaved in the same manner during the later stages of folding. In Fig. 69 the most apparent synclines and anticlines are summarized in addition to those rock masses which probably acted as resistant blocks during folding. The area is consequently divided into mobile belts (argillaceous rocks and distinctly banded rocks) and resistant blocks (older granites and large masses of pure quartzites).

In the northern area, a NW—SE trend for the main foldaxes is apparent. This trend is influenced by adjoining older granites only in the extreme north-west and south-east. During the early stages of deformation the southern area could also have been characterized by a NW—SE trend of the folds. If this was the case, the original fold patterns must have been disturbed by a westward advancing mass of older granite, the Hamnö granite, according to Kresten (1972). The close conformity between the metasediments and the granite contact is demonstrated by the marked "bay" of sediments against the granite at the western boundary of the massif. The beddings of the metasediments closely follow the contacts, fold axes and the facing directions pointing from the granite towards the metasediments.

In the central area, which is separated from the northern area by a belt of older granites, the main fold structures are extremely contrasting. We find fold axial planes trending E—W, N—S and every direction in between. One gets the impression that the primary folding was overtaken by a series of movements which had very little to do with the primary pressure gradients. The most plausible interpretation is that a primary fold pattern in NW—SE was completely changed by later movements. From Fig. 69 it appears as if the mobile metasediments were completely overtaken by movements between the resistant blocks. This means that we are dealing with a process of the same kind as continental drift but on a small scale. In this interpretation, the granite which borders the area to the west should also act as a resistant block. In other words, it should

represent a primarily older granite, which has later attained the appearance of a younger granite. Some field observations could be taken to favour such an interpretation. The structural patterns both in the southern and in the central area clearly speak in favour of the assumption that this granite massif represents an early resistant block.

The N—S trend of the metasediments along the eastern border of the granite could thus be explained by the pre-existence of the granite (or perhaps an early granite emplacement) in relation to the folding of the mobile metasediments. An amazing feature, however, is the regular and constant plunge towards the north of fairly open and gentle folds, such as those which are pictured in Fig. 69 (Pipareholmen).

It has been mentioned previously that the second stage of metamorphism which may have led to granitization and veined gneisses was accompanied by strong movements. During this stage of metamorphism different parts of the rock mass attained still more contrasting physical properties than previously. Flow and flow folding were characteristic of the mobile portion, as well as fracturing and breaking up of the resistant or high-competent portions. Drag folding, which frequently belongs to the second stage of folding, may sometimes be governed by marked shear zones. In the field, such a shear or slip zone is seen along the northern shore of Lökholmen (cf. Fig. 69), oriented E—W. Southwest of this area, around Hultö—Ängholmen, we find similar structures oriented N—S. This latter direction is also the direction of the small massifs of younger granites and surrounding gneisses.

From what has been said above it is convenient to regard the tectonic evolution of the area as a result of two main phases. The first of these would be the pre- and syn-Loftahammar granite folding with fairly open folds, oriented NW—SE. This folding was followed by a plastic deformation of the mobile belts, which was controlled by resistant blocks of granite or large masses of pure quartzite. This later phase continued with the formation of veined gneisses and finally the younger granites.

It must be admitted that in many respects the above presentation of a possible interpretation of the main tectonic evolution is very weakly founded. A detailed study of local and regional structural data would most certainly make it possible to discern more than two tectonic phases. But from my present data I do not want to extend the interpretation further.

In recent literature on structural geology it is common to express the various stages of folding in figures as f_1 , f_2 , f_3 , etc., and schistosity formed during various deformations as s_1 , s_2 , s_3 , etc. Elbers (1971) could discern two main phases of deformation in the area examined by him. According to Elbers, the first phase gave rise to a certain kind of folds and also to schistosity. These structures were then folded in a later stage. This is a very interesting observation which shows that a thorough examination of the rocks may give very important

tectonic results. It is very difficult to correlate Elbers' results with those discussed above. His studies were restricted to a small area which means that regional tectonic features could not always be considered. One of his conclusions seems to be impossible, viz. that the first folds (and schistositities) were formed while the sediments were still in their original horizontal position. This is not compatible with the idea stated earlier that the schistosity of the older granites was formed during the first stage of folding. In addition, I myself believe that Elbers has placed too much emphasis on the shapes of the folds in his reasoning. From the pictures shown by him it appears that exactly the same patterns may be seen in metasediments within the Västervik area which without doubt have been deformed prior to their consolidation. Elbers' approach, however, is still valuable. This type of study could be very useful in future work on the tectonic history of the Västervik area.

In this connection it is worthwhile quoting two recent publications which concern the structural evolution of high-metamorphic areas within the Svecofennian space, the Skåldö area in south-western Finland (Hopgood, Bowes and Addison 1976, Hopgood and Bowes 1978). These papers are of particular interest because they refer to the same orogenic zone as the Västervik rocks and since they refer to a classical area of the Svecofennian — an area used by J. J. Sederholm in his presentation of new ideas on high-grade metamorphism and palingenesis. The concluding remarks in both papers are very much the same.

However, the figures, which are important for the discussions, complement each other. There are certainly some reasons why it is difficult to make a more detailed comparison between the Västervik and the Skåldö areas, for example the compositions of primary rocks. However, it is evident that the processes which started by sedimentation (and volcanism) cover a large number of steps including folding, various kinds of more or less local kinematic events, thermal and pressure metamorphism, intrusions, and magmatism. It seems somewhat questionable to me if it is possible to characterize the various steps of deformation on the basis of the shapes of individual folds. Slips and other movements must be governed by the physical properties of the deformed masses and their positions in relation to resistant blocks; but the complexity and interaction of various kinds of metamorphic events during deep-orogenic evolution must lead to the creation of extremely complicated patterns.

4.4.3. FAULTING

Faults that are clearly postkinematic with respect to the Västervik orogenesis have only been studied rather superficially. Some of them can be recognized by a cursory look at a topographic map of the area. A thorough study of new aerial photos from the area will probably give further information. Kresten (not

published) has given a survey of the most important fault zones on his map on granites. At least some of them are represented on the present map. Not all movements between blocks come out as displacements on the map. If, for example, movements were mainly vertical and rock structures and boundaries were steep then displacements are small. In some cases, however, there have existed dislocations in the horizontal plane (for instance the N—S fault 2.5 km west of E 66, just east of Lake Flugén). On the map one can see that the western block has been displaced with regard to the eastern block for about 1 km. A thorough analysis of the fault structures is beyond the scope of this investigation, however.

4.4.4. THE BASEMENT PROBLEM

In any stratigraphic analysis of a sedimentary sequence, one of the salient questions which arises is the nature and position of a substratum or basement. As concerns the Västervik metasediments — as in so many other cases within the Fennoscandian Precambrian — no pre-sedimentary substratum has been established. If one examines the profiles in Pl. 1, it is apparent that the lowest lithostratigraphic unit (no. 1) always borders to, or is very close to, the oldest granite — the Loftahammar granite. It would therefore be close at hand to interpret the Loftahammar granite as a substratum for the metasediments. This was also the position taken by A. Gavelin (1904), in his first comments on the Loftahammar area. Later, Gavelin (1910) changed his position and admitted that the Loftahammar granites behaved intrusively towards the metasediments. However, he added some very noteworthy reflections on the problem, namely that the Loftahammar granite, in its *present state*, behaved intrusively but that, "our knowledge of metamorphic and mobilizing processes is poor and some contact phenomena could possibly be explained by metamorphism". These ideas are very similar to those presented by Eskola (1948) under the heading of "mantled domes", in which he demonstrated a number of examples from Finland where granites, which stratigraphically represented basement rocks, appear to behave intrusively against the sediments.

During our mapping we have found many examples of xenoliths of quartzite and other metasediments in the Loftahammar granite. Thus, there is no question about the intrusive character of these granites. But at the same time it is clear that the Loftahammar granites underlie the metasediments and that the stratigraphically lowest units of the metasediments are those which border on the granites. This means that in the field we find many analogies with the examples presented by Eskola.

Elbers (1971) also discussed the problem of a basement but rejected the possibility that the Loftahammar granite represents a basement for structural

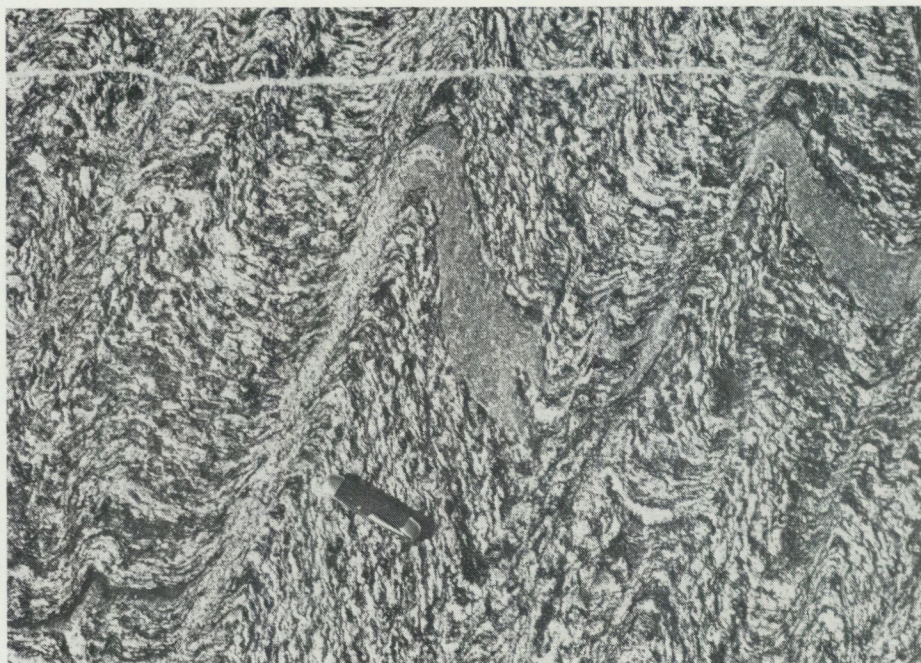


Fig. 71. Schistose Loftahammar granite, intensely plastically folded. L. Göstasholm island, 1.5 km SW of Hasselö village. Map-sheet Loftahammar SV (2a). Photo Th. Lundqvist.

reasons. As mentioned above, in its present position, the granite shows intrusive contacts with respect to the metasediments. However, the question can be asked whether or not the present structures can be used to interpret eventual predeformation conditions. Elbers' conclusions are based on mapping of a fairly small area.

In the north-eastern part of the map area, around and south-west of Hasselö (4—5 km south-west of Elbers' area), Loberg studied Loftahammar granite-metasediment contact relations. On some islands, for example L. Göstasholm and Husö—Rotsö, the early *s*-planes of the Loftahammar granite have been plastically deformed to such an extent that the rocks clearly correspond in their physical behaviour to regenerated "magma" of a conventional type, see Fig. 71. Moreover, from a large number of other localities it is evident that the old granite grades into a plastically deformed state — which is evidenced by the occurrence of metabasite xenoliths, rocks originally occurring as dikes, in the granite. The evolution of such phenomena may be exemplified by a couple of field examples.

Where the Loftahammar granite shows no or very weak plastic deformation of the schistosity (*s*-planes), metabasite dikes appear as straight fissure fillings,



Fig. 72. Undeformed dikes of metabasite in Loftahammar granite. Highway E 66, 300 m SSE of the southernmost bay of Lake Ommen. Map-sheet Västervik NO (5i). Photo S. Gavelin.

Fig. 72. Where the *s*-planes of the granite show slight plastic deformation, the metabasite dikes may still appear as continuous sheets although the contacts tend to be somewhat deformed with bays and points. *s*-planes then plastically follow the contacts, Fig. 73. With increasing deformation, the dikes are broken up, Figs. 74 and 75. In the last case the dikes are both broken up and plastically folded. The same outcrop can show both intensely folded and broken up dikes as well as continuous dikes, the two types lying only a few metres apart. This observation clearly shows that plastic movements were intensified along certain shear zones within the granitoid mass.

A find of Kresten (1972, Ab. 12) demonstrates this behavior very clearly. On the northern shore of Händelöp there occurs an exposure where the dominating old granodiorite is brecciated by a coarse metabasite. This breccia is sharply cut by an intensely sheared granite which contains the same metabasite as large, lenticular xenoliths. The mobilized granitoid rock is apparently located in a shear zone; but it represents not only a crush breccia but also a flow in a mobilized portion of the more acid rock. The result is noteworthy, since the old granodiorite appears fairly massive whereas the mobilized granite is characterized by a very pronounced preferred orientation — a fact that proves that care must be taken in using structural features as indicators of granite age.



Fig. 73. Metabasite dike in gneissic Loftahammar granite; contacts displaying slight plastic deformation. Ringskär, south-eastern shore (SE of Händelöp island). Map-sheet Kråkelund NV (8b). Photo S. Gavelin.

The above considerations have concerned the Loftahammar granite as an eventual pre-metamorphic basement for sedimentation. It is seen that the granite in its present state cannot have been the basement. If an older and subsequently remobilized granite had existed, it is not certain that its chemical and mineralogical composition was identical to that of the present Loftahammar granite.



Fig. 74. Metabasite dikes broken-up and intruded by mobilized Loftahammar granite. NW point of Ängholmen (E of Nävelsö). Map-sheet Kråkelund NV (9a). Photo Th. Lundqvist.



Fig. 75. Metabasite dikes plastically folded and broken up in schistose Loftahammar granite. Locality as Fig. 74. Photo Th. Lundqvist.

Moreover, a basement must also have contained other rocks of which we know nothing at present. The only thing that can be said for certain is that it must have contained many rocks that were rich in quartz. Probably, rocks rich in potash feldspar were also abundant.

If one assumes that the basement had a chemical composition corresponding to that calculated for the upper sialic crust, the Västervik sedimentary sequence represents an enrichment of potassium and a still more pronounced depletion of calcium. These elements must then have been depleted, resp. enriched, in neighbouring sedimentary environments where different sedimentary conditions were prevalent.

4.4.5. RADIOMETRIC AGE DETERMINATIONS

The problems concerning stratigraphy and the basement can also be considered in the light of radiometric age determinations within the area. A recent publication of Åberg (1978) is quoted here. Data have also been presented in several previous publications; but since these are all included in Åberg's paper I will refer to this work only and to its list of references¹.

Åberg analyzed his samples using the Rb-Sr (whole rock), K-Ar and U-Pb (zircon) methods. The main problem on which his work was focused can be expressed by the question: "What kind of age is actually determined?" Metamorphism has to be considered, especially with regard to the K-Ar method; but also for other methods this must also be taken into consideration.

With regard to the Västervik metasediments, nothing could be definitely said about their primary age. Åberg (1978, p. 135) mentions, however, that the determinations were carried out in order to determine the age of the last metamorphic event. His results seem to confirm that there exist an older and a younger generation of granites. The younger group, the Småland granite, assigned an age of 1 730 (1 690) Ma, which is in good agreement with Welin's previous value, 1 740 (1 705) Ma. The older granites are represented by the Loftahammar and the Örö—Hamnö massifs. Different methods give different values. Zircon ages from these granites are estimated to be 1 845 Ma. Concerning the Örö—Hamnö massifs, Åberg states that U-Pb ages "are highly discordant and increase in apparent age towards the centre of the massif". This seems to

¹ The decay constants which have been recommended by the IUGS Subcommittee on Geochronology have been somewhat changed since Åberg's investigation. Welin (1980) has published a new list of radioactive ages recalculated on the new decay constants. Where Åberg's values are quoted below, both his original values and the new ones according to Welin (in brackets) are given. The older data cited by Åberg have also been recalculated by Welin.

be in agreement with the observations of Kresten (1974), viz. that the salic outer zone of the massif represents a last, mobilized stage of the intrusive mass. Kresten also identified three generations of zircons, the oldest being assumed to represent pre-intrusive detrital individuals.

Åberg also discusses the question of whether or not the Loftahammar granite represents a basement for the metasediments (p. 149). He concludes that it does not, mainly on account of the ages of the zircons which are interpreted as magmatic. If, however, the old granites contain both "detrital" and "magmatic" zircons the zircon ages are perhaps not decisive. Åberg's statement that the Loftahammar granite is intrusive in its present state is also verified by field data, as has been mentioned before. The previous demonstration of the geological development as interpreted from field observations seems to be in good agreement with Åberg's data. The old granites are estimated to 1 845 Ma, the younger to 1 730 (1 690) Ma. A still younger, clearly postkinematic granite, the Götemar granite (Kresten and Chyssler 1976) situated 30 km south of Västervik (about 4 km south of the map area), has been dated to 1 380 (1 350) Ma. For the argillitic forms of the metasediments, Rb-Sr whole rock determinations give 1 620 (1 585) Ma, whereas K-Ar whole rock ages are found to be 1 495 (1 500) Ma. Since the metasediments originally predate the granites, the above values could be taken to indicate declining metamorphic events. Dating the very sedimentation itself is of course a difficult task. U-Pb ages from probably detrital zircons in the metasediments lie between 2 220 and 2 465 Ma. They can be interpreted to represent the age of an eroded land mass which yielded the material for sedimentation. Erosion and accumulation must therefore have taken place between 2 200 Ma and 1 850—1 900 Ma (older granites).

5. METAMORPHISM

5.1. REGIONAL NON-GNEISSIC METAMORPHISM

In the geological literature the grade of regional metamorphism is often characterized by certain index minerals. As such, metamorphism is generally considered to be mainly of an isochemical nature. The bulk composition of the primary rocks is of course decisive for the final mineral compositions. Two groups of rocks are particularly suitable to study in this respect, viz. pelitic rocks (alumina-rich) and calcareous rocks. Since, on the whole, the metasediments of the Västervik area are very poor in calcium, we have to deal with the first group. This means that only pelitic or semipelitic metasediments are of a primary interest — a certain restriction if one wants to define metamorphic gradients in detail.

The main part of the metasediments in the Västervik area are meta-arenites. Quartz dominates and variable amounts of feldspar constitute the essential constituents. Pelitic components are quantitatively subordinate. Up to date, three publications have been presented which contain contributions to the problems on regional metamorphism within the area. Russell (1969) studied the flecky gneisses in a restricted area along the north-eastern shores of Gamlebyviken. He constituted a two-fold division of regional metamorphism — a northern area called the sillimanite-andalusite zone, and a southern area characterized as the cordierite-muscovite zone. These zones were believed to represent a prograde metamorphism from south to north.

Elbers (1971) examined an area in the north-eastern part of the map area. His main study was focused on deformation and structures within the metasediments; but he also paid some attention to regional metamorphism. His results are summarized in a diagram (Elbers, *op.cit.*, fig. 17) where some specific mineral associations are taken to represent various grades of metamorphism. The diagram indicates an evolution involving decreasing grade, i. e. retrograde metamorphism. This is certainly a simplification. There must have existed prograde evolution also in the mineral associations of Elbers. For example, there are pictured textures where sillimanite postdates andalusite. The metamorphic evolution of the area is most probably more intricate than shown by the diagram. Kresten (1971b) studied the metamorphism in the southernmost archipelago of the Västervik area, around the large syncline which dominates the structural pattern there. Kresten admits the existence of retrograde metamorphism, but maintains that it is not at all so important as stated by Elbers. In Kresten's summary of the metamorphism mineral associations in the metasedimentary rocks (Kresten 1971b, fig. 2) an evolution is pictured from medium-grade over high-grade (prograde) and back to medium-grade and very low-grade (retrograde) metamorphism.

My impression, based on a more regional study of the metasediments within the entire area, is mainly in agreement with Kresten's model. It is possible to record both prograde and retrograde stages of metamorphism. The latter is of less importance quantitatively, the most common feature being sericitization. Chloritization of such minerals as feldspars, biotite, andalusite, cordierite is also seen; but even such transformations generally have only a more local extension. Andalusite and sillimanite are seen in several different developments. These could represent various steps in the evolution, but I don't think that it is possible to prove with certainty over the whole map area that there existed four different stages of andalusite formation and three stages of sillimanite formation, as done by Kresten. We will return to this question later.

In non-calcareous pelitic metasediments, such minerals as sillimanite, andalusite, kyanite, almandite, and cordierite are generally taken to characterize medium- to high-grade metamorphism. In the Västervik area sillimanite, anda-

lusite and cordierite are common. Kyanite has never been observed and almandite is very rare. I have observed the latter mineral in two cases only. Kresten mentions almandite from five localities within the area examined by him.

A reaction which is frequently used for a characterization of metamorphic grade in metasediments (and which has also been discussed by the authors cited above) is muscovite + quartz \rightleftharpoons sillimanite/andalusite + potash feldspar + water. It is very difficult, however, to use this reaction in the present case since most of the metasediments in question contained primary potash feldspar. It is generally impossible to determine whether the potash feldspar is a primary detrital constituent or if it was formed through decomposition of muscovite. Very often the light mica observed in thin section is clearly the result of retrograde metamorphism and represents replacement of such minerals as feldspars, biotite, cvordierite, and andalusite. This holds true both where the mica appears as fine-grained sericite or when it is seen to occur as larger flakes. Very rarely the textural relationships between the minerals in question give definite indications as to the reactions that led to their formation. Of course this does not mean that the muscovite \rightarrow potash feldspar reaction never occurred, but only that such transformations cannot be used regionally to define the grade of metamorphism. Certainly, progressive metamorphism must have passed a temperature—pressure interval where the pelitic rocks contained plenty of muscovite. However, most probably the rocks also contained chlorite. The first step to prograde metamorphism would thus be the formation of biotite from muscovite + chlorite.

As a general characterization one may say that the Västervik metasediments have almost always passed the temperature—pressure conditions of the lowest biotite zone. In my opinion this means that muscovite was largely consumed to form biotite in association with chlorite. The reaction muscovite + quartz \rightarrow potash feldspar + Al_2SiO_5 + H_2O may have occurred where the contents of early muscovite exceeded the amount consumed for the formation of biotite; but from the present mineral parageneses it is impossible in most cases to determine the extent and importance of this transformation.

From the above considerations it is evident that sillimanite, andalusite and cordierite are the most important minerals which can be used for an estimation of the grade and type of regional metamorphism within the area. Garnets are rare, which makes this mineral less interesting when discussing metamorphism on a regional scale. Winkler (1976, pp. 90—91) uses the formation of garnet or cordierite as pressure indicators, cordierite representing the low-pressure form. He adds, however, that if almandite and cordierite occur together the $\text{Fe}^{2+}/\text{Mg}^{2+}$ ratio is very important. It is a well-known fact that wide areas of gneisses are characterized by the association cordierite-almandite. Their formation consequently covers a P-T field where both minerals were stable. The Fe/Mg ratio in the rocks made it possible for both minerals to form contemporaneously.

In the Västervik area the main explanation for the rare occurrence of almandite seems to be found in the chemical composition of the metasediments. Almandite-bearing samples appear in close proximity to almandite-free, cordierite-bearing samples. It is there out of question to assume a difference in regional pressure between the two types of paragenese. An examination of the analyses makes it apparent that the cordierite-rich samples are mostly characterized by high *fm* and *mg* values, which makes the formation of almandite impossible. In this connection it is worthwhile to quote the results of Gorbatshev, 1968. On the basis of experimental work he states that, "the distribution of Fe and Mg between garnet and cordierite is dependent of temperature and Mg/Fe concentration, thus implying non-ideal mixing of Fe and Mg in garnet".

However, one may make the general statement that the absence of kyanite and the wide-spread occurrence of cordierite in different parageneses indicate that metamorphism in the Västervik area took place under fairly moderate pressures.

Sillimanite and andalusite could also be taken to represent different P-T conditions. In the Västervik metasediments these two minerals very frequently occur together, even in the same thin section. After examining 115 thin sections, representing metamorphic rocks from the entire area, the material was divided into the following 8 classes.

1. Sillimanite + andalusite + cordierite; 19 cases (16.5 %).
2. Sillimanite + andalusite; 13 cases (11.5 %).
3. Sillimanite + cordierite; 9 cases (8 %).
4. Andalusite + cordierite; 6 cases (5 %).
5. Sillimanite alone; 8 cases (7 %).
6. Andalusite alone; 12 cases (10.5 %).
7. Cordierite alone; 22 cases (19 %).
8. None of these minerals present, although in hand specimen the rocks could be supposed to contain some of the minerals in question; 27 cases (23 %).

Fig. 69 (p. 96) attempts to show how the different minerals are distributed over the entire field. We can see that within many areas several mineral combinations are represented. For example, around Lake Rummen (in north-west) generally all three minerals, cordierite, sillimanite and andalusite, occur together. In Fig. 76, the individual localities represented by one thin section are shown. We see that north and north-west of Lake Rummen most of the samples contain both andalusite and sillimanite. In most cases, cordierite is an additional constituent. Immediately east of the lake, four localities could be taken to represent a sillimanite area; but further to the east the rocks again contain sillimanite + andalusite. Further to the east sillimanite alone is again found. Still further to the east the rocks contain sillimanite + andalusite. Some 4 km to the south and 8 km

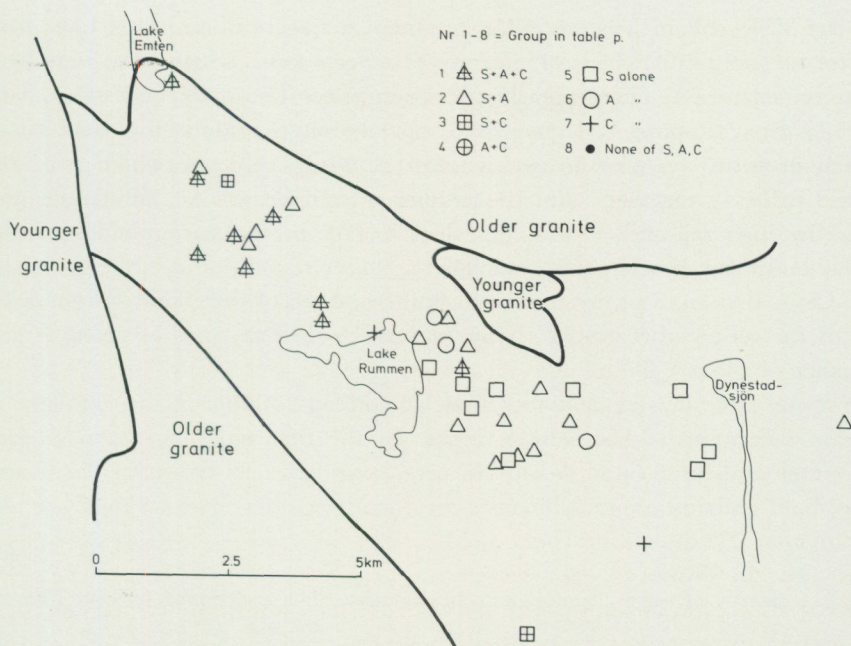


Fig. 76. Survey of the distribution of sillimanite (S), andalusite (A), and cordierite (C) in thin sections from an area around Lake Rummen. Mainly map-sheet Västervik SO (4f-g).

to the south-east of Lake Rummen there are scattered localities with andalusite alone, sometimes accompanied by cordierite. However, at the easternmost locality one specimen was found to contain sillimanite+andalusite. The distribution of sillimanite and andalusite shows no consistent pattern which might be interpreted to indicate the existence of regional metamorphic gradients. Neither can the presumptive small areas of andalusite or sillimanite be correlated with any differences in metamorphic intensity recorded in the field (for example degree of gneissification or granitization, or distance to neighbouring granites).

Cordierite seems to be distributed quite irregularly. Cordierite-bearing samples without andalusite and sillimanite contain a lot of muscovite. They could be taken to represent the muscovite-cordierite zone of Russell (1969); but as they are surrounded of rocks belonging to the andalusite-sillimanite zone of Russell they must represent local developments. This probably holds true also for Russell's example, since only 3.5 km south-east of Russell's map the metasediments have reached the sillimanite zone. From the relationships described above it must be concluded that the distribution of the minerals sillimanite, andalusite and cordierite in the Västervik area cannot be taken to characterize different metamorphic areas on a conventional basis.

Some complementary examples can be mentioned. The first refers to an area

4—5 km ESE—SE of Västervik. On the map, the rocks of this area have been denoted as gneisses. There occur gneisses of several kinds which have here been called veined gneiss. There are also flecky gneisses. The material from Loberg (1963) is from this area and there occur many strongly granitized gneissic rocks. Nine analyses are available from this area, the Niggli values of which are listed below (Table 4) together with the contents of andalusite (A), sillimanite (S), cordierite (C), muscovite (M), and biotite (B) in the corresponding rocks, roughly estimated from the thin sections.

The four first analyses are from the southern shore of the island Borgö, 5 km ESE of the center of Västervik. They represent different types of gneiss within a distance of about 150 m.

From the table it is evident that there is nothing to indicate the existence of separate sillimanite and andalusite zones. In the first group we have gneisses with either andalusite or sillimanite in neighbouring gneiss types. In the second group, both andalusite and sillimanite are found together. The *t* values are also

TABLE 4. Survey of some chemical and mineralogical data concerning gneisses from an area E to SE of Västervik.

Analysis number	<i>al</i>	<i>fm</i>	<i>c</i>	<i>alk</i>	<i>mg</i>	<i>k</i>	<i>t</i>	<i>A</i>	<i>S</i>	<i>C</i>	<i>M</i>	<i>B</i>
62	42.8	21.4	1.4	34.4	0.31	0.70	7.0		+		+	+
63	46.6	31.9	1.3	20.2	0.45	0.72	25.1		+	+	+	+
64	47.0	27.3	1.7	24.0	0.38	0.62	21.3	+			+	
L1	40.1	25.5	2.1	32.2	0.43	0.63	5.8		—			++
65	43.3	31.3	5.7	19.5	0.40	0.43	18.0		+	—	+	++
66	44.5	29.5	1.9	24.0	0.37	0.68	18.6	—	+			++
67	43.2	28.6	4.2	23.9	0.20	0.55	15.1	—	+		(+)	+
61	44.2	31.1	0.9	23.8	0.36	0.87	19.5				+	+
41	42.7	17.9	3.8	35.6	0.56	0.56	3.3				+	

Analysis no.

62. Red, veined gneiss with biotite-rich schlieren.

63. Veined gneiss with red, pegmatitic schlieren and better preserved mica-schist.

64. More homogeneous granitoid gneiss, sometimes with visible sedimentary structures.

L1. Flecky gneiss, matrix (Loberg 1963).

Analyses 65—67 are from an outcrop of Spårösund, 1600 m ESE of the group 62—64 and L1. These analyses represent three different types of flecky gneiss, which here occur together.

Analysis no.

65. "Normal" flecky gneiss.

66. Very biotite-rich development.

67. Acid pink development.

61. Intensely veined and banded gneiss (see Fig. 39, p. XX) situated 400 m south of the group 65—67.

41. Intensely veined gray-red gneiss situated about 1 km north of the group 64—66.

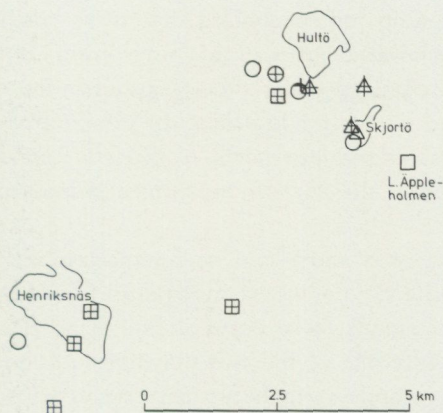


Fig. 77. The same as in Fig. 76 though covering the archipelagos around Hultö, Skjortö and Henriksnäs within the south-eastern part of the mapped area. Symbols as in Fig. 76. Map-sheets Kråkelund NV (7—8a) and Vimmerby NO (6—7j).

presented in the table. Since t values reflect excess alumina, it is significant that the samples with the lowest t values are devoid of aluminosilicates and those with only very small amounts of sillimanite also have comparatively low t values (nos. 64 and L1).

Similar conditions are seen in the south-eastern archipelago. Fig. 77 is a presentation of a number of localities, given in the same manner as in Fig. 76 (p. 111). The figure suggests that there exists a sillimanite-cordierite area without andalusite in the south-western part of the sketch (Henriksnäs—Tullerön—Storön). If we compare with fig. 3 in Kresten (1971b) this area can be taken to extend over the whole metasedimentary belt to the south-east. Andalusite is found in the northern parts of the area in Kresten's map. But even here andalusite and sillimanite localities vary irregularly. Since Kresten's presentation apparently presents localities where either andalusite or sillimanite clearly dominates, his presentation cannot be directly compared with my own account which is intended to show localities where one of these minerals is missing.

One area in Fig. 77 is particularly worth consideration, namely the area covering the islands of L. Äppleholmen and Skjortö plus their surroundings. The rocks on L. Äppleholmen are characterized by distinct primary bedding, with mud cracks in the meta-argillitic beds, as pictured in Fig. 21 (p. 27). Micaceous bands contain abundant sillimanite which to the naked eye appears as white spots. Neither andalusite nor cordierite is present. Just 1 km to the WNW, on the south-western shore of the island Skjortö, mica-schists contain large amounts of andalusite, often appearing as idiomorphic porphyroblasts, cf. Fig. 18 (p. 24). Studies of two thin sections show that in one case only andalusite is present, while in the other even sillimanite and cordierite are present in minor amounts.

Field studies give no reason for concluding that these two localities have been subjected to higher or lower degrees of metamorphism. Both appear within a large area where no marked gneissification or granitization has taken place.

The island of Skjortö is about 1 km long. In the central and northern parts of the island, and on an island just north of Skjortö, mica-schists contain both sillimanite and andalusite, the former sometimes dominating. Generally, cordierite is also present.

The relationships discussed above can be summarized as follows. In general, sillimanite and andalusite do not occur in separate areas but seem to be irregularly mixed. Very frequently, they occur in the same thin section. However, there are areas where only one of the two polymorphs is present or where one clearly dominates. There appears to be no correlation between such areas and adjoining granite contacts or with areas of intense gneissification or granitization.

The distribution of cordierite seems to be independent of the distribution of both sillimanite and andalusite. A cordierite-muscovite zone in the sense of Russell (1969) may exist at some places but does not apply regionally. It is therefore considered to be a local phenomenon where existing. It has been mentioned previously that there probably existed several stages of mineral formation during metamorphism. Kresten (1971b, fig. 2) assumed three generations of sillimanite formation and four generations of andalusite formation. From the same paragenesis he describes prekinematic, fibrolitic and synkinematic, porphyroblastic types of sillimanite. On the basis of petrofabric analyses of the flecky gneiss, Loberg (1963) also describes two generations of sillimanite crystallization. The older was seen as sillimanite bundles or enclosed in feldspars. This sillimanite was interpreted as synkinematic. Sillimanite enclosed in quartz was thought to be postkinematic. It is not possible, however, to relate mineral formation to kinematic metamorphism from separate localities, since kinematic metamorphism covered a long period of the geological time and apparently took place in several steps.

What can be stated with certainty is that there must have existed more than one phase of sillimanite formation. It is also evident that no true equilibrium was achieved. One of the two minerals sillimanite and andalusite must have existed in a metastable form. Out of the 115 specimens presented on p. 110, 32 specimens contain both minerals in the same thin section, whereas only 35 contain either sillimanite (17) or andalusite (18). The localities where sillimanite or andalusite occur alone are intermixed, however, and do not indicate a zonal arrangement for the respective minerals.

In the search for explanation of the sillimanite-andalusite puzzle one can examine textures in thin sections where both minerals occur together. Andalusite may appear as large porphyroblasts, sometimes extremely poikiloblastic, sometimes as fairly well-defined individuals lacking inclusions. There certainly exist all kinds of transitions between these two forms. A very different type of andalu-

site is seen in connection with the formation of flecky gneisses. Here, andalusite appears as often fine-grained granular masses. This type is generally combined with green biotite, which in turn is a transformation form of the normal brown biotite. Both Loberg (1963) and Russell (1969) have found the same association and commented on it. Gavelin (1975) has shown that the andalusite-green biotite assemblage often appears as a transition zone in a metamorphic differentiation series that finally results in a pure quartz-feldspar micro-region on one hand and a brown biotite sillimanite/andalusite-quartz micro-region on the other. This circumstance was taken to prove that metamorphic differentiation at least started in the andalusite field of a P-T diagram.

Sillimanite appears in several textural developments. Very often it occurs as fibrous, fine needles irregularly penetrating other minerals as pictured in Gavelin (1975, fig. 7). However, such needles may be concentrated to form spots from which the fine needles radiate. Such spots are frequently arranged along micaceous bands or sharply outlined, narrow shear zones in the thin sections. Usually, such shear zones have been subsequently deformed and crumpled, which means that the formation of this sillimanite must be characterized as synkinematic. Sillimanite has also been found as larger individuals or bundles of crystals. Sometimes this development has the appearance of postkinematic crystallization, although the fact that there are obvious transitions between the fine-fibrolitic and the more porphyroblastic textures makes it difficult to prove a two-fold primary division for the origin of the mineral.

The most puzzling problem as regards the relationship between sillimanite and andalusite is that, usually, where both minerals occur together, they do not display any spatial relationship whatsoever. Sillimanite needles or bunches of sillimanite penetrate quartz, biotite, and sometimes feldspar if present. They also penetrate andalusite, and may cross the boundaries between the other minerals mentioned. Sillimanite shows very little preference for any pre-existing mineral, perhaps with the exception of biotite, which is often found as diffuse relics in spots of sillimanite.

Where sillimanite and andalusite are in contact with each other, the former generally penetrates the latter. It is remarkable, however, that where andalusite appears as large porphyroblasts, the sillimanite needles are restricted to the very border zone of the andalusite grains. The texture gives the impression that andalusite is resistant to sillimanite formation. The question can be asked whether or not there existed an early sillimanite formation followed by subsequent crystallization of andalusite porphyroblasts. This in turn might have been followed by renewed sillimanite crystallization. The existence of a second period of sillimanite crystallization could explain the conspicuous spatial relation between andalusite and sillimanite in some rocks. In such cases, especially in the area around Lake Rummen, andalusite porphyroblasts are surrounded by a thin rim of sillimanite which also penetrates the andalusite grains along cleavage

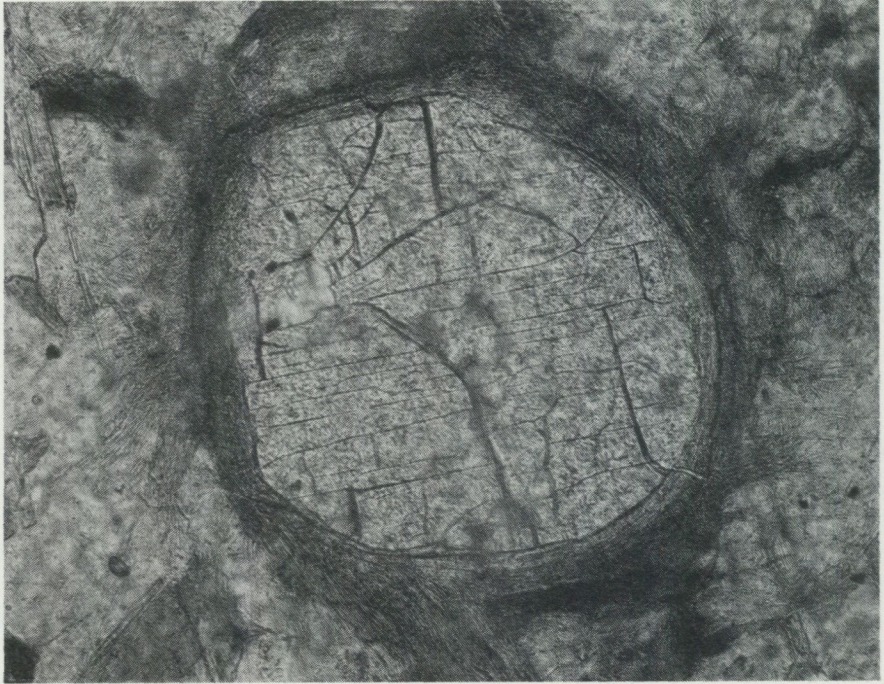


Fig. 78. Sillimanite bordering large porphyroblast of andalusite. + nic., 129 \times . North of Lake Rummen. Map-sheet Västervik NO (4f).

faces, Fig. 78. It is worth mentioning, however, that even in such cases a lot of sillimanite is found with no particular spatial relationship to andalusite.

These observations are in agreement with the assumption that there have been several generations of sillimanite and andalusite crystallization. This in turn must have been the result of variations in metamorphic activity during the geological evolution of the area. The fact that two polymorphs of Al_2SiO_5 occur together has been observed by several other authors. Chinner (1961) describes an example where kyanite passes over into sillimanite but points out that the sillimanite starts by growing in biotite rather than in kyanite — in principle the same situation as in the Västervik area. Chinner explains the phenomenon by suggesting that the trigonally arranged oxygen octahedra and tetrahedra in the alternating biotite layers act as nuclei for the growth of octahedral Al-O and tetrahedral (Al, Si)—Al chains in the sillimanite structure. Consequently, the nucleation of sillimanite takes place in biotite and not in kyanite. It is readily seen that the process proposed by Chinner is also well-suited for the Västervik rocks although here the polymorphs are sillimanite and andalusite. In contrast to Chinner, I would also suggest that the Al of biotite probably takes some part

in the mineralization since in the Västervik rocks there are many examples of biotite remnants in sillimanite spots.

From the discussion above it is clear that within the Västervik area metamorphic conditions must have existed where one polymorph, perhaps both, persisted as metastable minerals during certain stages of the evolution. In other words, true equilibrium was not achieved. In their laboratory work, Richardson *et al.* (1969) found that the transformations between kyanite, sillimanite and andalusite are very sluggish. Moreover, the transformation andalusite to sillimanite and *vice versa* is more sluggish than those where kyanite was involved. They state, "In contrast to the experiments involving kyanite bearing equilibria, in none of our andalusite-sillimanite runs did we observe complete conversion of one polymorph to the other".

Winkler (1976, pp. 9—95) discusses the phase boundaries between andalusite, sillimanite and kyanite. Because of the appreciable differences between results of several experimental investigations, he suggests that the stability lines in the diagrams should be replaced by bands covering larger areas within the P-T field. Applying these observations to the Västervik area, we can conclude that the higher grades of metamorphism took place under P-T conditions within the transition belt between andalusite and sillimanite in the P-T diagram.

A very vital problem still remains. If P-T conditions during metamorphism change from the stability field of one polymorph to that of another, why doesn't the new mineral start to crystallize in the pre-existing polymorph. It is evident that where andalusite existed initially, and P-T conditions were raised, sillimanite did not start to form in the andalusite. Under the microscope one can see many examples where sillimanite needles have grown in clusters, often in biotite, or as needles penetrating other minerals, especially quartz. This would be in accordance with the examples and interpretations given by Chinner (1961, p. 191). If we assume that a large part of the sillimanite was formed from biotite, this means that in the first hand (Fe, Mg)O, K₂O and water were expelled. Since much of the metamorphism is connected with a metamorphic differentiation (Gavelin 1975) it might be possible that the ultimate cause of the sillimanite formation is to be found in those special conditions which created the metamorphic differentiation. That would of course mean that the metamorphic P-T conditions were such that the sillimanite field in a P-T diagram during this very stage in the metamorphism of the rocks was reached.

If one attempts to evaluate the temperatures and pressures which prevailed during the process, some difficulties are encountered. Loberg (1963) made an estimate of about 500°C for the mineral formations. Russell (1969) gave the tentative figures, 580°C and 3.5 Kb for his flecky gneiss formation, which is in good agreement with a recent estimation of Loberg's results by G. W. Fischer 1970, p. 95, founded on new experimental data: 580 ± 80°C at about 3 Kb. Winkler's P-T diagram, which is an attempt to summarize various experimen-

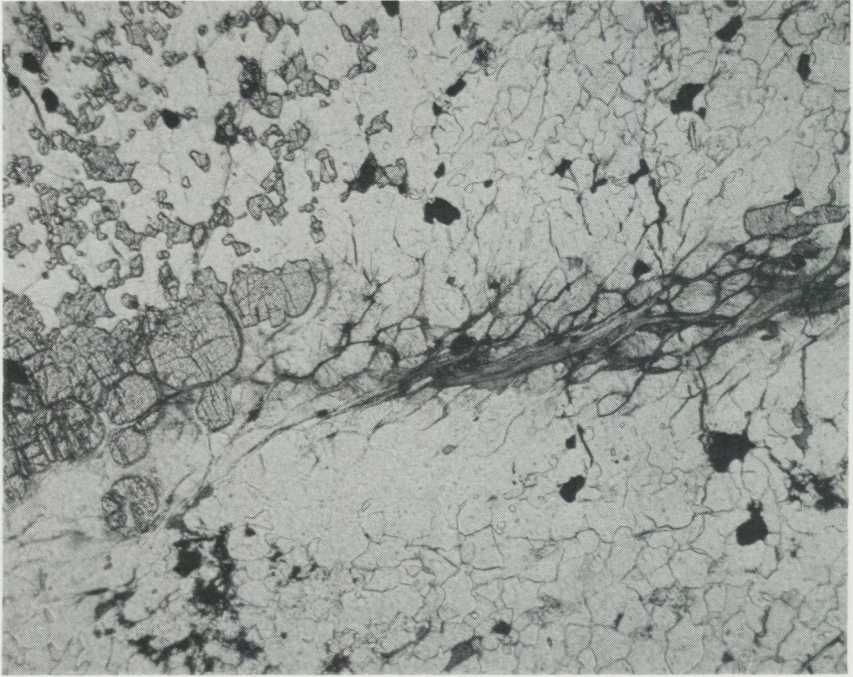


Fig. 79. Sillimanite on shear zone cutting a porphyroblast of andalusite. + nic., 32 \times . North of Tjust Motell (2 km S of Gamleby). Map-sheet Västervik SO (3h).

tal results, seems to indicate definitely higher pressures (at least 4.5–5 Kb). Temperatures may also have been somewhat higher than the values of Loberg and Russell. However, with all the reservations presented by the various experimental workers on the sillimanite-andalusite-kyanite relations, it seems to me that attempts to exactly determine the P and T for the metamorphism within a certain area are fairly meaningless.

The peculiar spatial distribution of andalusite and sillimanite is a question that also must be considered. In general both polymorphs occur separately in the same thin section, as was mentioned before. In many cases the spots or clusters of sillimanite are concentrated in biotite-rich stringers which could represent shear zones. A sample from a flecky gneiss situated 2.5 km south of Gamleby and described by Gavelin (1975, pp. 68–69) is particularly interesting. In the intensely flecked red bed (analysis no. 68), andalusite occurs as scattered large porphyroblasts, whereas sillimanite is missing in the main part of the thin section. A marked shear zone, however, contains plenty of sillimanite, Fig. 79. The shear zone cuts a large andalusite porphyroblast which seems to be fairly unaffected by shear. Along the shear zone sillimanite needles penetrate

the andalusite. In this case, it is absolutely clear that shearing created favourable conditions for sillimanite formation.

If we try to summarize the data defining regional metamorphism it can be stated that there exist mineral associations characteristic of several different metamorphic grades, as conventionally presented in P-T diagrams. Kresten (1971b) discerned 8 different metamorphic parageneses. Here we can restrict ourselves to those characterized as medium- and high-grade. Russell (1969) distinguished between a high-grade sillimanite-andalusite zone and a low-grade muscovite-cordierite zone. If one tries to adopt the system of isograds one would expect a sillimanite zone and an andalusite zone, both with potash feldspar and a muscovite zone, perhaps in part with andalusite, but with little or no potash feldspar. Regional field experience shows, however, that all the parageneses characteristic of the individual zones are completely mixed together. In other words the conventional P-T diagram fails to provide an explanation of the conditions, if the area examined is considered on the whole.

It is a well-known fact that different mineral facies may arise at similar P and T but with variations of other variables. Yoder (1955) could show experimentally that green schist and amphibolite facies parageneses could be produced at the same P-T conditions but under different H_2O -pressure. Later contributions have shown that mineral-forming processes are highly dependent on such parameters as f_{H_2O} , pH and a_{K^+} . An important example has been given by Eugster (1970) who demonstrated experimentally that the triple point between muscovite, potash feldspar and Al_2SiO_5 (in the presence of quartz) in a P-T diagram varies considerably with changes in f_{H_2O} , pH and a_{K^+} . Consequently, even the stability fields for the respective minerals varied with f_{H_2O} , pH and a_{K^+} . Since the three minerals mentioned above are frequently present in the Västervik metasediments, f_{H_2O} , pH and a_{K^+} must have had a certain influence. Dahl (1972), in his discussion of the origin of flecky gneisses, gives good reason for assuming that a_{K^+} might have had a decisive effect on the final result. Very interesting points of view have been presented by G. W. Fischer (1970), who has combined Loberg's results with new data on equilibria. He was able to show that the variables mentioned above ought to have been of great importance for the exchange of elements during metamorphism.

On several occasions, we have seen that sillimanite is enriched within shear zones. My first idea was that such zones could represent some kind of overpressure. Today, the role of overpressure is controversial. Many skilled researchers believe this effect to be negligible in metamorphism (except possibly as a kind of catalytic effect). There is one example from the Västervik area where local overpressure cannot be responsible for the formation of either sillimanite or andalusite in the rock. Previously, it was mentioned that in the southern archipelago there are two islands only 700 m apart where on the one (L. Äppelholmen) the rock contains micaceous bands with plenty of sillimanite but no

andalusite, on the other (southern Skjortö), the mica-schists are spotted with andalusite and very subordinate sillimanite. In the field, there is nothing to indicate that any one of these localities has been more intensely kinematically metamorphosed than the other. If there were any such difference, the andalusite schist would have been more intensely deformed than the sillimanite schist.

Consequently, we can conclude that metamorphism of the Västervik area, on the whole, took place within the transition zone between the stability fields between sillimanite and andalusite (and also cordierite). The variations in "metamorphic grade" must largely be explained by variations in f_{H_2O} , a_{K^+} and pH. The activities of these variables are greatly dependent on the mobility of fluids within the rock masses. Mobility was in turn dependent on the distribution of channelways in the rocks. Such channelways are largely a result of tectonic deformation and are of course difficult to record or to predict. This seems to be the most plausible explanation for the somewhat confusing picture of the distribution of various metamorphic types of zones throughout the map area. I believe that this last statement is particularly important, since the importance of kinematic effects on metamorphics which leads to the formation of granitoids is often neglected in the discussions on granitization. Within the Västervik area we have found at least some examples which show that metamorphic differentiation and selective mobilization of materials may be activated through kinetometamorphism and pressure gradients created during such processes. This may lead either to homogenization of heterogeneous rocks or differentiation of homogeneous rocks.

In attempts to find some motive power for the metamorphic differentiation leading to "flecks" or "metasomatic veins" both Loberg (1963) and Gavelin (1975) have tentatively proposed the formation of local pressure gradients during the metamorphic events. Such a factor has on several occasions been proposed to explain atomic migrations in the solid state by Ramberg (1952, pp. 174—265, 1955, 1956) on the basis of both field data and thermo-dynamic considerations.

5.2. METASOMATISM AND METAMORPHIC DIFFERENTIATION

In this discussion the word "metasomatism" is used as an expression for any change of a rock portion in the solid state through the supply of certain chemical elements and removal of others, irrespective of the source of the supplied material. The volume of the rock is supposed to be approximately constant. The extent of such metasomatic activities may vary considerably. They may be of a regional character, covering several square kilometres or they may be restricted to reaction zones measured in millimetres or centimetres. Within the Västervik area the only types of large scale metasomatism that can be recognized with certainty are processes which involve an introduction into a previous rock of

elements forming either potash feldspar or plagioclase. This could be characterized as mainly potassium or sodium metasomatism. Of course it is possible that other chemical elements — for example magnesium and iron — have also been mobilized during various stages of metamorphism and caused metasomatic transformations. Such processes, however, have never been positively verified, at least on a regional scale. Where potassium metasomatism can be demonstrated it is generally associated with feldspathization. Potash feldspar is sometimes seen to invade quartzites but only to a very limited extent. Small feldspar veinlets or feldspar individuals may sometimes be found in very pure quartzites; but this phenomenon is rare and always local. One gets the impression that the invading feldspar has emanated from adjoining potassic metasediments. The same holds true in the case of small potassic veinlets in banded potassic metasediments. On the whole, it is clear that much of the potassium metasomatism which can be directly observed has resulted from the mobilization of potassium within the metasediments themselves.

It might be possible that potassium metasomatism on a larger scale has also taken place and that certain episodes of gneissification and granitization may have been connected with a certain supply of potassium. Kresten (1971a) found a rock on the island of Lammholmen which he interpreted as a result of intense potassium metasomatism which led to the formation of extremely potassic granitoid rocks. He calls such rocks "rheosome".

As to the source of potassium, it is evident that local potassium metasomatism represents a type of metamorphic differentiation. On a regional basis, there exists no correlation whatsoever between granitic bodies and feldspathization phenomena recorded in the field. It seems probable therefore that even where potassium metasomatism occurs on a larger scale, for example Lammholmen according to Kresten, the process represents a type of metamorphic differentiation on a somewhat larger scale. Both Loberg (1963) and Gavelin (1975) have shown that the formation of flecky gneisses and similar metamorphic differentiation involves a depletion of potassium in the original rock. This mobilized potassium may give rise to a potassium metasomatism within other parts of the rock mass.

The other metasomatic trend — sodium metasomatism — is more obvious and easier to recognize in the field. It has been mentioned before that the border zones of metasediments towards the Loftahammar granites, to the north-east, are largely characterized by an enrichment in plagioclase (oligoclase). In the south-eastern part of this belt we find rocks which megascopically look like somewhat "dirty" quartzites from other parts of the area, but which in reality are composed of about equal amounts of quartz and oligoclase. Within the areas mentioned, these rocks look quite homogeneous. In the beginning of the study they were thought to represent approximately ordinary sedimentary compositions. However, in the north-western part of the belt the same rocks were found

to occur as veins and breccias — clearly discordant to bedding in the metasediments. Consequently, they must have resulted from metasomatic processes. The plagioclase rocks are here mainly found within the border zones between Loftahammar granite and the metasediments. The granite, too, has been affected by the process, which means that potash feldspar and, to a certain extent, biotite in the granite have been replaced by oligoclase.

The process has been examined and discussed by T. Hahn (licentiate thesis, not yet published) and later by Elbers and Hoeve (1971), Elbers (1971), and Hoeve (1974). In these publications excellent photographs of outcrops showing the pattern of breccias and discordant veins are presented. All of these authors agree in their interpretation of the rock as having resulted from a kind of metasomatic activity, mainly sodium metasomatism. As to the age of metasomatism, all three authors state that it must postdate the Loftahammar granite, since the granite has been strongly affected by the metasomatic agents. Elbers (1971) found that the metasomatism generally postdates his last deformation phase (f_2). Consequently, it must be of a fairly late date in the geological evolution.

Within the areas covered by the investigations of the authors mentioned the relation to the younger granites seems to be somewhat unclear. Elbers (1971) states that the younger granites sometimes seem to cut the metasomatic veins and that these granites have never been found to be affected by metasomatism. Kresten, on the other hand, has found a locality (road-cutting, highway E 66, 500 m south of Botorp) where a younger granite has also been affected by sodium metasomatism.

From the above, it is evident that the most characteristic feature of the process was a supply of sodium and possibly also of some calcium to the pre-existing rocks and a contemporaneous removal of potassium in the first place. Hoeve (1974) found an interesting connection between sodium metasomatism and a slight U-mineralization, which sometimes occurs in the metasediments (cf. Uytendogaardt 1960; Welin and Uytendogaardt 1963; Welin 1966). It has not been possible to determine the age of this mineralization with certainty. It has only been said to represent a fairly late stage in the geological evolution. Hoeve suggests a certain connection with the younger granites. However, since he believes that the younger granites have been formed through anatexis at deeper levels, he suggests that the solutions leading to soda metasomatism could have been mobilized during this process and moved upwards from the granitization front.

All three investigators have worked within the same area, i. e. the border zone between Loftahammar granite and metasediments, where it has in part a regional extension. If one takes the entire map area into consideration, one finds that exactly the same metasomatic activity has taken place at several other localities, although on a minor scale. Two examples are considered here which resemble

the cases already cited with respect to geological environment. At a locality 2.5 km south-west of Västra Ed there occurs normal schistose Loftahammar granite. The granite has been penetrated by a network of bleached, somewhat diffuse, veins which cut across the schistosity of the granite. The bleaching has resulted from a replacement of microcline by oligoclase. The bleached rocks look exactly like the replaced Loftahammar granites described by Hahn, Elbers and Hoeve. No connection whatsoever can be recognized between these rocks and either younger granites, metabasites or even structural peculiarities.

Along highway E 66, just east of the main road to Vimmerby, the contact between an older granite and metasediments is exposed. Both the metasediments and the granite have been affected by a sodium metasomatism resulting in an introduction of oligoclase in the metasediments and the replacement of microcline in the granite by the same mineral. Even in this example there can be found no relationship at all between the altered rocks and younger granites, metabasites or local structures.

It is probable that many more similar examples could be found if one were to carry out a systematic search for the phenomena over the entire map area. At several places, plagioclase-rich rocks — both granitoids and metasediments — have been observed where they appear highly contrasting to the surroundings.

Other examples of soda metasomatism can be found where the extension of the alteration is on very much smaller scale but where, on the other hand, one can establish a clear relationship between geological environment and metasomatism. Gavelin (1960) showed that pure quartzite was invaded by oligoclase where the quartzite bordered on metabasite and both rocks had been affected by strong kinetometamorphism. Kinetometamorphism also caused the quartzite to flow, the metabasite to fracture. Only the flowable, sheared parts of the quartzite were feldspathized. In one case, the original quartzite contained potash feldspar which was completely removed where the rock was invaded by oligoclase. In principle, this process is the same as the alteration of Loftahammar granite.

A similar phenomenon can be studied in a road-cutting along highway E 66, 500 m north of the junction road to Blankaholm. Here we find metabasite dikes in an older granite. The dikes have been broken up by secondary flow of the granite. The pattern is very similar to that shown in Fig. 74 (p. 105). In the present case, however, the broken pieces of metabasite have sometimes flown even further apart, are more displaced and sometimes rotated. Normally, the granite is pink; but the broken blocks of metabasite are always surrounded by a bleached reaction zone, 1—2 cm wide. In this reaction zone the microcline of the granite is replaced by oligoclase. This is exactly the same phenomenon as was found in normal Loftahammar granite.

In the two last-mentioned examples, the extent of the metasomatic activity is certainly insignificant, compared with that along the Loftahammar granite-metasediment border to the north-east; but it is particularly interesting from a

genetic point of view since in these cases the source of soda is obvious — i. e. the adjoining metabasites. Concerning the broken up metabasite in granite, it is surprising, however, that similar reaction zones have not been found in many other examples observed. The pattern in the example with reaction zones is somewhat different from the others, however. It might be possible that the development of kinematic deformation was specific in this case, with greater movement of plastic, granitoid material along the brittle pieces of the metabasite. Such a mechanism could explain the formation of the examples presented by Gavelin (1960) where feldspathization of pure quartzite took place in cases where the quartzite was shown to have "flowed" most intensely. If the metabasites were the source of sodium in the instances where metasomatic activity was restricted to a few centimetres, it is difficult to adopt the same explanation for the supply of sodium in the examples of more extensive or even regional development. Hahn has discussed the possibility that metabasites acted as source rocks but believed such a source to be very improbable and pointed out that, in the examples given by Gavelin (1960), metasomatic activity was of a very local nature.

It was stated before, however, that in none of the examples of the formation of plagioclase rocks on a larger scale it has been possible to establish any spatial relationship between these rocks and metabasites. On the other hand, if sodic hydrothermal solutions were formed in connection with granitization on a more regional scale (as suggested by Hoeve), the source of the sodium would most probably be sought in the basic constituents of the granitized rock masses. As was mentioned before, most of the original metasediments are extremely poor in sodium.

The Loftahammar granites to the north-east are associated with large masses of various metabasites. Immediately north of the map area, the gneisses were largely formed from basic volcanics. Everywhere, metabasites are also common constituents in the metasedimentary areas. Therefore, the rock masses which were transformed to veined gneisses and granitoids must have contained a lot of material which could give rise to sodic hydrothermal solutions. Sometimes sodium metasomatism may be related in space to metabasites. In other cases, the solutions must have migrated independently. Their spatial distribution may have been governed by special structural features. Why a particular sodic hydrothermal solution should form at a particular stage in the metamorphism of the rocks, and why, in at least some places, it should contain U as suggested by Hoeve, are questions which still cannot be answered satisfactorily. If the sodium is derived from granitized sediments, it might be possible that even U was primarily and syngenetically enriched in the sediments.

Gandhi (1978) reports an example of U mineralization from Labrador where a conspicuous Na metasomatism has also taken place, Na_2O being enriched and K_2O depleted in the host rock. Even in this case, the mineralizations have been

interpreted to be related to anatexis. As to the distribution of the Na metasomatic rocks within the map area, it was mentioned before that these rocks appear quite unexpectedly and irregularly. Their best development, however, is found along border zones between Loftahammar granite and metasediments.

At first, this relationship might lead one to believe that the Na metasomatism was caused by rest solutions from the granite itself. The fact that the phenomenon is sometimes found independent of the older granites and also in younger granites makes such an interpretation impossible — at least if the process is considered to have been contemporaneous over the whole map area. Moreover, a particular enrichment of sodium in the end products of a granitic evolution is improbable. However, in my opinion, the plagioclase invasions need not necessarily represent one single process over the entire area. They could have occurred where physical conditions facilitated mobilization and exchange of chemical elements between chemically contrasting rocks. The examples described above of smallscale exchange between metabasite on one hand and granite or quartzite on the other support this view. It was stressed in the discussions on folding and kinetometamorphism that the older granites acted as resistant blocks towards the more mobile metasediments. Consequently, the border zones must have represented areas of physical discontinuity. It was also pointed out that, during regional granitization, the metabasites must have delivered material to the homogenized granitoids. Sodium metasomatism could have been initiated by solutions formed at that time, i. e. by materials from the metabasites which migrated from their original source and were active where the necessary physical prerequisites prevailed.

5.3. ORIGIN OF GNEISSES AND GRANITIZATION

One of the main purposes of the present investigation was a study of the problems of granitization, based on field data. Shore-lines in the area offer excellent outcrops where many unambiguous relationships between granitoid rocks and their lower-grade metamorphic surroundings can be studied in great detail. During the mid-thirties, a very intense international discussion on the genesis of granites took place. In part, some general ideas presented much earlier were taken up again; but many new and drastically contrasting explanations on the formation of granitic bodies were advanced. Many researchers suggested that granitoid rocks might form from solid crust by high-grade, deep-seated metamorphism, for example in connection with orogenesis. Much of the discussion was concerned with the question whether such processes took place through melting, i. e. if granitic magmas were formed, or whether granitoids were formed mainly through various kinds of transformations in a solid state, i. e. metasomatism. The metasomatic school generally stated that metasomatic processes can often be indicated

by field data, where metasediments show continuous gradations into granitoids and where relic, metasedimentary structures are observed within fairly homogeneous granitoidal massifs.

The Västervik area offers excellent examples where the transitions between granitoids and metasediments can be studied in detail. Even during the initial field work, frequent gradational sections were observed from well-preserved metasediments into granitoids. This development is perhaps most clearly seen on the islands and the mainland east of the town of Västervik. Spotted gneisses are particularly interesting since the spots seem to represent a small-scale metamorphic differentiation into a granitic portion ("leucosome") and a mafic portion ("melanosome"). Well-defined, individual flecks are sometimes connected by leucosome, giving the rock the appearance of a veined gneiss. Loberg (1963), who studied the fleck formation in detail, called this phenomenon "confluent flecks". Flecky gneiss was also examined by Russell (1969) in an area further to the north-west. Both he and Loberg were able to prove that the differentiation leading to fleck formation was a process that took place without melting, i.e. metamorphic differentiation in the solid state, where a rock portion of granitoidal type is formed. The second metamorphic step from metasediment to granitoid was called veined gneiss (see the chapter on gneisses, p. 58 ff). In the past, the origin of veined gneisses has been interpreted in two contrasting ways. According to one explanation they are a result of intrusive materials from granitic magmas (arterites). The other explanation is that the veins were mobilized from pre-existing rocks (venites). In the Västervik area, it can be established that there is no spatial correlation between the large granite bodies and the development of veined gneisses. They would therefore be supposed to represent venites. Field studies seem to confirm this explanation as do the analytical data. Fig. 80 is a part of the triangle Or-Ab-An. Areas where both gneissic and non-gneissic metasediments occur together are examined first. One can see that gneissic and non-gneissic samples are grouped in respective fields. No tendency to an increase in the Or component in the gneisses can be seen — a condition that might have been expected if the veins had represented intrusions from the end products of a granitic magma. The fields represented by broken lines (a—d) represent four separate areas. However, they could very well represent similar metasediments in different grades of metamorphism. On the whole they give the same impression as the three more well-defined areas. Field b is seen to vary considerably with respect to the Or/Ab-ratio. It is interesting to note that the two analyses of typical gneisses from Lökholmen (field d, 4.5 km NNE of field b) fall exactly in the centre of the b-field.

Venites are often explained as the result of selective melting, where a melt of approximately eutectic composition forms the mobile portion of the rock mass (leucosome). The more immobile portion (melanosome) represents the residual

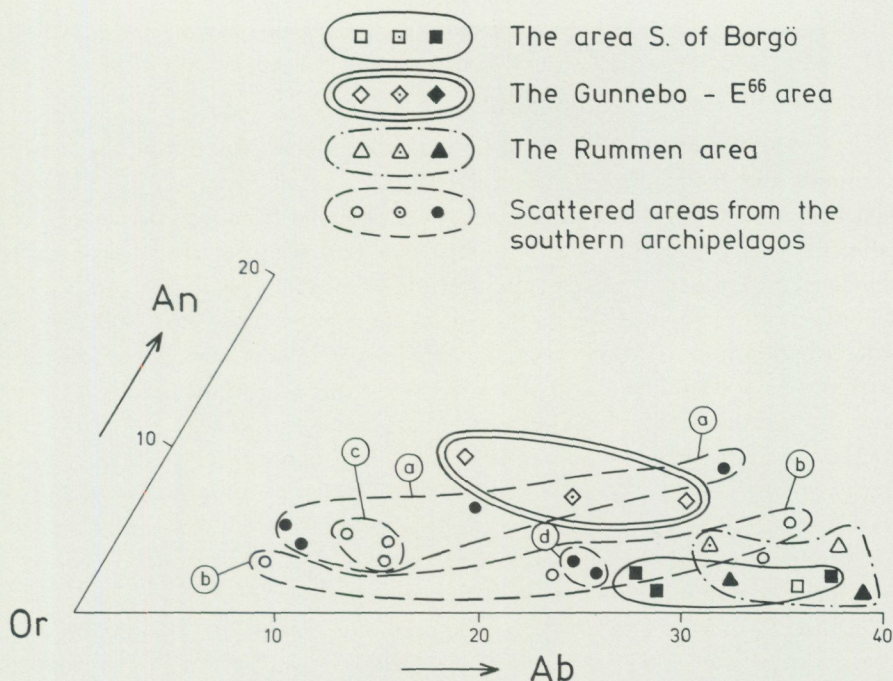


Fig. 80. The Or corner of an Or-Ab-An triangle intended to show the relations between low-metamorphic (open signs), medium-metamorphic (signs with a dot) and strongly gneissic metasediments (filled signs) mainly belonging to the red-gray and the gray metasediments. As to the scattered areas a = Henriksnäs-Tullerön, b = L. Appleholmen-Skjortö, c = small islands SW of Hultö, d = Lökhölmén. Mapsheets Kråkelund NV (7—8a) and Vimmerby NO (6—7j).

rock after removal of the melt. This process accounts of course for high temperatures and pressures and also for chemically suitable compositions which permit the formation of a melt. It is also a process that probably requires the presence of volatiles. In the Västervik area, it has been shown that metamorphic differentiation leading to two-component flecks took place without melting (Loberg 1963; Russell 1969). It would be close at hand to assume that veins developing from flecks also formed without melting. Through a fortunate find between Västervik and Gamleby I was able to prove that a veined gneiss, which at first sight could seem to represent bodily injected granitoid material in a metasediment, was instead the result of metamorphic differentiation in a solid rock without melting (Gavelin 1975). In this case, the chemical and mineralogical characteristics of the various parts of the rock are practically identical with those of the flecky gneisses.

These relationships prove that in the Västervik area granitoids belonging to the flecky gneisses and to the veined gneisses were frequently formed without melting. It could be argued that the examples given do not prove that melting



Fig. 81. Continuous band of pure quartzite in Judö granite. Shore of mainland SW of Borgö (eastern shore of big bay). Map-sheet Loftahammar SV (0a). Photo S. Gavelin.

never occurred within the rocks characterized as veined gneisses. On the other hand, nowhere has evidence of melting been found, while clear evidence for metamorphic differentiation without melting is available in some places.

In a tentative interpretation of the further stages of high-grade metamorphism, it is necessary to discuss the development of granitoid rocks from gneisses. One of the best examples where this phenomenon can be studied in the field is the mainland immediately south of the island Borgö (see Loberg 1963, plate 1). On approaching the granite shown on Loberg's map (called "Judö granite", here corresponding to the "Lucerna granite" of Svenonius), the gneiss becomes more

homogeneous. Close to the granite, we find a rock which in hand specimens of the gneiss would certainly be called granite by most people. In some cases one can discern weak remnants of sedimentary bedding. Along the shore the very contact between "gneiss" and "granite" is not exposed, although some 30 m landwards contacts are visible. Here, it is possible to define a fairly sharp contact between gneissic rocks and the more massive granite. This would mean that the more homogenized granite was mobile to the extent that it could behave "intrusively". On the other hand, there exist localities where absolutely continuous transitions can be followed from metasediments to a homogeneous granitoid. Such conditions exist for example at Lammholmen, described by Kresten (1971a).

In the section south of Borgö, there are additional features which are very significant for interpreting genetical relationships. Here, the Judö granite always contains abundant, small, lens-shaped xenoliths of metabasite. They are so widespread here that they must be taken to characterize the granite itself. There are also other xenoliths, sometimes of bedded, gray metasediments, but more frequently of pure quartzite. Such quartzites may form broken pieces; but they may also occur as narrow slabs, generally 0.5—2 m wide, Fig. 81. Such quartzite slabs can be traced for a distance of more than 200 m along the strike. How can such slabs persist during an intrusive phase when they are surrounded by normal granite for hundreds of metres? My interpretation is that the quartzite slabs represent resistant beds in an elsewhere completely granitized mass of feldspar-quartz-biotite-bearing metasediments. This interpretation is supported by the relations between quartzite and the feldspathic and micaceous metasediments which have been transformed to gneisses south-east of the granite. On Loberg's map (op. cit., pl. 1) we see that the southern part of Grönö is dominated by quartzite. In a section along the eastern shore of Grönö towards the north, the rocks consist of practically pure quartzite, sometimes with narrow inlayers of feldspathic and gneissic metasediments. Proceeding northwards, the latter increase in frequency. Soon, red-gray metasediments in gneissic form dominate. These always contain narrow beds of pure quartzite. The frequency of the quartzite beds is roughly the same as in the Judö granite. My explanation is that the Judö granites proper represent completely granitized parts of the red-gray metasediments and that the quartzites represent relict beds of the sedimentary sequence. It was mentioned before that the granite mass must have been mobilized to some extent. Such movements, however, may well have occurred within the mass although certain portions — the quartzite beds — retained their original positions.

The frequent occurrence of lens-shaped xenoliths of metabasites needs some explanation. It was mentioned before that the gneisses were affected by flow-folding during which metabasites were broken up to form xenoliths in the flowable mass. I have previously described a locality which is highly instructive for the present problem (S. Gavelin 1960, fig. 18) where there exists an association with



Fig. 82. Large lens-shaped block of undeformed metabasite surrounded by veined gneiss, which makes the impression of "flowing" around the metabasite. Lökholmen, central part of northern shore. Map-sheet Kråkelund NV (8a). Photo S. Gavelin.

abundant metabasite within more acid mobile gneisses. At several places, especially where gneissic material dominates, the metabasite has been broken up. With respect to shape and dimensions, these pieces are practically identical with those seen in the Judö granite (and several other small granite massifs of similar occurrence). These relationships suggest that the xenoliths in such granites are not the result of a brecciating granitic melt but were formed by irregular deformation in the gneisses due to contrasting folding competences.

The behaviour of larger masses of metabasite, however, may also lead to other patterns. Close to the localities mentioned above and closely associated with the east-westerly shear zone along the northern shore of Lökholmen, the gneisses contain large elongated blocks of metabasite which seem to be completely unaffected by mechanical deformation, at least in their inner parts. The plastic, acid gneiss mass seems to have flown around such resistant blocks which may attain a size of tens of metros across. Fig. 82 is an example of this kind of gneiss pattern.

Now, if the hypothesis of local granitization holds true, there should also be a clear relationship between the chemistry of the metasediments believed to have been transformed into granites and the granites themselves. This does not seem to be the case at first sight. A large number of diagrams have been made in

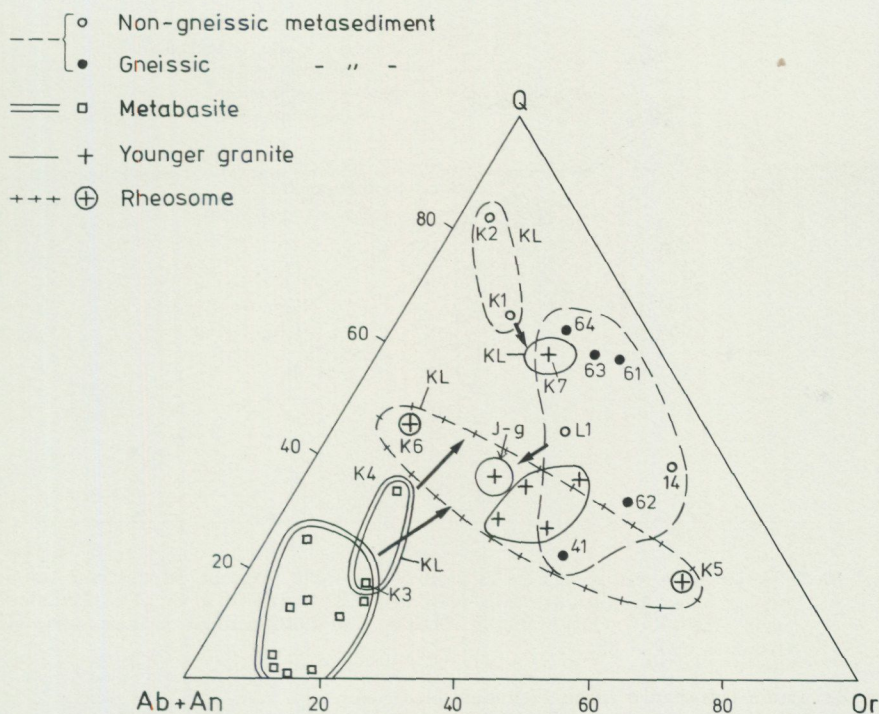


Fig. 83. Q:Or:(Ab+An) triangle intended to show the relations between metasediments, gneisses and granitoids within two restricted areas. 1. Mainland south of Borgö-Spårösund-Gränsö: analyses nos. 14, 41, 61—64 in Table 1; L represents "matrix" (Loberg 1963); J-g = Judö granite, no. 93 in Table 1. For comparison the other analyses from small massifs of younger granites are also plotted. 2. Lammholmen Island (Kresten 1971a): K1, K2 = metasediments; K3, K4 = metabasites; K5, K6 = rheosome; K7 = younger granite. Arrows indicate direction of transfer of material from metasediments as well as metabasites towards granitoid compositions (J9 and K7).

which various components of the chemical analyses are compared. For the present discussion, however, only two of them will be presented. These illustrate several significant features.

The metasediments are always very poor in Ca. The granites on the other hand differ somewhat in this respect. Fig. 83 shows the relationships as plotted in a Q-Or-(Ab+An) triangle. The Judö granite (analysis no. 93) and also the analyses of some granites which have a similar mode of occurrence (nos. 90, 91, 92) all show distinctly higher c values and therefore come closer to a "normal" granite. Fig. 84 shows the characteristics of the Niggli values c and alk in the same rocks.

The preceding discussion concerns areas where field relations clearly speak in favour of a continuous and direct transition from metasediment — in part in gneissic form — to homogeneous granitoids. The area south of Borgö (see Loberg

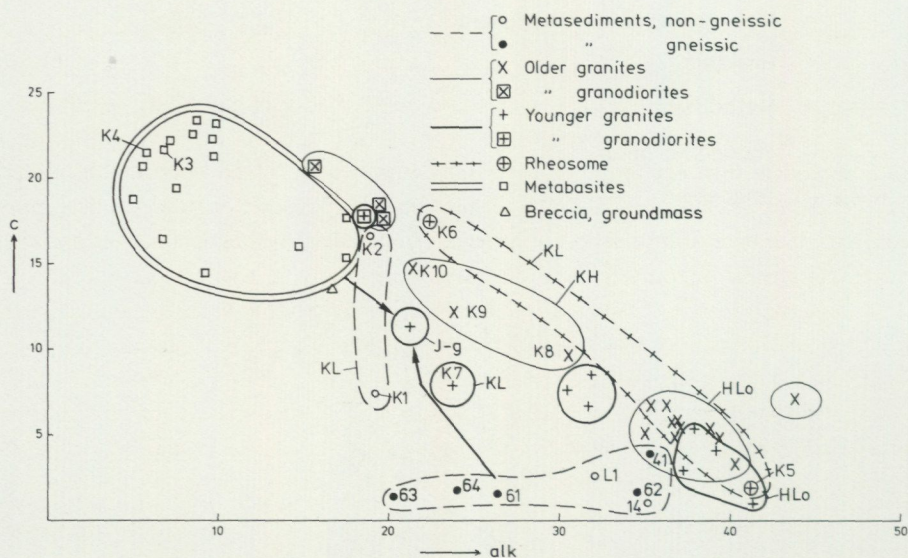


Fig. 84. The same analyses as in Fig. 83 plotted in a *c-alk* diagram. In this case the analyses of older granites are also presented (P. Kresten 1974): The Hamnö-Örö massif, K8—K10 (KH) and T. Hahn: The Loftahammar granite area, HLo. Arrows as in Fig. 83.

1963, plate 1) is one example. The analyses (nos. 14, 62—64 and L1) are from localities within a very restricted area and should represent the bulk composition for the homogenized metasediments leading to Judö granite (analysis no. 93 = J-g in Figs. 83 and 84). To the primary material can also be added analyses nos. 61 and 41 which represent localities somewhat more distant from the granite but which must be considered to represent varieties of the "granitized" metasediments.

It is seen from the diagram that the analyses mentioned cover a fairly wide area within the triangle. It is also evident, however, that the composition of the granite, J-g (= no. 93), differs significantly from the metasediments. It is displaced towards the Ab+An corner of the diagram. In other words, the granitoid is richer in plagioclase. One might argue that the position of analysis no. 93 in the triangle suggests a true magmatic origin of the granite, since this composition comes closer to an eutectic proportion between Q, Or and Ab+An. Therefore, field relations and chemical data seem to be controversial in this case.

However, one has to consider still another important factor. All the analyses of the metasediments and gneisses refer to the mobile, more acid portions of the heterogeneous rocks. As mentioned previously, the gneisses practically always contain plenty of metabasites. In Figs. 83 and 84 the fields of analysed metabasites have also been marked. If the metabasites during high-grade metamorphism had contributed to the composition of the homogenized granitoid one might ex-

pect compositions between the field of metasediment-gneiss and the metabasites. The position of J-g in the triangle could thus be explained in such a way. It was mentioned above that the Judö granite contains plenty of xenoliths which seem to have been only slightly affected by the granitoid. On the other hand, there is clear evidence that exchange of material actually took place between the metasediments and metabasites. Gavelin (1960) described several examples where pure quartzite has been intensely feldspathized by the metabasites in connection with strong kinematic metamorphism. In these cases, the feldspar is always plagioclase. The only source for such a feldspathization must have been the metabasites, which themselves show little sign of reaction zones. These examples refer to very local processes — perhaps a few centimetres — but they show that even the metabasites contributed to the exchange of elements during regional metamorphism. It seems therefore evident that in a large-scale homogenization leading to granitoid rocks the metabasites, too, must be taken into account.

The second locality where continuous transitions from metasediments—gneisses into granitoids have been recorded is Lammholmen (Kresten 1971a). Kresten reports two analyses of the preserved metasediments (K1 and K2, in the figures). Both refer to fairly quartzitic forms. From field experiences, we know that more feldspathic and micaceous types also occur within this area.

Granitoid K7 could therefore represent a fairly plausible average for the pre-existing sediments. However, in this case it is obvious that analysis K7 lies far from a theoretical eutectic proportion between Q-Or-(Ab+An). Kresten also describes a latest form of granitoid, which he calls "rheosome". Its geological occurrence shows that it is highly mobile. Kresten suggests that this was due to high contents of fluids. The rock is sometimes very K-rich. Kresten believes this form was a result of late K-metasomatism. Analyses K5 and K6 can be taken to represent this kind of rock, which, however, has a fairly small extension (Kresten 1971a, Abb. 2). The analyses projected in Fig. 83 show that "rheosome", in the sense of Kresten, may vary considerably with regard to composition. Analyses K3 and K4 represent metabasites which, in this area, mainly occur as magmatites. Their genetic importance in granite formation cannot be interpreted from the figure.

Fig. 84 shows the relationship between c and alk in the analyses in question. On the whole it gives the same impression as Fig. 83. Concerning the area south of Borgö, metasediment—gneiss analyses cover a well delimited field in the diagram. The various analyses differ mainly with respect to alk . The Judö granite (J-g) shows much higher c -values, but is even here situated between the metasediment-gneiss field and the metabasite field.

In the Figs. 83 and 84 four analyses of so-called younger granite are also included. All represent small massifs with geological developments similar to the Judö granite, but where direct transitions between granitoid and metasediment—

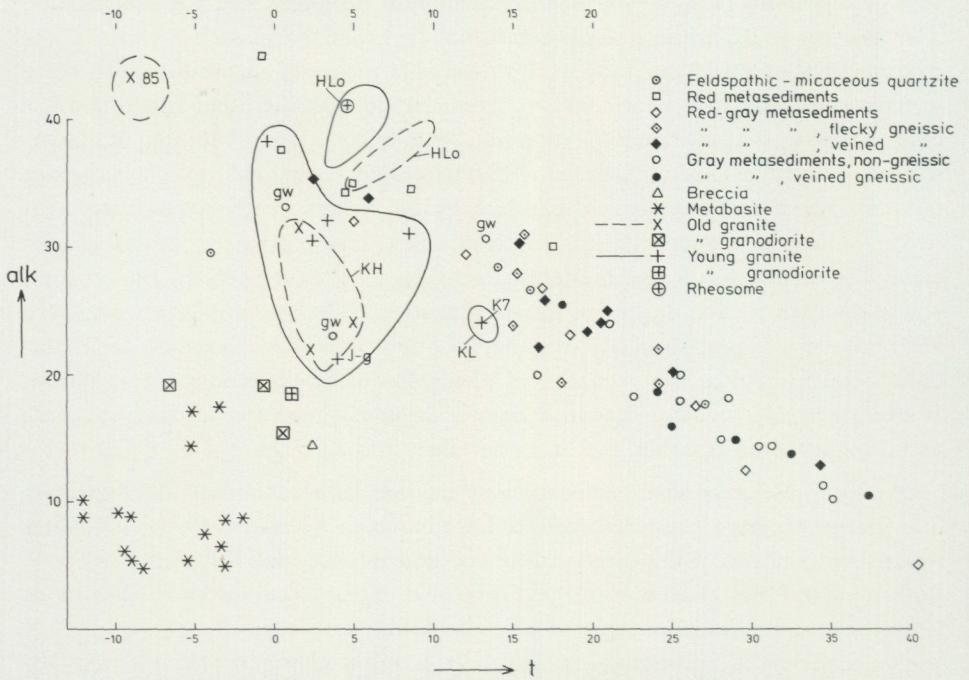


Fig. 85. Metasediments, gneisses, metabasites, granites and granodiorites plotted in an *alk-t* diagram. gw = graywacke types of the gray metasediments. Symbols as in Figs. 83, 84.

gneiss cannot be demonstrated in the field. Their position in the diagram indicates that they are somewhat more potassic and alkaline than the Judö granite.

Torbjörn Hahn has investigated the Loftahammar granite-metasediment areas to the north-east. He has presented 8 analyses of the Loftahammar granites and 3 analyses of younger granites from this area. They have also been plotted in Figs. 83 and 84; however, his analyses of the younger granites come very close to the analysis from the Judö granite, J-g. So does the average of the older granites. In Fig. 84 they cover a field which represents somewhat higher *alk* values than my examples. For comparison, available analyses of the older granites have also been plotted in Fig. 84. In this figure, the field covered by Hahn's eight analyses of Loftahammar granite is indicated. This field is almost identical with that of the younger granites from the Loftahammar area.

Kresten's (1974) analyses of the Hamnö granites are also presented. The values in the diagram represent averages of Kresten's three main granite types; the acid zonal type (K8), the intermediate type (K9), and the basic central type (K10). It is seen that, chemically, the Hamnö granites and the Loftahammar granites represent two somewhat different types. My own analyses included only one

example of older granite (no. 85). This analysis, however, represents a specific acid and regionally uncommon type.

In Figs. 83 and 84 only some gneisses situated close to the granites are presented. In the chapter on the chemistry of the metasediments some characteristic features of these rocks are described. It is seen that many of the non-quartzitic metasediments are characterized by "excess alumina". Niggli values express this by the factor t . Fig. 85 shows the relationship between t and alk in metasediments, gneisses, granites, and metabasites. We find a very regular distribution from high to low alk/t ratios in the diagram. It is characteristic that the metasediments representing the gray metasediments are mostly found in the low-ratio alk/t field (with the exception of analyses nos. 16 and 17, which represent the true graywackes — gw in the figure). Representatives of the red and red-gray metasediments are preferentially found in the higher alk/t ratio field. The last-mentioned group is the one which is transformed to flecky or veined gneisses and granitoids. This is not normally the case with the gray metasediments. My own analyses of the younger granites cover a wide field in the diagram. In the main, they are fairly closely associated with the fields of the red and the red-gray metasediments, but with a certain tendency towards the metabasite field (especially the analysis of Judö granite, J-g). The analyses of Hahn cover a somewhat different field. Kresten's granite from Lammholmen (no. K7) is fairly closely connected with the fields of the red-gray metasediments and gneisses.

Differences are also seen in the fields of older granites from the Hamnö granite (Kresten 1971a) and the Loftahammar granites (Hahn). On the whole, the fields of older and younger granites in the diagram cover each other fairly well.

In his summary of the geological evolution at Lammholmen, Kresten (1971a, p. 120) makes a statement, which must shock many petrologists dealing with high-grade metamorphism (translation from the German), "The formation of migmatite was completed, however, under fundamentally lower temperatures (than the highest P-T conditions, given as 650°C and 2 Kb), approximately corresponding to greenschist facies, and was followed by the supply of materials in hydrothermal solution". I have commented this question in the paragraph on the non-gneissic metamorphism (p. 119 ff), but I repeat that I agree with Kresten's general idea. In my opinion, temperature and pressure are not the deciding factors in the granitization process but rather H_2O , which we know may create new "facies" under constant P-T conditions. Local systems may form where water can circulate on a larger scale.

The presentation above is a survey of those field relationships which make the Västervik area so suitable for field demonstrations and discussions of the problems in question. What has been studied, however, are geological phenomena within an exposed section of the earth's crust. In all the cases which have been considered, the younger granites form small massifs. The large masses of

granite which delimit the metasediments or divide them into subareas deserve special consideration. A great deal of evidence indicates their intrusive behaviour towards the metasediments. Even Loftahammar granite is often found to contain xenoliths of quartzite and other metasediments. The xenoliths are often lens-shaped, although angular xenoliths have also been observed. What can be stated with certainty is that these large granite bodies (older or younger) have moved over large distances — probably mainly upward. But if one assumes that many of the smaller granites mentioned above were formed as a result of regional metamorphism without melting, it is obviously impossible from a scientific point of view to conclude that all the larger granites were formed in the same way. It has been pointed out before that metamorphic differentiation can create rock types which approach eutectic, granitic compositions and consequently must be apt to form melts under suitable P-T and F_{H_2O} conditions. At lower levels within the earth's crust granite melts might have formed. Due to their lower density they moved upwards. On the other hand, Ramberg (1970) states that mathematical treatment of results from model experiments shows that large domes or mushroom-shaped bodies of granite cannot have formed from melts rising from deep sections of the earth (see especially p. 285). The rising material must have had a much higher viscosity. He admits, however, that melts may form locally which give rise to narrow cross-cutting veins. The relationships described here indicate that the entire process is far more complicated than is generally stated in textbooks.

A final remark concerning the existence of xenoliths in the granite should be added. It has been stated before that many granitoid rocks which have been interpreted as products of granitization more or less *in situ* contain xenoliths. These xenoliths can be explained as resistant portions in a rock sequence which was exceptionally heterogeneous with respect to physical properties. Such xenoliths need not have been transported over considerable distances. However, rocks have also been found where such an explanation fails. One example is described here. The large island of Idö, 9 km south-east of Västervik, is mainly occupied by typical Loftahammar granite, with pronounced schistosity and typical feldspar phenocrysts. Along the western shore of the island, Loftahammar granite is cut by a set of veins of fine-grained pink granite or aplite, which is definitely massive and non-schistose. The aplite must therefore be characterized as postkinematic and classified as belonging to the suite of younger granites. These veins contain a great number of angular xenoliths of surprisingly different rocks: metabasites (coarse gabbroic as well as fine-grained massive forms of the normal dike type), quartzites and fine-banded and folded representatives of the "gray metasediments". The puzzling thing is that none of these xenolith rocks have been observed in the vicinity of Idö. In this area, the Loftahammar granite is always surrounded by flecky or veined red-gray gneisses. This means that the veins must have broken

through a fairly distant and heterogeneous rock region, included pieces from the same, and transported them a considerable distance. It has not been possible to determine the direction in which the vein material moved. It seems unlikely that the Loftahammar granite is underlain by fairly low-metamorphic sediments and metabasites, and that the dikes intruded sideways or were pressed downwards from an overlying younger granite. These observations are described here in order to emphasize that the geological patterns as they appear today have resulted from many factors, of which movements and kinematic metamorphism are especially worth consideration. Especially worth-while is the fact that the formation of local pressure gradients within the granitized primary rocks could be an important factor for the evolution (cf. p. 120).

6. GEOLOGY OF NEIGHBOURING AREAS

On the most recent geological map of Sweden (Magnusson *et al.* 1960) it is seen that the Västervik metasediments are bordered towards the south and west by granites, mainly belonging to the group which has been called younger granite or late- to postkinematic granite. These are called Småland granites in this part of the country. Within the granite areas there are narrow belts, coloured yellow, which represent volcanic rocks, the Småland porphyries. About 100 km WSW of the Västervik metasediments there is an additional area of metasediments which have been given the same symbol as the Västervik metasediments. These latter rocks have been called the "Vetlanda series".

Two recent investigations provide new information on these supracrustal rocks. Lars Persson (1973, 1974) examined an area of Småland porphyries situated 5—10 km south of Vimmerby, about 60 km WSW of Västervik. These volcanics are mainly acid and fairly low-metamorphic. Well-preserved primary structures show that many of them are ignimbrites. Folding is weak. In general, the formation has an almost horizontal position. On the basis of their structural behaviour, Persson characterized the volcanics as postorogenic. This interpretation fits in with a radiometric age determination by Åberg (1978) which gives an age of 1 680 ($1\ 645 \pm 20$) Ma. This age should be compared with the ages of granites seeming to be older than the volcanics: 1 730 ($1\ 649 \pm 64$) Ma, Åberg 1978, or 1 740 (1 705) Ma., Welin *et al.* 1966. However, if the errors in the ages given are also considered, the volcanic rocks and granites might be practically contemporaneous. Persson also found granites which intrude the porphyries and consequently must be definitely younger. Both granites were formerly included in the concept Småland granites. In recent years, several geologists have stated that the conventional concept of a single Småland granite actually includes granites of different ages, (see Persson 1974, p. 30, where recent literature on this question is quoted). It

was stated earlier in this paper, that among the younger granites, there are both late-orogenic and postorogenic forms which may explain the conditions related here. Within the map area presented in this paper, only the late-orogenic form has been identified with certainty. The volcanic area described by Persson is particularly interesting when compared to the area of acid volcanics situated about 20 km west of Västervik examined by Jonuks. There we find again acid porphyries, representing metarhyolitic rocks. On the regional maps they have been put under the heading Småland porphyries. At first sight, the dominating acid porphyries (metarhyolites) seem to be very similar to those described by Persson. As shown in the following text, there are, however, significant dissimilarities.

The western and southern volcanic rocks described by Persson have been much less affected by metamorphism and recrystallization than the Västervik porphyries. Normal Småland porphyries, as described by Persson and others, are clearly postkinematic, whereas the volcanics described here are prekinematic. These latter rocks are concordant with respect to the metasediments and have been metamorphosed to the same degree as the metasediments. It is quite clear that the volcanic rocks described by Jonuks in the Västervik area belong to a stage in the sedimentation and have nothing to do with the postorogenic volcanism described by Persson.

On the whole, the analyses of volcanics presented by Persson also seem to indicate a more acid volcanism than in the case of Jonuks. This is illustrated in diagram $si:t+fm$ (Fig. 51, p. 57), although this impression needs not to be significant since we do not know exactly the proportions between the analysed rocks in the field in the two cases. Between other characteristic chemical components, there seem to exist no significant differences.

The "Vetlanda series" has been discussed in a new investigation by Röshoff (1973), in an area situated around Lake Nömmen, about 100 km WSW of Västervik. Within this area, there are both volcanic rocks and epiclastic metasediments. The metasediments differ from those in the Västervik area proper by containing no pure quartzites. From Röshoff's description, one gets the impression that they could be related to the "graywacke suite" in the sense of Pettijohn.

Röshoff has presented two analyses of these metasediments. His samples were characterized as mica-quartzite and phyllite. If these metasediments are compared chemically with the gray metasediments of the Västervik rocks, they seem to represent something between the true graywackes and the potassic forms of these metasediments. In the diagrams $Q:AB+An:Or$, $si:t+fm$ and $t:fm$ (Figs. 24—25a, b, pp. 32, 33), Röshoff's analyses take an intermediate position between the potassic forms and the true graywackes from the Västervik area (see also the diagram on $si:t+fm$, Fig. 51, p. 57). The Nömmen metavolcanics are mainly basic. Pyroclastic forms seem to be dominant, although amygdaloidal lava is also mentioned. So far, we find good agreement with the basic volcanism in the south-

eastern part of the Västervik map area. The Nömmen metasediments contain intercalations of acid volcanic rocks. These could be taken to correspond to the acid porphyries in Jonuks' areas. In summary, the investigations of Persson and Röshoff show that there existed two separate stages of volcanic activity in south-eastern Sweden, a fact which has also been emphasized by the two authors in their common publication (Persson and Röshoff 1975).

Towards the north from the Västervik metasediments one finds on Magnusson's map (Magnusson *et al.* 1960) first an intercalation of older granites and basic leptites — the latter gneissic or intensely transected by pegmatites. Further north (around Lake Mälaren and near Stockholm and Eskilstuna etc.) the map shows metasedimentary gneisses, the so-called Sörmland gneisses.

In recent times our knowledge of areas in eastern Sweden, from Stockholm and southwards, has been greatly extended by a number of new publications: Stålhös 1969 (the Stockholm area), 1975 (map-sheet Nyköping NO), 1979 (map-sheet Nynäshamn NV/SV); Lundström 1974 (map-sheet Nyköping SV); Wikström 1975 (map-sheet Norrköping NO); Kornfält 1975 (map-sheet Norrköping NV). In all these works, we find the same main rock units.

1. Gneisses formed from argillitic and arenaceous metasedimentary rocks, frequently veined and containing one or several of the minerals garnet (almandite), cordierite, sillimanite, andalusite as characteristic constituents.

2. Quartz-feldspar-dominant gneisses, sometimes with limestone intercalations, which are considered to correspond to the limestone and iron ore-bearing leptite formation in Bergslagen further to the north-west and which has been interpreted as volcanic.

3. Older, synkinematic granites.

4. Younger late- and postkinematic granites and pegmatites.

In all these cases, the structural geology is characterized by two separate stages of folding, the last being combined with the formation of veined gneiss and younger granites. Stålhös (1976) has described some very illuminating examples of this two-fold tectonic evolution.

At the time when the geological map of Sweden by Magnusson *et al.* (1960) was published, eastern Sweden was believed to be represented by two separate orogenic cycles — the Svecofennian (or Svionian) in the north, and the Gothian in the south. In Magnusson's presentation, the boundary between these two units was taken to run just north of the belt of Loftahammar granite where the basic gneisses begin on Magnusson's map. These gneisses were believed to have originated from volcanics, not corresponding to the normal acid leptites, however, but to the basic ones. Magnusson interpreted the basic gneisses as high-metamorphic, basaltic and andesitic products, now appearing as amphibolites. Such gneisses, characterized by Wikström (1975) as metadacites and meta-andesites, occur on the southern part of the map-sheet Norrköping NO. Shortly after the publication of

the map by Magnusson *et al.* (1960), the model embracing Svecofennian and Gothian as two chronologically separate cycles had to be abandoned. Radiometric age determinations (Welin *et al.* 1966) as well as new geological investigations (Th. Lundqvist 1968) clearly showed that the Svecofennian and Gothian rocks cannot represent two, in time separate orogenic units. Th. Lundqvist (1979) has summarized the new concepts of the Precambrian of Sweden up to 1979. Returning to the Västervik area, the border zone between the former Gothian and Svecofennian rock units can be studied in a great number of fresh road cuts along highway E 66. The northernmost outcrop on the map is an amphibolite gneiss. These rocks would represent the southernmost Svecofennian gneisses according to the map of Magnusson. The veins in the gneiss consist of gray, pegmatitic or granitic material. Bedding is sometimes visible in the amphibolites. Analysis no. 47 shows that the rock here has a basaltic composition. It apparently represents a metabasaltic tuff. The amphibolitic gneiss contains slabs of somewhat gneissic metasediments apparently belonging to the red Västervik metasediments. The same metasediments occur to the south, frequently with numerous intercalations of metabasite. One gets the impression that within an area of a few kilometres there is a mixture of red metasediments and metabasites, with a continuously increasing proportion of metabasite towards the north. Consequently, we have here a mixture of "Svecofennian" and "Gothian" rocks according to the former definitions.

In order to study the border zone, the author studied highway exposures further to the north, up to a point 5 km NNW of Valdemarsvik, Fig. 86 (in part situated on the map-sheet Norrköping SO). North of the road-cuttings at the northernmost part of the present map follow dark porphyroblastic gneisses and then for about 10 km very pure amphibolite gneisses. The veins are often gray; but red microcline also occurs. Further to the north follow red-gray gneisses where the pegmatitic veins are rich in microcline. From my experience of the Västervik area, I would interpret them as being derived from metasediments of the red-grey type. For a distance of about 10 km along the road, metabasites are very rare or absent. In the northernmost outcrops metabasites occur again. The entire sequence is intensely folded with open symmetrical folds of varying dimensions. Through this folding one gets then impression that the main trend of the structures is roughly parallel to the highway. Fold axes consistently pitch towards the east with some variations and generally with a moderate plunge (see Fig. 86). This general trend seems to fit very well with the structures belonging to the second phase of deformation in the areas further to the north (Stålhös 1969, 1975, 1979; Wikström 1975; Lundström 1974).

The original nature of the acid gneisses is of course somewhat dubious. To a geologist who might follow the rock patterns from the low-metamorphic, leptitehällflinta areas in Bergslagen and southwards, it would be easy to interpret the

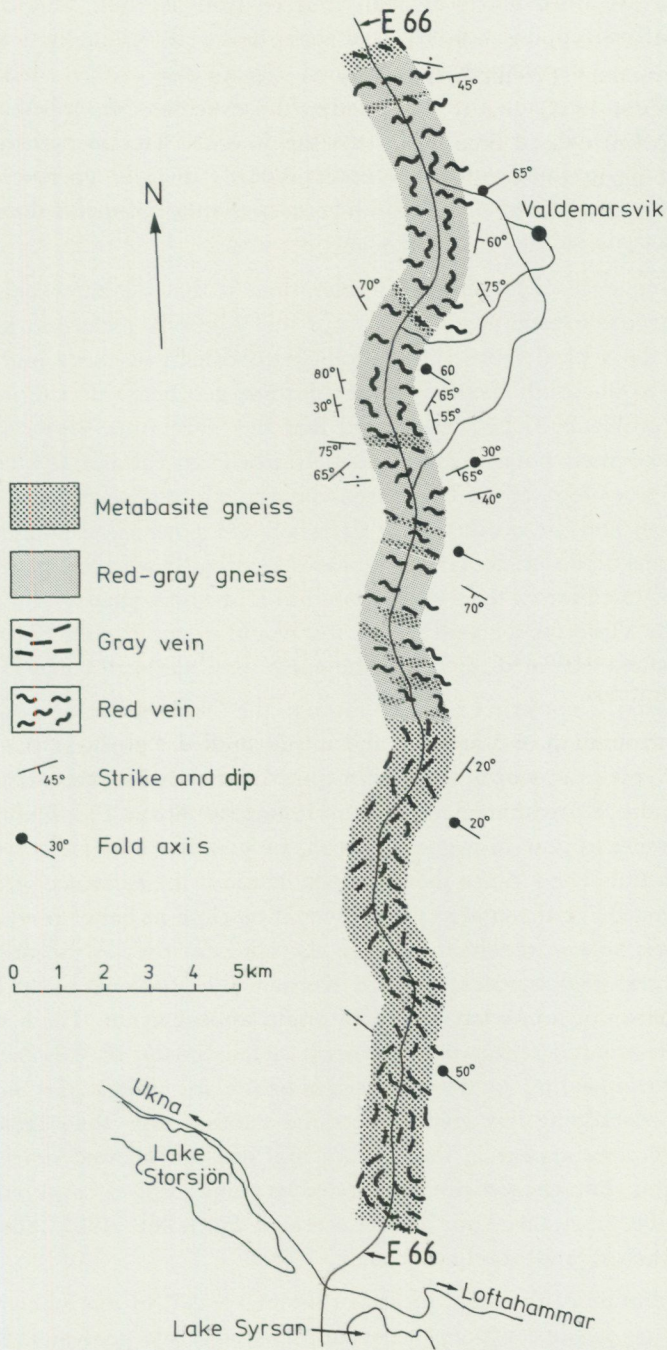


Fig. 86. Survey of rock types and structural features in road cuts along highway E 66, north of the map area. Map-sheets Västermik NO (8—9i) and Norrköping SO (0—1j).

acid gneisses discussed above as being derived from leptites. This, according to conventional conceptions, would mean that they were originally acid volcanics. For example, on the map-sheet Eskilstuna (Lundegårdh 1959) one finds rocks presented as leptite gneiss which are very similar to those described above along the highway E 66. If, on the other hand, the geologist were to approach the area from the south he would without difficulty identify the salic gneisses as high-metamorphic representatives of the red-gray, or, in places, red metasediments; consequently epiclastic sediments of the Västervik area.

The consequence of the above considerations is that we know neither exactly where the true epiclastic metasediments of the Västervik rocks end to the north, nor where the typical leptite formation (with calcareous beds and iron ores) wedges out to the south. Perhaps there are some geochemical criteria which can solve these problems. It has been stated that the feldspathic Västervik metasediments are extremely potassic and absolutely free from calcareous inlayers or minerals. The true "leptites" of Bergslagen contain calcareous beds as a characteristic constituent and are on the whole definitely not potassic, although potash-dominated forms do occur. So far, the gneisses mentioned seem more similar to the Västervik metasediments than to true leptites. If the acid gneisses discussed above belong to the Västervik metasediments, this would imply that the Västervik facies of sedimentation extended further to the north than has been believed previously.

If we now try to construct a profile through the Precambrian of eastern Sweden from the surrounding of Västervik and northwards, we begin in the south with identifiable epiclastic sediments, where pure quartzites are abundant. Towards the north, more feldspathic metasediments dominate. About 15 km north of Gamleby metabasites appear in a gneissic form. Originally, these rocks were basaltic tuffs and possibly lavas. Since these gneisses manifest the existence of a basic volcanism during the sedimentary cycle, it would be close at hand to compare them with the basic volcanites which occur in the southern part of the map area and which were classified as generation I by Kresten (1972). North of the basic gneisses, acid gneisses of somewhat uncertain origin appear again. These rocks might belong to the arenitic, feldspathic Västervik metasediments or they may represent volcanics corresponding to the Bergslagen leptite formation. Just north of the Slätbaken-Söderköping bay gneisses of quite another type than those found in the Västervik area appear in the bedrock and can be followed northwards past Lake Mälaren. The gneisses are interpreted as being derived from sediments belonging to the graywacke suite in the sense of Pettijohn (1957). Both arenites (true graywackes) and argillites occur.

The distribution of the main rocks can be interpreted in the following way. In the north a geosyncline was formed where characteristic geosynclinal sediments accumulated. In the south, sediments were deposited under shallow water conditions on the border zone of the geosyncline proper. In both areas, volcanic activity

took place, mainly as basic magmatism. This activity was most intense along the border zone between the two sedimentary environments, thus giving rise to large masses of basaltic rocks.

7. SVECOFENNIAN EVOLUTION IN SOUTH-EASTERN AND CENTRAL SWEDEN

It has been stated that the Västervik metasediments are in general shallow water, in part shore-line, sediments. Very thick beds of the same facies — for example lithostratigraphic units 3 and 3a — indicate that they were deposited during a subsidence, the rate of which was approximately equal to the rate of accumulation of sediments. The fact that geosynclinal facies sediments belonging to the same evolutionary cycle are found to the north and perhaps towards the west indicates that the continents at the time of sedimentation were probably situated to the south and possibly to the east of the present areas of Västervik metasediments. If they were contemporaneous with the deeper water formations in the north — which of course need not necessarily be absolutely true — the Västervik area would represent an area of subsidence at the very border of the main Svecofennian geosyncline. Within this area, minor and more local vertical movements certainly took place which could account for the results of Russell (1967) where, in a limited area, a transport direction of sedimentary matter from north-west to south-east was indicated. Conglomerates are generally missing within the sedimentary column, although one locality in the southern archipelago contains an intraformational conglomerate with pebbles of underlying metasediments. Scattered pebbles of the same kind have also been found in approximately the same stratigraphic position at other localities. It is interesting to note that this conglomeratic development appears in the same lithostratigraphic position as the first metabasites, which represent volcanic activity during the sedimentation.

On pp. 91—92, a comparison is made between the delta facies of the Västervik area and the Mississippi delta. It is interesting that the interpretation of the position of the Västervik sediments as being formed on a sinking platform representing a border zone of a major syncline to the north gives further analogies with the Mississippi delta. The Gulf of Mexico is interpreted as an active, present-day geosyncline. The sediments of the Mississippi delta are accumulating on the slowly sinking northern border of this geosyncline.

The initial, basic volcanism in the Västervik metasediments indicates the opening of feeder channels downwards. It is very likely that this tectonic period also was connected with vertical block movements which brought certain parts of the sediments already deposited above water level. The proceeding sedimentation seems to be characterized, both in the southern and in the western part of the

area, by mostly feldspathic and micaceous arenites. The purest (most mature) arenites are found in the lithostratigraphic units which have here been called 3 and 3a. Before the initiation of more intense folding, the sedimentary sequence was intruded by abyssal or hypabyssal basites, designated as generation II by Kresten (1972). If one compares the analyses of these metabasites with those of generation I (Figs. 36 and 37, pp. 44, 45) we find that generation I represents tholeiitic magmas whereas generation II is decidedly calc-alkaline. It is therefore possible that this early magmatism reflects an increasing assimilation of sialic matter in the primary magma, as suggested by Barth (1962, p. 174).

There also occurs an area of acid volcanics 20 km west of Västervik. Its position suggests that these rocks are approximately contemporaneous with the metabasites of generation I. This latter volcanic suite comprises a sequence of volcanics which are basic to acid in composition (cf. p. 51). It is possible that they represent a suite of normal magmatic differentiation. If we take into consideration the wide-spread volcanism in the north, even the proportions between acid and basic products could support such a hypothesis.

It is of course impossible to correlate in detail the geological events within the geosynclinal areas with those north and north-west of the Västervik area, areas where rocks considered to represent acid to intermediate volcanics (leptites) dominate.

The fact that the leptite formation, to the north, contains sedimentary iron ores and limestones — sometimes with stromatolites — suggests that there, too, marine conditions were realized — at least intermittently. Where true epiclastic metasediments occur in these areas they have generally been found to overlie the leptites. Recent investigations in the archipelago east of Stockholm (S. Gavelin *et al.* 1976) have shown that there also exist epiclastic metasediments which underlie the leptite formation, which here is fairly thin. In that paper are also summarized the stratigraphic columns of the Fennoscandian rocks from Central Sweden to south-western and central Finland, showing the changes of facies development from east to west in the Central Svecofennides. The existence of sub-leptite epiclastic metasediments in gneissic form within the easternmost part of central Sweden have also been mentioned by Stålhös (1975, 1979). Possibly, there existed a land mass continent in the north, an area characterized by volcanism and at intervals invaded by the sea. A deep geosyncline developed in the south with geosynclinal sediments and intermittent basic magmatism.

At the southern border of the geosyncline proper, there existed a slowly sinking platform characterized by shallow-water sediments — the Västervik area — where the metasediments of the area mapped here were deposited. Folding started in the north with E—W fold axes. In the Västervik area fold axes were NW—SE. During early phases of this folding the granites of the older group were emplaced. Basic magmatism giving rise to generation III occurred, although its age relation

to the older granites is somewhat obscure. This basic magmatism seems to have been fairly restricted. The first phase of folding also affected the older granites and seems to have been followed by a period of non-folding but with tensional stress over wide areas. This stress gave rise to tensional fractures, both in the folded metasediments and in the older granites. Such fractures must have formed feeder channels downwards which enabled basaltic tholeiitic magmas to intrude, generation IV according to Kresten (1971b). These metabasites are widely spread over the whole mapped area.

The position of the metabasites belonging to generation VI is uncertain. They have been defined with certainty only within the southern area examined by Kresten (1971b). The geological evolution after the formation of the basites (generation IV) was characterized by down-warping of the entire rock mass, both in the south and north, and by metamorphism under increased temperature and pressure along with accompanying kinematic deformations. These latter brought about vast deformation of pre-existing structures (fold axes, axial planes, etc.). An example of this deformation can be seen in the big bends of the main rock structures in the gneisses south of Stockholm and some of the distortions of primary axial planes, etc. in the southern archipelago of the Västervik area. During this phase of deformation significant metamorphic differentiation took place. Veined gneisses and *in situ*-granitoids were formed. In addition, this process apparently led to the formation of granitoidal melts which may have intruded the older rocks as post-orogenic granites or acid volcanics (Småland porphyries; Persson 1973, 1974), in the outer borders of the metamorphic zones described above. The position of the Götömar granite massif and its structural behaviour suggests that it might represent such a postorogenic granite belonging to the Svecofennian cycle. However, radiometric age determinations by Åberg (1978) indicate ages 300 Ma lower than the acid volcanics described by Persson. If these ages are correct, it seems unlikely that the Götömar granite formed as a result of the Svecofennian orogenesis. It is very interesting to note that basic magma also intruded after the culmination of metamorphism and granitization. Generation VI, according to Kresten, escaped more intense metamorphism. Especially hydrous metamorphism was of minor importance, as evidenced by the fact that the rocks contain such minerals as olivine and titan-augite. It must be admitted, however, that generation VI has been identified with certainty only in the southern part of Kresten's area.

The characteristic feature of generation VII was defined by the fact that these basites transect granites which are classified as belonging to the younger granites — the Småland granites. Now it was stated before that there must exist several age groups within the granites which have been summarized as Småland granites. The granite which was found to be penetrated by a dike, called generation VII, probably belongs to the earliest forms of the younger granites, those

which are most closely connected to the gneiss-forming processes and granitization. Dikes, exactly like those classified as generation VII by Kresten within his area, have also been found sporadically in the northern archipelagos. The occurrence of femic dikes after the culmination of metamorphism and plastic deformation shows that the crust below the sedimentary cover also during this stage could open up and allow magmas to move upwards.

In summary the geological evolution in the Västervik area can be characterized by several steps. In chronological order, these include: sedimentation — gentle folding — emplacement of older granites and first steps of progressive regional metamorphism — continued folding and increasing metamorphism — second phase of folding, shear-folding, metamorphic differentiation, formation of veined and flecked gneisses, granitization — emplacement of late-kinematic granitoids — emplacement of postkinematic granites. The appearance of basic magma at intervals during the course of most of this evolution means that intermittently channelways were opened from the deeper levels within the crust. During the earlier stages of the magmatic activity, acid and intermediate volcanics were formed. These might be related to the first generation of metabasites and represent a magmatic differentiation product. More pronounced and wide-spread volcanic activity took place during the post-orogenic stages to the west and to the south of the sedimentary areas proper. The volcanics, in turn, are intruded by postkinematic granites. Many authors, however, believe that the granites emanated from the same magmatic source as do the acid volcanics. Persson (1973) believed these magmas to be anatectic — an explanation which is frequently adopted for ignimbrites. Another part of the Svecofennian orogenic belt, the Los-Dalarna area, shows very similar conditions. The vast sub-Jotnian volcanic area forms a border zone to the orogenic rocks in the east. Part of this area has been examined by Lundqvist (1968) who points out that a similar appearance of post-orogenic anatectic magmas can be established in similar geological environments in several other parts of the world. Their presence is then considered to be a general consequence of orogenic evolution (for references see Lundqvist 1968). Lundqvist has also discussed the possibility that similar conditions were present in both the Los-Dalarna area and the Västervik-Småland area. The present investigations and the radiometric age determinations seem to confirm the analogies proposed.

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 SGU = Sveriges geologiska undersökning

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TABLE 1. Chemical analyses and Niggli values of various rocks of the Västervik area.

Analysis no.	1	2	3	4	5	6	7	8	9
Weight %									
SiO ₂	97.5	97.1	94.8	93.9	89.6	89.0	86.6	82.6	82.0
TiO ₂	0.02	0.12	0.14	0.24	0.92	0.21	0.35	0.25	0.48
Al ₂ O ₃	0.8	1.1	2.0	2.7	3.0	5.7	6.4	8.4	9.3
Fe ₂ O ₃	0.20	0.20	0.20	0.34	1.90	0.42	1.60	1.40	1.20
FeO	0.20	0.40	0.40	0.70	0.40	0.80	0.50	1.30	1.20
MnO	0.01	0.01	0.01	0.02	0.10	0.02	0.01	0.03	0.04
MgO	0.05	0.10	0.31	0.73	0.65	1.56	0.30	0.66	0.56
CaO	0.10	0.20	0.10	0.10	0.20	0.15	0.10	0.30	0.30
Na ₂ O	0.10	0.20	0.20	0.43	0.10	0.33	0.10	0.50	1.30
K ₂ O	0.50	0.30	0.80	0.67	1.20	1.60	3.10	2.10	3.40
H ₂ O	0.50	0.20	0.40	—	0.90	—	1.00	1.30	0.60
Sum	100.0	99.9	99.4	99.8	99.0	99.8	100.1	98.8	100.4
Niggli values									
<i>al</i>	33.69	34.22	39.96	35.41	30.78	41.00	46.84	48.07	45.52
<i>fm</i>	28.64	33.92	32.34	43.32	49.85	40.61	25.81	30.59	23.05
<i>c</i>	7.93	11.51	3.76	2.47	4.34	2.00	1.57	3.61	2.93
<i>alk</i>	29.72	20.33	23.87	18.79	15.01	16.36	25.76	17.71	28.48
<i>si</i>	6969	5126	3214	2090	1560	1087	1076	802	681
<i>k</i>	0.76	0.49	0.72	0.50	0.88	0.76	0.95	0.73	0.63
<i>mg</i>	0.18	0.23	0.48	0.55	0.35	0.69	0.21	0.31	0.30
<i>t</i>	— 3.96	2.36	12.32	14.15	11.42	22.63	19.50	26.74	14.11
Analysis no.	10	11	12	13	14	15	16	17	18
Weight %									
SiO ₂	92.0	84.2	80.3	77.7	73.3	72.9	67.2	63.2	63.9
TiO ₂	0.25	0.16	0.64	0.51	0.37	0.16	0.61	0.78	0.76
Al ₂ O ₃	4.0	7.4	10.0	10.9	12.0	13.5	16.4	21.6	17.2
Fe ₂ O ₃	0.50	0.10	1.10	0.50	2.00	0.40	0.50	0.30	0.80
FeO	0.40	0.30	0.90	0.90	1.60	1.00	0.80	1.70	4.80
MnO	0.01	0.01	0.01	0.03	0.02	0.04	0.02	0.02	0.05
MgO	0.12	0.13	0.60	0.62	0.58	0.52	3.60	1.40	2.50
CaO	0.10	0.20	0.10	0.60	0.10	0.90	1.00	1.10	2.60
Na ₂ O	0.20	1.10	0.80	2.30	0.80	3.00	7.90	7.00	3.70
K ₂ O	2.50	4.90	4.50	5.20	8.10	4.90	1.30	2.00	2.40
H ₂ O	0.30	0.20	1.30	0.60	0.40	0.60	0.60	—	1.10
Sum	100.4	98.7	100.3	99.9	99.3	97.9	99.9	99.1	99.8
Niggli values									
<i>al</i>	45.58	46.67	48.44	43.60	41.83	45.99	37.66	48.06	38.32
<i>fm</i>	17.36	5.65	20.41	14.11	22.03	13.42	25.05	16.97	31.70
<i>c</i>	2.45	2.79	1.17	4.63	0.98	5.68	4.19	4.50	10.60
<i>alk</i>	34.58	44.86	29.97	37.65	35.15	34.88	33.04	30.44	19.35
<i>si</i>	1779	901	660	527	434	421	262	239	242
<i>k</i>	0.89	0.74	0.78	0.59	0.86	0.51	0.09	0.15	0.29
<i>mg</i>	0.19	0.36	0.36	0.44	0.23	0.33	0.83	0.62	0.44
<i>t</i>	8.54	—0.98	7.30	1.32	5.70	5.42	0.39	13.11	8.36

Analysis no.	19	20	21	22	23	24	25	26	27
Weight %									
SiO ₂	66.1	72.7	64.9	82.6	78.7	69.2	64.5	66.4	66.2
TiO ₂	0.64	0.48	0.70	0.28	0.64	0.68	0.92	0.81	0.80
Al ₂ O ₃	18.3	14.4	17.3	8.8	10.9	16.4	18.7	19.0	19.1
Fe ₂ O ₃	1.20	0.80	1.32	0.90	2.10	4.40	3.50	1.00	1.10
FeO	4.30	3.80	5.00	1.60	2.00	4.30	6.90	1.60	1.60
MnO	0.08	0.05	0.06	0.01	0.02	0.02	0.02	0.03	0.02
MgO	2.10	1.80	2.25	0.93	1.40	0.70	0.83	4.90	4.90
CaO	0.40	0.30	0.44	0.40	0.20	0.20	0.20	0.20	0.20
Na ₂ O	1.50	1.10	0.55	0.70	0.40	0.30	0.20	0.40	0.40
K ₂ O	3.80	3.60	4.45	2.20	2.70	3.80	3.10	3.60	3.80
H ₂ O	1.50	1.00	—	—	—	—	—	—	—
Sum	99.9	100.0	97.0	98.4	99.1	100.0	98.9	97.9	98.1

Niggli values									
<i>al</i>	47.26	45.37	45.02	46.64	45.52	46.99	47.77	47.60	47.34
<i>fm</i>	33.73	34.78	37.88	30.67	37.96	38.74	41.86	40.04	39.89
<i>c</i>	1.99	1.86	2.20	3.96	1.54	1.06	0.94	0.94	0.93
<i>alk</i>	16.99	17.97	14.88	18.72	14.95	13.20	9.41	11.41	11.82
<i>si</i>	290	389	287	743	558	337	280	282	278
<i>k</i>	0.62	0.68	0.84	0.67	0.81	0.89	0.91	0.85	0.86
<i>mg</i>	0.40	0.41	0.34	0.40	0.38	0.13	0.12	0.77	0.76
<i>t</i>	28.27	25.52	27.92	23.95	29.02	32.73	37.41	35.24	34.58

Analysis no.	28	29	30	31	32	33	34	35	36
Weight %									
SiO ₂	68.1	56.0	64.1	60.8	56.2	69.0	73.7	83.4	83.0
TiO ₂	0.67	0.79	0.74	0.69	0.96	0.65	0.47	0.42	0.25
Al ₂ O ₃	17.0	22.0	19.6	22.0	23.3	14.0	12.4	7.6	7.4
Fe ₂ O ₃	1.70	3.70	1.20	0.90	0.30	3.20	0.90	0.60	1.20
FeO	1.00	3.60	5.10	1.80	1.50	1.60	2.60	1.40	1.20
MnO	0.03	0.08	0.05	0.03	0.05	0.04	0.03	0.01	0.04
MgO	4.30	2.20	2.80	4.20	7.90	1.30	1.30	0.70	0.47
CaO	0.20	0.20	0.20	0.30	0.40	0.70	0.10	0.10	0.10
Na ₂ O	0.40	1.40	0.30	1.30	2.90	0.10	0.10	0.30	0.60
K ₂ O	4.30	6.70	5.10	4.90	3.80	5.10	5.70	3.60	3.80
H ₂ O	2.30	3.50	1.50	2.90	1.50	2.60	1.50	1.00	0.40
Sum	100.0	100.2	100.7	99.8	98.8	98.3	98.8	99.1	98.5

Niggli values									
<i>al</i>	45.69	46.32	46.75	49.52	41.96	45.61	45.67	45.33	42.98
<i>fm</i>	38.99	32.66	37.98	32.35	40.64	31.61	30.09	27.07	26.03
<i>c</i>	1.03	0.89	0.91	1.36	0.38	4.25	0.89	1.40	1.36
<i>alk</i>	14.27	20.11	14.34	16.79	16.00	18.52	23.33	26.18	24.62
<i>si</i>	311	200	259	232	172	381	461	844	818
<i>k</i>	0.87	0.75	0.91	0.71	0.46	0.97	0.97	0.88	0.80
<i>mg</i>	0.74	0.35	0.44	0.73	0.88	0.33	0.40	0.39	0.26
<i>t</i>	30.38	25.31	31.49	31.41	24.58	22.83	21.45	17.74	11.99

Analysis no.	37	38	39	40	41	42	43	44	45
Weight %									
SiO ₂	82.8	79.2	78.6	65.7	69.0	71.4	49.6	46.1	47.9
TiO ₂	0.27	0.34	0.50	0.52	0.46	0.78	2.90	3.60	3.00
Al ₂ O ₃	9.7	11.3	11.1	17.1	15.1	11.8	14.2	15.0	14.4
Fe ₂ O ₃	1.00	0.10	0.90	0.60	0.70	1.10	5.50	7.98	7.60
FeO	1.00	2.40	1.30	1.00	1.30	3.40	8.90	8.80	8.10
MnO	0.01	0.05	0.02	0.03	0.02	0.08	0.25	0.17	0.27
MgO	2.90	2.90	2.00	4.20	1.40	2.60	5.50	6.20	6.30
CaO	0.10	0.20	0.30	0.70	0.70	2.70	7.00	5.50	7.90
Na ₂ O	0.10	0.60	0.60	3.60	3.30	2.30	2.40	3.20	1.70
K ₂ O	0.80	2.10	3.00	2.90	6.60	2.00	0.90	1.10	1.00
H ₂ O	1.00	—	0.90	1.80	0.70	1.50	2.00	2.50	1.80
Sum	99.7	99.2	99.2	98.2	99.3	99.7	99.2	100.2	100.0

Niggli values									
<i>al</i>	46.25	43.66	46.27	42.42	42.72	33.14	21.57	21.43	20.50
<i>fm</i>	47.90	42.27	33.69	31.88	17.85	36.29	51.55	55.01	53.44
<i>c</i>	0.93	1.45	2.38	3.20	3.84	13.84	19.39	14.33	20.52
<i>alk</i>	4.91	12.59	17.65	22.48	35.57	16.70	7.47	9.22	5.52
<i>si</i>	670	519	556	277	331	340	128	112	116
<i>k</i>	0.84	0.69	0.76	0.34	0.56	0.36	0.19	0.18	0.27
<i>mg</i>	0.73	0.67	0.62	0.82	0.56	0.50	0.41	0.40	0.42
<i>t</i>	40.41	29.61	26.93	16.73	3.30	2.59	-5.29	-2.12	-5.53

Analysis no.	46	47	48	49	50	51	52	53	54
Weight %									
SiO ₂	49.4	49.2	48.4	53.7	49.5	52.5	48.5	50.8	57.1
TiO ₂	3.00	0.80	1.70	1.25	3.10	2.00	2.40	1.80	1.09
Al ₂ O ₃	13.6	15.7	19.2	17.1	13.6	14.6	14.0	15.4	16.0
Fe ₂ O ₃	8.60	1.90	3.20	2.99	5.00	3.40	8.00	3.60	2.77
FeO	6.60	7.30	7.40	4.70	9.60	8.30	5.30	7.10	4.50
MnO	0.24	0.18	0.17	0.11	0.21	0.21	0.18	0.19	0.10
MgO	6.60	7.60	4.50	4.29	5.10	4.60	6.50	6.40	3.59
CaO	6.80	9.10	8.60	4.69	8.00	7.60	8.70	7.90	5.22
Na ₂ O	1.70	3.40	2.60	3.78	2.00	2.10	2.40	2.80	4.02
K ₂ O	0.50	1.40	1.40	3.45	1.20	1.20	1.90	1.80	2.45
H ₂ O	2.20	2.00	2.10	—	1.30	1.60	—	—	—
Sum	99.2	98.6	99.3	96.1	98.6	98.1	97.9	97.8	96.8

Niggli values									
<i>al</i>	20.38	21.91	28.70	29.86	20.61	23.33	19.91	22.81	29.63
<i>fm</i>	56.05	45.04	39.19	37.54	50.33	44.83	48.98	46.13	35.46
<i>c</i>	18.55	23.11	23.43	15.20	22.10	22.15	22.55	21.33	17.74
<i>alk</i>	5.00	9.92	8.66	17.38	6.95	9.47	8.54	9.71	17.15
<i>si</i>	126	117	123	159	127	142	117	128	179
<i>k</i>	0.16	0.21	0.26	0.37	0.28	0.37	0.34	0.29	0.28
<i>mg</i>	0.44	0.59	0.43	0.50	0.38	0.41	0.47	0.51	0.47
<i>t</i>	-3.17	-11.12	-3.39	-2.72	-8.44	-8.50	-11.18	-8.22	-5.27

Analysis no.	55	56	57	58	59	60	61	62	63
Weight %									
SiO ₂	46.3	50.1	66.8	58.5	62.7	46.9	75.7	72.2	72.2
TiO ₂	1.30	3.00	0.47	1.50	0.72	3.90	0.56	0.63	0.53
Al ₂ O ₃	15.1	12.2	14.5	13.2	15.7	16.1	11.8	13.2	13.8
Fe ₂ O ₃	3.20	9.60	1.20	2.60	3.30	12.00	1.10	1.60	0.70
FeO	8.10	7.70	3.70	7.90	4.10	5.70	2.70	1.70	3.00
MnO	0.20	0.34	0.07	0.11	0.05	0.18	0.02	0.02	0.01
MgO	11.10	3.80	2.80	3.40	2.60	2.10	1.20	0.83	1.70
CaO	6.90	5.40	2.40	4.60	1.00	5.50	0.10	0.20	0.20
Na ₂ O	2.10	2.30	3.30	2.00	2.50	1.60	0.50	1.90	1.00
K ₂ O	1.70	2.90	2.70	4.10	3.30	3.20	5.10	6.90	4.00
H ₂ O	2.20	0.90	1.40	1.00	2.90	2.00	1.30	0.20	1.70
Sum	98.2	98.2	99.3	98.9	98.9	99.2	100.1	99.4	98.8
Niggli values									
<i>al</i>	19.63	19.59	35.18	56.61	37.43	26.28	44.22	42.81	46.57
<i>fm</i>	57.13	53.45	33.88	44.24	39.76	47.31	31.10	21.35	31.94
<i>c</i>	16.35	15.83	10.66	15.99	4.47	16.45	0.90	1.45	1.31
<i>alk</i>	6.88	11.11	20.26	14.68	18.32	9.95	23.76	34.36	20.16
<i>si</i>	102	137	275	189	254	130	481	397	413
<i>k</i>	0.34	0.45	0.34	0.57	0.46	0.56	0.87	0.70	0.72
<i>mg</i>	0.63	0.28	0.50	0.36	0.39	0.18	0.36	0.31	0.45
<i>t</i>	-3.60	-7.35	4.25	-5.59	14.63	-0.12	19.54	6.99	25.09
Analysis no.	64	65	66	67	68	69	70	71	72
Weight %									
SiO ₂	77.5	69.6	70.3	87.4	71.4	76.6	80.3	62.2	67.3
TiO ₂	0.38	0.65	0.57	0.22	0.60	0.22	0.34	0.88	0.74
Al ₂ O ₃	11.2	15.5	14.4	6.0	14.5	11.1	8.9	20.1	16.7
Fe ₂ O ₃	1.20	1.50	1.00	1.00	2.20	1.40	0.70	2.80	2.30
FeO	1.70	3.40	3.30	1.30	2.00	0.80	1.50	5.50	3.20
MnO	0.02	0.03	0.03	0.02	0.12	0.01	0.01	0.04	0.04
MgO	1.00	1.80	1.40	0.32	1.50	0.60	0.80	1.40	1.50
CaO	0.20	1.10	0.30	0.30	0.10	0.10	0.10	0.30	0.20
Na ₂ O	1.30	2.40	1.50	0.90	0.30	0.50	0.40	1.10	2.20
K ₂ O	3.30	2.80	4.90	1.70	5.80	5.80	4.60	3.40	4.80
H ₂ O	1.00	1.10	1.10	0.50	1.20	1.30	0.90	1.90	0.80
Sum	98.8	99.9	98.8	99.7	99.7	98.4	98.6	99.6	99.8
Niggli values									
<i>al</i>	46.99	43.21	44.53	43.29	46.77	48.42	44.86	48.85	44.84
<i>fm</i>	27.28	31.30	24.51	28.51	30.55	19.43	25.50	36.40	30.42
<i>c</i>	1.74	5.72	1.91	4.17	0.82	1.17	1.21	1.39	1.06
<i>alk</i>	23.96	19.45	24.04	23.95	21.84	30.97	28.41	13.34	23.66
<i>si</i>	552	329	369	1070	391	567	687	257	307
<i>k</i>	0.62	0.43	0.68	0.55	0.92	0.88	0.88	0.67	0.58
<i>mg</i>	0.38	0.40	0.37	0.20	0.40	0.34	0.39	0.23	0.33
<i>t</i>	21.28	18.03	18.58	15.15	24.11	16.27	15.23	34.12	20.10

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Analysis no.	73	74	75	76	77	78	79	80	81
Weight %									
SiO ₂	84.6	75.5	57.1	65.6	76.1	76.0	75.8	75.7	74.7
TiO ₂	0.08	0.55	0.88	0.63	0.22	0.20	0.07	0.23	0.20
Al ₂ O ₃	8.0	11.9	20.7	18.6	12.5	12.9	13.7	13.0	12.6
Fe ₂ O ₃	0.70	0.70	0.80	0.80	0.10	0.10	0.10	0.10	0.70
FeO	0.90	2.60	0.50	1.10	1.30	0.60	0.30	0.80	1.60
MnO	0.02	0.03	0.02	0.02	0.02	0.01	0.02	0.02	0.03
MgO	0.41	1.00	7.40	3.30	0.42	0.31	0.16	0.50	0.36
CaO	0.10	0.20	0.70	0.40	0.70	0.40	0.60	0.70	0.70
Na ₂ O	0.80	1.00	7.00	4.70	2.40	2.70	2.70	2.60	2.20
K ₂ O	3.50	4.90	2.70	2.60	4.90	5.50	5.30	5.00	5.60
H ₂ O	0.60	0.90	1.70	1.10	0.70	0.50	0.40	0.70	0.20
Sum	99.7	99.3	99.5	98.9	99.4	99.2	99.2	99.4	98.9

Niggli values									
<i>al</i>	48.26	45.02	36.37	45.50	47.82	49.91	52.71	48.91	45.49
<i>fm</i>	19.52	27.07	35.98	26.80	11.72	6.87	3.79	9.61	14.86
<i>c</i>	1.41	1.60	2.26	1.89	5.04	2.99	4.32	5.01	4.64
<i>alk</i>	30.79	26.24	25.37	25.79	35.40	40.21	39.16	36.45	34.95
<i>si</i>	866	285	170	272	494	499	495	483	458
<i>k</i>	0.74	0.76	0.20	0.26	0.57	0.57	0.56	0.55	0.62
<i>mg</i>	0.32	0.35	0.91	0.76	0.34	0.44	0.40	0.49	0.22
<i>t</i>	16.05	17.13	8.74	17.80	7.4	6.7	9.2	7.4	5.8

Analysis no.	82	83	84	85	86	87	88	89	90
Weight %									
SiO ₂	74.6	73.7	71.3	78.0	58.3	52.6	63.8	74.8	71.4
TiO ₂	0.27	0.25	0.18	0.18	1.28	1.60	0.92	0.27	0.31
Al ₂ O ₃	13.3	13.4	15.0	10.3	16.1	21.2	17.1	12.2	14.4
Fe ₂ O ₃	0.10	0.50	0.10	0.60	2.68	3.80	1.30	1.30	0.60
FeO	1.00	1.50	1.10	0.40	4.30	4.00	3.50	1.10	1.60
MnO	0.02	0.02	0.02	0.02	0.13	0.11	0.08	0.03	0.03
MgO	0.46	0.41	0.54	0.14	2.55	2.40	1.90	0.47	0.74
CaO	0.60	0.90	0.80	0.90	5.17	6.70	4.40	0.60	1.10
Na ₂ O	2.20	2.70	2.70	2.90	3.92	4.20	3.80	2.30	2.70
K ₂ O	5.90	5.40	6.30	5.40	3.26	2.20	2.30	6.70	5.10
H ₂ O	0.60	0.30	0.90	0.40	—	—	—	0.40	0.70
Sum	99.1	99.1	98.9	99.2	97.7	98.8	99.1	100.2	98.7

Niggli values									
<i>al</i>	48.88	45.89	48.59	42.40	31.11	35.64	37.65	42.26	45.91
<i>fm</i>	10.06	13.12	9.98	7.06	31.23	28.17	25.42	15.42	15.78
<i>c</i>	4.27	5.74	4.92	6.81	18.37	20.55	17.67	4.07	6.52
<i>alk</i>	36.77	35.23	36.48	43.70	19.28	15.62	19.74	38.23	31.76
<i>si</i>	465	428	392	545	191	150	238	440	386
<i>k</i>	0.63	0.56	0.60	0.55	0.35	0.25	0.28	0.65	0.55
<i>mg</i>	0.42	0.27	0.44	0.20	0.39	0.36	0.41	0.26	0.37
<i>t</i>	8.0	4.9	7.2	-8.11	-6.53	0.53	0.73	-0.04	7.62

Analysis no.	91	92	93	94	95	96	97	98	99
Weight %									
SiO ₂	69.8	68.8	68.4	76.5	75.6	75.6	61.7	71.1	70.8
TiO ₂	0.26	0.61	0.99	0.08	0.10	0.11	1.05	0.65	0.61
Al ₂ O ₃	15.4	14.7	13.7	12.8	13.1	13.2	17.6	15.0	13.4
Fe ₂ O ₃	1.00	1.00	1.30	0.10	0.10	0.50	1.93	1.40	1.6
FeO	1.10	2.00	3.90	0.50	1.00	1.00	3.50	1.00	1.1
MnO	0.03	0.04	0.08	0.01	0.02	0.02	0.09	0.08	0.08
MgO	0.67	1.20	1.70	0.21	0.10	0.14	1.88	0.72	2.1
CaO	1.60	1.40	2.30	0.30	0.60	0.90	4.58	3.40	0.71
Na ₂ O	3.30	2.50	2.30	2.40	3.20	3.00	3.67	1.70	3.7
K ₂ O	5.00	6.20	3.90	6.10	4.70	5.00	2.47	3.90	5.1
H ₂ O	0.60	0.80	0.70	0.70	0.50	0.10	—	—	0.4
Sum	98.8	99.3	99.3	99.7	99.0	99.6	98.5	99.0	99.6

Niggli values									
<i>al</i>	45.54	41.57	36.47	50.62	49.66	47.76	37.43	44.93	38.90
<i>fm</i>	13.53	20.38	30.90	5.46	6.93	8.82	26.19	15.40	16.01
<i>c</i>	8.85	7.72	11.30	2.18	4.16	5.96	17.83	18.63	11.37
<i>alk</i>	32.06	30.61	21.31	41.72	39.24	37.43	18.52	21.02	33.70
<i>si</i>	350	330	309	513	486	464	223	361	349
<i>k</i>	0.49	0.62	0.52	0.62	0.49	0.52	0.30	0.60	0.47
<i>mg</i>	0.37	0.42	0.37	0.32	0.13	0.14	0.38	0.35	0.32
<i>t</i>	4.62	3.53	3.85	6.7	6.3	4.4	1.06	5.27	-6.16

Analysis no.	100	101	102	103	104	105	106	107	108
Weight %									
SiO ₂	70.2	69.0	68.4	68.3	61.7	61.2	59.0	57.9	56.4
TiO ₂	0.57	0.55	0.87	0.65	0.95	1.20	0.93	0.93	1.30
Al ₂ O ₃	14.5	14.9	16.4	17.3	16.7	16.3	13.8	15.5	15.2
Fe ₂ O ₃	1.60	1.60	2.20	1.50	2.60	4.30	3.30	3.20	4.30
FeO	1.10	0.90	1.40	1.90	3.40	3.80	3.90	3.70	4.20
MnO	0.09	0.07	0.10	0.07	0.10	0.12	0.14	0.15	0.17
MgO	0.58	0.68	1.00	1.10	2.30	1.90	4.10	3.50	2.80
CaO	1.70	2.10	2.60	1.00	3.30	5.00	6.60	6.80	7.90
Na ₂ O	3.60	3.60	1.50	1.00	3.20	2.90	3.0	3.50	3.60
K ₂ O	5.50	5.70	3.70	4.70	4.60	3.50	3.20	2.70	2.80
H ₂ O	0.40	0.60	1.40	—	—	—	0.80	0.39	0.70
Sum	99.8	99.7	99.6	97.5	98.9	100.2	98.8	98.3	99.4

Niggli values									
<i>al</i>	41.71	41.26	46.68	51.74	35.42	32.53	25.27	28.21	26.48
<i>fm</i>	14.96	14.23	21.26	22.41	29.92	31.85	37.21	33.50	32.71
<i>c</i>	9.15	10.99	13.62	5.69	12.91	18.42	22.12	22.70	25.20
<i>alk</i>	34.16	33.49	18.42	20.13	21.73	17.18	15.38	15.57	15.59
<i>si</i>	343	324	330	347	222	209	183	179	167
<i>k</i>	0.50	0.51	0.61	0.75	0.41	0.44	0.41	0.48	0.33
<i>mg</i>	0.28	0.33	0.33	0.37	0.40	0.30	0.51	0.48	0.37
<i>t</i>	-1.60	-3.22	14.63	25.91	0.78	-3.00	-12.23	-10.05	-14.32

Analysis no.	109	110	111	112	113	114	115
Weight %							
SiO ₂	52.4	62.5	61.5	62.6	68.0	56.0	76.2
TiO ₂	1.30	0.79	1.2	1.2	0.63	1.6	0.35
Al ₂ O ₃	17.2	17.1	15.4	17.5	16.3	16.8	15.5
Fe ₂ O ₃	4.7	2.2	5.7	5.1	3.2	4.6	0.8
FeO	4.5	2.0	2.6	2.2	0.7	5.6	0.1
MnO	0.20	0.10	0.12	0.10	0.03	0.23	0.01
MgO	3.9	1.6	1.9	1.8	0.59	3.7	0.17
CaO	10.8	5.0	4.8	2.0	0.6	4.5	0.1
Na ₂ O	2.7	3.3	2.9	1.8	1.2	3.7	0.3
K ₂ O	1.4	3.7	3.3	3.7	6.3	2.4	4.6
H ₂ O	0.5	0.6	—	0.9	1.0	1.0	—
Sum	99.6	98.8	99.4	98.9	98.6	100.1	98.1
Niggli values							
<i>al</i>	26.30	37.54	31.74	41.16	49.54	29.33	67.91
<i>fm</i>	34.46	21.59	32.87	33.71	20.12	41.04	7.04
<i>c</i>	30.11	20.14	18.18	8.74	3.52	14.45	1.05
<i>alk</i>	9.10	20.71	17.19	16.38	26.75	15.16	23.97
<i>si</i>	136	233	215	250	351	166	567
<i>k</i>	0.25	0.42	0.42	0.57	0.77	0.29	0.90
<i>mg</i>	0.43	0.41	0.30	0.31	0.22	0.39	0.26
<i>t</i>	-12.92	-3.31	-3.63	16.03	19.32	-0.28	5.09

- Analysis no. 1. White quartzite. East of Lake Rummen. Map-sheet Västervik SO (4g).
- Analysis no. 2. Coarse white quartzite. Grönö, south-west of southern mouth of Spårösund. Map-sheet Kråkelund NV (9a).
- Analysis no. 3. Coarse cross-bedded white quartzite. Skjortö, western shore. Map-sheet Kråkelund NV (7a).
- Analysis no. 4. Coarse recrystallized quartzite. Långö, north-eastern shore. Map-sheet Kråkelund NV (8a).
- Analysis no. 5. "Granular" quartzite. Old water tower, Västervik city. Map-sheet Loftahammar SW (0a).
- Analysis no. 6. Fine-grained white quartzite. Långö, north-eastern shore. Map-sheet Kråkelund NV (8a).
- Analysis no. 7. Micaceous quartzite. North of Lake Rummen. Map-sheet Västervik SO (4f).
- Analysis no. 8. Cross-bedded feldspathic quartzite. Tallskär. Map-sheet Kråkelund NV (7b).
- Analysis no. 9. Meta-arenite bed in bedded red-gray metasediments. L. Äppleholmen. Map-sheet Kråkelund NV (7a). (Cf. Fig. 21.)

- Analysis no. 10. Meta-arkose (red metasediments). Björnsholm. Map-sheet Västervik NO (5h).
- Analysis no. 11. Meta-arkose (red metasediments). Björnsholm. Map-sheet Västervik NO (5h).
- Analysis no. 12. Meta-arkose (red metasediments). Tjust Motell. Map-sheet Västervik SO (3h).
- Analysis no. 13. Layered red metasediment. NNE of Smedstorp. Map-sheet Västervik NO (5h).
- Analysis no. 14. Red layered meta-arenite. South of Borgö. Map-sheet Loftahammar SV (0a).
- Analysis no. 15. Gneissic red meta-arenite. Intercalation in metabasite. Highway E 66. Map-sheet Västervik NO (6i).
- Analysis no. 16. Metagraywacke. Tuvgölen. Map-sheet Vimmerby NO (8h).
- Analysis no. 17. Metagraywacke. South-east of Lake St. Flugen. Map-sheet Vimmerby NO (8h).
- Analysis no. 18. Gray metasediment bed in veined gneiss. Lökholmen, eastern part. Map-sheet Kråkelund NV (8a).
- Analysis no. 19. Gray, fairly coarse metasediment. North of Lake Rummen. Map-sheet Västervik SO (4f).
- Analysis no. 20. Gray, slightly layered metasediment. North of Lake Rummen. Map-sheet Västervik SO (4f).
- Analysis no. 21. Dark layered micaceous meta-arenite. Oxebo farmhouse. Map-sheet Västervik SO (3f).
- Analysis no. 22. Quartzitic band in the gray metasediments of the Tullerö-Henriksnäs region. The island Hjortskallen, south of Tullerön. Map-sheet Vimmerby NO (6j).
- Analysis no. 23. Gneissic gray metasediment band of the Tullerö-Henriksnäs region. Henriksnäs, south-western shore. Map-sheet Vimmerby NO (7j).
- Analysis no. 24. Gray band in the gray metasediments of the Tullerö-Henriksnäs region. Same locality as analysis no. 22.
- Analysis no. 25. Dark band in the gray metasediments of the Tullerö-Henriksnäs region. Same locality as analysis no. 22.
- Analysis no. 26. Gray micaceous meta-arenite. Lindholmen island. Map-sheet Kråkelund NV (8a).
- Analysis no. 27. Gray micaceous meta-arenite. Älholmen island. Map-sheet Vimmerby NO (8j).
- Analysis no. 28. Gray micaceous meta-arenite. Älholmen island. Map-sheet Vimmerby NO (8j).
- Analysis no. 29. Bed of mica-schist with abundant sillimanite in the banded red-gray metasediments. L. Äppleholmen. Map-sheet Kråkelund NV (7a). (Cf. analysis no. 9 and Fig. 21.)
- Analysis no. 30. Mica-schist with abundant andalusite. Skjortö shore. Map-sheet Kråkelund NV (7a). (Cf. Fig. 18.)
- Analysis no. 31. Micaceous meta-arenite. Road-cutting at E 66, 500 m south of Botorpström. Map-sheet Vimmerby NO (8h).
- Analysis no. 32. Gray gneiss with abundant cordierite. 700 m SSE of Botorp farmhouse. Map-sheet Vimmerby NO (8h).

- Analysis no. 33. Sericitized quartzite. North of Rummen. Map-sheet Västervik SO (4f).
- Analysis no. 34. Gray micaceous meta-arenite. 350 m south-east of Tjust Motell. Map-sheet Västervik SO (3h).
- Analysis no. 35. Gray band in red-gray metasediments. Tjust Motell. Map-sheet Västervik SO (3h).
- Analysis no. 36. Red-gray banded metasediments. Highway E 66, 2 km north-west of Gamleby. Map-sheet Västervik SO (4g).
- Analysis no. 37. Red-gray banded metasediments. Highway E 66, 1 km north of Gladhammar church. Map-sheet Vimmerby NO (9h).
- Analysis no. 38. Red-gray banded metasediments. Main road to Vimmerby, 1.5 km NNW of Gladhammar church. Map-sheet Vimmerby NO (9h).
- Analysis no. 39. Red-gray banded metasediments, somewhat gneissic. Gunnebo. Map-sheet Vimmerby NO (9i).
- Analysis no. 40. Red-gray banded metasediments, gneissic. Highway E 66, north-east of Lake Kvarnsjön. Map-sheet Vimmerby NO (7h).
- Analysis no. 41. Intensely gneissified red-gray metasediments. Gränsö udde. Map-sheet Loftahammar SV (0a).
- Analysis no. 42. Breccia, groundmass. Lökholmen, western point. Map-sheet Kråkelund NV (8a).
- Analysis no. 43. Stratified metabasite tuff. North-east of Skälöbro. Map-sheet Vimmerby NO (7j).
- Analysis no. 44. Metabasite with amygdaloids of quartz. 200 m north-west of Skälöbro. Map-sheet Vimmerby NO (7j).
- Analysis no. 45. Bedded metabasite. Dense band. Skavdö farmhouse. Map-sheet Kråkelund NV (6a).
- Analysis no. 46. Bedded metabasite. Porphyritic band. Locality as analysis no. 45.
- Analysis no. 47. Gneissic, somewhat bedded metabasite. Highway E 66, 500 m east of Bällsjö. Map-sheet Västervik NO (6i).
- Analysis no. 48. Hypabyssic metabasite. Skavdö, south-western shore. Map-sheet Kråkelund NV (6a).
- Analysis no. 49. Metabasite of generation III, Kresten (1972). St. Ekholmen. Map-sheet Kråkelund NV (7a).
- Analysis no. 50. Metabasite of generation IV, Kresten (1972). St. Ekholmen. Map-sheet Kråkelund NV (7a).
- Analysis no. 51. Metabasite of generation IV, Kresten (1972). South of Lake Maren. Map-sheet Västervik SO (1j).
- Analysis no. 52. Gabbroid metabasite. Händelöp, northern shore. Map-sheet Kråkelund NV (9a).
- Analysis no. 53. Fine-grained metabasite. Locality as analysis no. 52.
- Analysis no. 54. Metabasite of generation V, Kresten (1972). Locality as analysis no. 49.
- Analysis no. 55. Metabasite of generation VI, Kresten (1972). Lindskäret. Map-sheet Kråkelund NV (5a).
- Analysis no. 56. Metabasite of generation VII, Kresten (1972). Highway E 66, 1.5 km west of Solstadström. Map-sheet Vimmerby NO (6i).
- Analysis no. 57. Rhyodacite. Ljusterö, north-western shore. Map-sheet Västervik SO (2j).
- Analysis no. 58. Porphyritic metabasite. South-east of Pärlobögen. Map-sheet Västervik SO (4h).

- Analysis no. 59. Intermediate dike. Locality as analyses nos. 10 and 11.
- Analysis no. 60. Gray porphyry. Skavdö, eastern part. Map-sheet Kråkelund NV (6a).
- Analysis no. 61. Veined gneiss. Grönö, south-eastern shore. Map-sheet Kråkelund NV (9a). (Cf. Fig. 53.)
- Analysis no. 62. Veined gneiss. Mainland south of Borgö. Map-sheet Loftahammar SV (0a).
- Analysis no. 63. Veined gneiss. Locality as analysis no. 62.
- Analysis no. 64. Veined gneiss. Locality as analysis no. 62.
- Analysis no. 65. Flecky gneiss, normal type. Central Spårösund. Map-sheet Kråkelund NV (9a).
- Analysis no. 66. Flecky gneiss, micaceous type. Locality as analysis no. 65.
- Analysis no. 67. Flecky gneiss, acid type. Locality as analysis no. 65.
- Analysis no. 68. Flecky band in red-gray metasediments. Tjust Motell. Map-sheet Västervik SO (3h). (Cf. analysis no. 35.)
- Analysis no. 69. Slightly flecky band in red-gray metasediments. Tjust Motell. Map-sheet Västervik SO (3h). (Cf. analyses nos. 35, 68.)
- Analysis no. 70. Slightly flecky band in red-gray metasediments. Tjust Motell. Map-sheet Västervik SO (3h). (Cf. analyses nos. 35, 68, 69.)
- Analysis no. 71. Veined gneiss with abundant andalusite. North of Lake Rummen. Map-sheet Västervik SO (4f).
- Analysis no. 72. Veined red-gray gneiss. North of Lake Rummen. Map-sheet Västervik SO (4f).
- Analysis no. 73. Veined gneiss, rich in microcline. Lökhölm, eastern part. Map-sheet Kråkelund NV (8a).
- Analysis no. 74. Biotite-rich veined gneiss. Locality as analysis no. 73.
- Analysis no. 75. Gray plagioclase gneiss. Highway E 66, 1.8 km north of road junction to Blankaholm. Map-sheet Vimmerby NO (7i).
- Analysis no. 76. Gray veined gneiss. Road exposure 2.5 km north of Blankaholm. Map-sheet Vimmerby NV (7i).
- Analysis no. 77. Red Loftahammar granite, remobilized. Kråkhölmarna. Map-sheet Loftahammar SV (2a). (T. Hahn.)
- Analysis no. 78. Loftahammar granite. Southern Björkö. Map-sheet Loftahammar SV (2a). (T. Hahn.)
- Analysis no. 79. Loftahammar granite. Solidö. Southern Björkö-Solidö-Kråkhölmarna area. Map-sheet Loftahammar SV (2a). (T. Hahn.)
- Analysis no. 80. Red Loftahammar granite. Locality as analysis no. 79. (T. Hahn.)
- Analysis no. 81. Red Loftahammar granite. Locality as analysis no. 79. (T. Hahn.)
- Analysis no. 82. Red Loftahammar granite. Locality as analysis no. 79. (T. Hahn.)
- Analysis no. 83. Red Loftahammar granite. Locality as analysis no. 79. (T. Hahn.)
- Analysis no. 84. Red Loftahammar granite. Locality as analysis no. 79. (T. Hahn.)
- Analysis no. 85. Fine-grained red older granite. South of Lake St. Flugén. Map-sheet Vimmerby NO (8g).
- Analysis no. 86. Older granodiorite. North of Verkeäcksviken. Map-sheet Västervik SO (0i).
- Analysis no. 87. Older granodiorite-gabbro. Northern shore of Händelöping. Map-sheet Kråkelund NV (9a).
- Analysis no. 88. Schistose mobilized older granite. Locality as analysis no. 87.

- Analysis no. 89. Younger granite. North-east of Grindstugan. Map-sheet Vimmerby NO (8g).
- Analysis no. 90. Younger granite. The island Högön (in Gudingen). Map-sheet Västervik SO (1j).
- Analysis no. 91. Younger granite. 2.5 km north of Gamleby. Map-sheet Västervik SO (4h).
- Analysis no. 92. Younger granite. Mansholmen. Map-sheet Kråkelund NV (8a).
- Analysis no. 93. Younger (Judö) granite. Mainland south of Borgö. Map-sheet Loftahammar SV (0a).
- Analysis no. 94. Younger granite. Locality as analysis no. 79. (T. Hahn.)
- Analysis no. 95. Younger granite. Locality as analysis no. 79. (T. Hahn.)
- Analysis no. 96. Younger granite. Locality as analysis no. 79. (T. Hahn.)
- Analysis no. 97. Younger granodiorite. 1.9 km SSE of Oxebo. Map-sheet Västervik SO (3f).
- Analysis no. 98. Metarhyolite. Locality see Fig. 38b. Map-sheet Västervik SO (0f). (R. Jonuks.)
- Analysis no. 99. Metarhyolite. Locality see Fig. 38b. Map-sheet Västervik SO (0f). (R. Jonuks.)
- Analysis no. 100. Metarhyolite. Locality see Fig. 38b. Map-sheet Västervik SO (0f). (R. Jonuks.)
- Analysis no. 101. Metarhyolite. Locality see Fig. 38b. Map-sheet Västervik SO (0f). (R. Jonuks.)
- Analysis no. 102. Bedded acid metatuffite with graded bedding. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 103. Acid metatuffite. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 104. Meta-andesite. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 105. Meta-andesite. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 106. Meta-andesite. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 107. Meta-andesite. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 108. Meta-andesite. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 109. Metabasalt. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 110. Andesitic meta-agglomerate. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 111. Andesitic meta-agglomerate. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 112. Bedded andesitic metatuffite. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 113. Groundmass in conglomerate. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)
- Analysis no. 114. Cross-bedded metasediment, intercalation in the volcanics. Locality see Fig. 38b. Map-sheet Västervik SO (0f). (R. Jonuks.)
- Analysis no. 115. Intensely sericitized metarhyolite. Locality see Fig. 38b. Map-sheet Västervik SO (0g). (R. Jonuks.)

APPENDIX

GUIDE TO EXCURSIONS

The Västervik area is extremely well suited for field excursions with the aim of studying primary structures in old metasediments on one hand, and the transformation of such sediments into various kinds of gneisses and granitoids on the other. In the guide to excursions A28 and C23 (Intern. Geol. Congr., XXI Session) by S. Gavelin and P. H. Lundegårdh (1960), several localities (loc. 64—83) are described. These localities were all visited by motorboat. Consequently, studies were mainly concentrated to shore-line exposures.

During field work after 1960, numerous new localities have been found which can be recommended for studies. Many of the rock types and structures described in this report can be studied in road cuttings or in areas which can be easily reached by car. A survey of these new, interesting excursion localities is given here. Localities which can be reached by car (from roads) and those which can only be reached by boat are grouped separately.

The locality numbers from the 1960 excursion guide (Gavelin and Lundegårdh) are denoted by C + number (meaning Congress excursion). New localities are given in current-figures without any prefix.

The localities from the Congress guide took three days to visit; but then the leaders knew exactly where to find each excursion stop. It is therefore difficult here to say exactly how many stops can reasonably be covered in one day. The weather can also be an important factor—especially for the boat excursions. Some landing places on skerries cannot be used if wind directions are unsuitable. Comments on these conditions will be given where needed.

It is recommended to consult the new Swedish topographical maps at 1:50 000 for orientation and names. The following map-sheets have been used: Västervik NO, Loftahammar SV, Västervik SO, Kråkelund NV, Vimmerby NO.

EXCURSIONS BY BUS OR CAR

If one approaches Västervik from the north along highway E66, the following stops are recommended.

- Loc. 1. Large road-cutting at the top of a hill, 400 m east of Bällsjö farm. Map-sheet Västervik NO, 6i. Metabasite gneiss, which borders the true Västervik metasediments to the north. Gray, pegmatitic or granitoidal veins in an amphibolitic rock. In places, faint bedding may be visible in the metabasites. Analysis no. 47.
- Loc. 2. Large road-cutting at the top of a hill, 600 m ENE of St. Hälleberg farm. Map-sheet Västervik NO, 6i. The northern part of the outcrop displays the same pattern as in loc. 1. Towards the south the rocks contain slabs of fine-grained, pink metasediments which in places are gneissic. These types look exactly like somewhat gneissic forms of the red metasediments found further to the south. The pattern has been interpreted as an intercalation of red metasediments and basic metavolcanics.

- Loc. 3. Immediately south of the junction highway E 66/small road to Hjulby, 4 km south of Västra Ed church. Map-sheet Västervik NO, 6h. Loftahammar granite. On the western side of the road, the granite is schistose porphyritic, transected by straight narrow metabasite dikes (see Fig. 72). To the north on the eastern side of the road, occurs porphyritic granite with oligoclase rims around the large microcline phenocrysts.
- Loc. 4. Road-cutting on highway E 66 at Björnsholm. Map-sheet Västervik NO, 5h. Typical red metasediments, meta-arkose. Analyses nos. 10 and 11 are from this locality. On the eastern side of the road, southern part, there is a gray dike (analysis no. 59).
- Loc. 5. Road-cutting about 2 km north-west of Gamleby, 450 m south of railway cross, (at the top of a slope from the north). Map-sheet Västervik SO, 4g. Typical red-gray metasediments. Lithostratigraphic unit 4. Analysis no. 36.
- Loc. 6. Tjust Motell. Map-sheet Västervik SO, 3h. Start with a small outcrop just south of the approach to the motel. Bedded, red-gray metasediments dipping north-east. Selective formation of flecks in various beds (see Gavelin 1975, p. 68). Lithostratigraphic unit 4. Walk to the top of the ridge just north-east of the motel. From this point one has a picturesque view across Gamlebyviken. On the other side one can see the manor called Kasimirsborg. Along the shore, south-east from Kasimirsborg, one can observe many of the outcrops described in loc. 12. Bedding there dips towards the observer. Gamlebyviken itself lies along the axis of the continuous syncline described in chapter 4.
- Loc. 7. Road-cutting 350 m south of Tjust Motell, eastern side of the road. Map-sheet Västervik SO, 3h. Gray micaceous feldspathic meta-arenite. Transition between lithostratigraphic units 4 and 3. Beautiful ripple marks, faint cross-bedding indicating "up" towards the north-east. In the northern part of the outcrop there is a beautiful erosion channel, pictured by Gavelin and Russell (1967, fig. 11 A; see also fig. 9 A, ripple marks). Analysis no. 34.
- Loc. 8. Further to the south-east along highway E 66. White, pure, generally only slightly stratified quartzite belonging to the lithostratigraphic unit 3. Map-sheet Västervik SO, 2h.
- Loc. 9. This locality may take some time to locate. It is situated at the south-western shore of the Almviksnäs peninsula. This requires a little separate tour which is well worth-while, however. In this exposure, one can see well developed cross-bedding, normal as well as overturned (pictured in Gavelin and Russell 1967, fig. 12). Drive the old road to Almvik, cross the railway and drive to the farmhouse Almviksnäs. Walk across the fields towards the south-west to an exposure on the shore, 250 m south-west of the farmhouse. Map-sheet Västervik SO, 2h.
- Loc. 10. Old water tower in the town of Västervik. Map-sheet Loftahammar SV, 0a. Typical, fine-grained, non-stratified "Västervik quartzite". Lithostratigraphic unit 3. Analysis no. 5.

Up to this point, the excursion route has been on the south-western limb of the Gamlebyviken syncline. If one wants to extend the excursion by studies of the north-eastern

limb of the same syncline, it is necessary to drive the road on the opposite side of the bay (Norrlandet).

Loc. 11. At the Museum (to the right after passing the bridge from Västervik) and along the road towards Stuverum. Map-sheet Västervik SO, 0—1j. White non-stratified quartzite belonging to lithostratigraphic unit 3.

Loc. 12. Exposures along the shore from Kasimirsborg towards south-east. Map-sheet Västervik SO, 3h. Excursion after Russell 1969, fig. 3, right part. Walk to the point 500 m south of the main building of Kasimirsborg. The rocks here are bedded metasediments belonging to lithostratigraphic unit 4, now dipping to the south-west and consequently overlying the quartzites closer to Västervik—we are on the north-eastern limb of the syncline. Across the bay, the motel previously visited is visible.

In the metasediments zoned flecks are beautifully developed. Where the rocks along the shore are too steep, walk up to a small path running parallel to the shore. Try, however, to follow the shore-line outcrops where it is possible. These exhibit several primary sedimentary structures, especially those representing pre-consolidation deformation (see Gavelin and Russell 1967, figs. 17, 18, 20, 21, 23, 24). During this walk we pass from the andalusite-sillimanite zone into the muscovite-cordierite zone according to Russell.

Loc. 13. Back to the main road, drive towards Gamleby. Map-sheet Västervik SO, 4h. Typical Gamleby granite in the cliff just north-east of the bridge and in a small quarry west of the bridge, north of the road. Analysis no. 91.

From Västervik it is possible to reach some additional very important and interesting localities by car. Most of them were presented in the guide to the Congress excursions and are therefore referred to here by the numbers given in Gavelin and Lundegårdh (1960). The first three localities are given in the order of travelling from Västervik, although it would be more logical to visit them in the opposite order.

Loc. C81. Lysingsbadet. Map-sheet Loftahammar SV, 0a. Two clean, flat exposures; one at the swimming tower, the other some 200 m towards north-west. Homogeneous Judö granite with abundant xenoliths. Lens-shaped metabasites, irregularly-shaped, gray, fine-grained, stratified, crumpled metasediments, quartzite etc.

Loc. C80. Mainland south of Borgö, see Loberg (1963, plate 1). Map-sheet Loftahammar SV, 0a. Take the road to Hornsudde, follow the smaller road to the left marked "Pepparängen" some kilometres after passing Örserumsviken and drive to Pepparängen to the end of the road at a small bridge to Borgö. Immediately to the east of the bridge, the rocks consist of fairly well-preserved red meta-arkose. To the west, there are highly flecky and veined gneisses with "xenoliths" of metabasites and better-preserved metasediments. The rocks show continuous transitions to granitoids towards the west. Visible contacts between true Judö granite and gneiss can be found near a small summer house 40—50 m from the shore. To the west, the bedrock consists of Judö granite with numerous lens-shaped xenoliths of metabasite, irregular-shaped xenoliths of bedded metasediments and quartzite. Pure

quartzite also occurs in the granite as continuous slabs 0.5—2 m thick. These slabs may be traced in the field 200—300 m along the strike (cf. Fig. 81).

- Loc. C77. The shore-lines south-west of the southern mouth of Spårösund channel. Map-sheet Kråkelund NV, 9a. This locality is most easily reached by boat. One can land at one of the jetties in the bay. Begin in the south, 200—300 m north of the southernmost point of Grönö, where very coarse pure quartzite occurs. Walk towards the north where beds of micaceous veined gneiss appear, at first only 0.5—2 m thick. The gneissic portions increase gradually. Close to the very mouth of Spårösund, the gneisses dominate. Here, one finds the very instructive pattern pictured in Fig. 53.

Localities C77, C80 and C81 form a coherent series of field data which have been considered to be particularly important in discussions on the genesis of the gneisses and granitoids (see pp. 131—132, Figs. 83, 84).

To this group of localities can be added C78 in Spårösund, map-sheet Kråkelund NV, 9a. Here, there are very good examples of various types of flecky gneiss within a single small exposure. This locality must be visited by boat; but since one has to pass through Spårösund in any tour from Västervik to the southern archipelago, this can be done separately in connection with such a boat excursion.

- Loc. 14. A very interesting locality can be recommended in connection with a drive towards Hornsudde, although it is not directly concerned with the genetic problems considered above. If one turns to the right 1 300 m north-west of Hornsudde and follows the road to Händelöp, one soon comes to a bridge over to the island itself. Drive over the bridge and stop some 100 m afterwards. Walk to the shore south-west of the road. Map-sheet Kråkelund NV, 9a—b. There one finds an old granodiorite brecciated by metabasite. The breccia, however, is cut by a strongly schistose granite with lenticular xenoliths of the same metabasite as in the breccia (see Kresten 1972, Abb. 12). The old granodiorite must have been remobilized and flown in some probably fairly restricted shear zone. It is worth noting that, in this case, the "older" plutonite is fairly massive, whereas the "younger" plutonite is characterized by a marked schistosity. The phenomenon is somewhat similar to what can be studied in the outcrops on northern Ängholmén which can be visited by boat, loc. 17.

SOME ADDITIONAL ROAD LOCALITIES SOUTH OF VÄSTERVIK

Along the road from Västervik to Oskarshamn there are many exposures which are of interest for a general study of the map area. However, in only two cases the localities are referred to separately in the text. Therefore only these two have received separate numbers in this guide.

- Loc. 15. Road-cutting on the northern side of the road just east of the road junction to Vimmerby. Map-sheet Vimmerby NO, 9h. Contact between older granite and metasediments. Along this contact both the granite and the metasediments are bleached due to an invasion of plagioclase. It can be taken as an example of sodium metasomatism (cf. p. 123).

- Loc. 16. About 500 m north of the road junction to Blankaholm, at the top of a slope towards the south, eastern side of the road. Map-sheet Vimmerby NO, 7h. The younger granite on the map apparently contains remnants of older granite which has been transected by metabasite. The older granite has been remobilized and has behaved plastically, whereas the metabasite dikes have been broken up, have flown apart and have sometimes been rotated (see Kresten 1972, Abb. 11 and p. 162 where this phenomenon is discussed). In this case the deformation of the metabasite is associated with chemical reactions, the broken pieces of metabasite being surrounded by a bleached zone representing an invasion of plagioclase in the granitoid, cf. p. 123.

EXCURSIONS BY MOTORBOAT

Excursions in the southern archipelago are assumed to start either from Västervik or from Händelöp. Most of the localities presented here are described in the guide to the Congress excursions; but there are also several new localities which can be recommended. They are presented here in the order of a continuous tour from Västervik and back. Such an excursion would take at least two days, although a one-day excursion with fewer stops is also worth-while.

Starting from Västervik one has to pass through Spårösund, where one can visit loc. C78, see p. 159.

- Loc. 17. The north-western point on the island of Ängholmen (750 m WSW of the western point of Händelöp). Map-sheet Kråkelund NV, 9a. Land against a steep rock slope on the western side of the bay and walk across the ridge. On the slope facing west one can study mobilized Loftahammar granite with broken up and plastically folded metabasite dikes. See Figs. 74, 75.
- Loc. C71. Continue towards the west from Ängholmen west of Nävelsö and Mäsö to a point south of Pipareholmen (north of Långö). Map-sheet Kråkelund NV, 8a. Studies from the boat. First a view of Pipareholmen where a beautiful open anticline can be seen (Fig. 70). For a study of the rocks drive slowly close to the vertical rock wall.
- Loc. C74. Lökholmen. Map-sheet Kråkelund NV, 8a. Land at the eastern point or, if a hard west wind prevails, in the passage on the southern shore. Walk eastwards along the southern shore and back along the northern shore. Along the southern shore it is possible to study a great number of gneiss varieties originating from the red-gray metasediments, especially flecky gneisses and veined gneisses. Further, large masses of metabasite occur. On the eastern end of the northern shore one finds still more intense gneissification with beautiful patterns. Midway along the northern shore there is a small point facing north which is cut by a marked east—westerly shear zone. One finds strongly sheared veined gneisses flowing around large, lense-shaped blocks of more resistant and undeformed metabasite (Fig. 82). Immediately to the west one finds the peculiar interplay of metabasite and gneiss pictured and discussed by Gavelin (1960, fig. 18). The gneiss has flown through a system of fractures in the metabasite which in turn has broken up into a number of small lens-shaped pieces. The shapes and sizes of these metabasite blocks and fragments resemble the lense-shaped metabasite xenoliths which are so typical for certain parts of for example the Judö granite. It

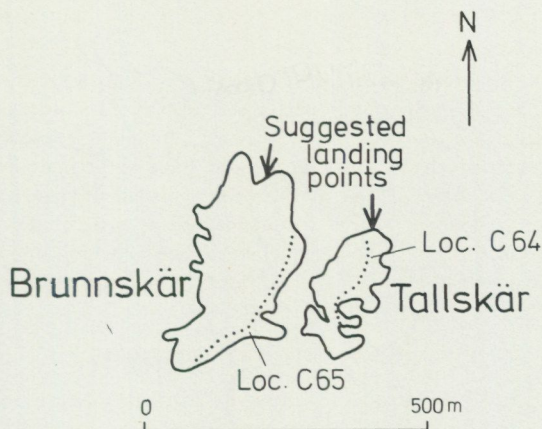


Fig. A:1. Orientation for landing at excursion localities C64 and C65.

has been suggested that the pattern here may be a clue to the origin of some xenoliths in a granitoid, see pp. 129—130.

At the western point of Lökholmen one finds a breccia, see pp. 29—31.

- Loc. C65. Brunnskär (north of Eknö). Map-sheet Kråkelund NV, 7a. Landing in the bay on the northern shore for a walk along the eastern and south-eastern shore (see Fig. A:1). First fairly coarse metabasite with xenoliths of quartzite and white granitic veins is met with. Then follows quartzite, sometimes with cross-bedding. This quartzite is transected by a metabasite dike, about 1 m thick. Quartzite is pressed into the metabasite where it is thereby invaded by oligoclase and takes on a pegmatite-like appearance. See S. Gavelin 1960, fig. 15. The phenomenon is also discussed in this publication see pp. 123—124. Somewhat further to the east there occurs a breccia, similar to the one found on the western side of Lökholmen, loc. C74.
- Loc. C64. Tallskär, north of the north-eastern part of Eknö. Map-sheet Kråkelund NV, 7a—b. On this small island one can study a large number of primary sedimentary structures. The best exposures are along the northern and north-eastern shore-lines of the island: normal and deformed cross-bedding, load casts, convolute bedding, rolled load casts, graded bedding (Fig. 7), ripple marks. (See Gavelin and Russell 1967, figs. 13, 14, 16, 19, 22.) Analysis no. 8.
- Landing may be somewhat difficult and must be performed with great caution, since there are numerous underwater skerries around the island. If the wind direction permits, the northern point of the island is most suitable; but it is also possible to land on the shore to the north-west (see Fig. A:1).
- Loc. C66. L. Äppleholmen. Map-sheet Kråkelund NV, 7a. The most typical example of the bedded, red-gray metasediments of the Äppleholmen type, viz. with crumpled mud cracks, Fig. 21 (see also Gavelin and Russell 1967, figs. 6, 7 A and B). Best landing place on the steep north-eastern shore. With hard

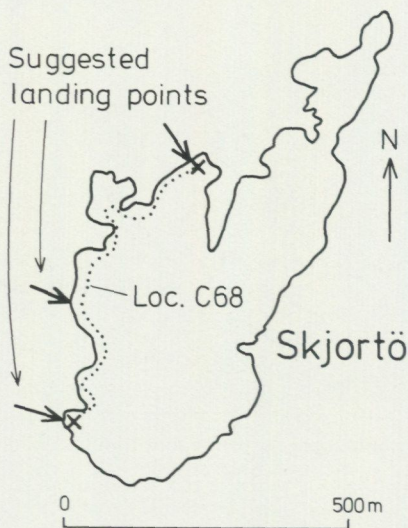


Fig. A:2. Orientation for landing at excursion locality C68.

eastern wind it is also possible to land on the western shore. Analyses nos. 9 and 29.

- Loc. C68. Skjortö. Map-sheet Kråkelund NV, 7a. Start from the north-western shore in the bay (see Fig. A:2) where the rocks consist of coarse, pure quartzite with beautiful lenticular cross-bedding, Fig. 6, analysis no. 3. From here one can walk along the shore towards the steep shore exposures on the western shore of the southern part of the island. Here, the bedrock consists of mica-schist with plenty of andalusite, analysis no. 30. During this walk one can study the alternation between quartzites, micaceous meta-arenites and mica-schists. It is also possible to save some time by travelling by boat from the first quartzite locality to the mica-schists in the south-west.
- Loc. 18. Western Eknö. Map-sheet Kråkelund NV, 7a. Land on the western shore, close to the northernmost point (see Fig. A:3). Here, pure quartzite occurs. Cross-bedding is often visible, facing towards the south-west. Walk south along the shore some 50–100 m until reaching a narrow bed of mica-schist (about 0.5–1 m thick) with intercalations of meta-arenite. In this bed, well-preserved primary sedimentary structures can be seen where pre-consolidation deformation patterns are particularly worth consideration. Cf. Figs. 10–14.

The following localities are found in the southernmost archipelago and probably require a separate day. Coming from the north by boat, one has to go through the narrow passage between Hamnö and Skavdö.

- Loc. 19. Here it is convenient to land at Hamnö and study the acid form of the Hamnö granite. See Kresten 1974. Map-sheet Kråkelund NV, 6a.

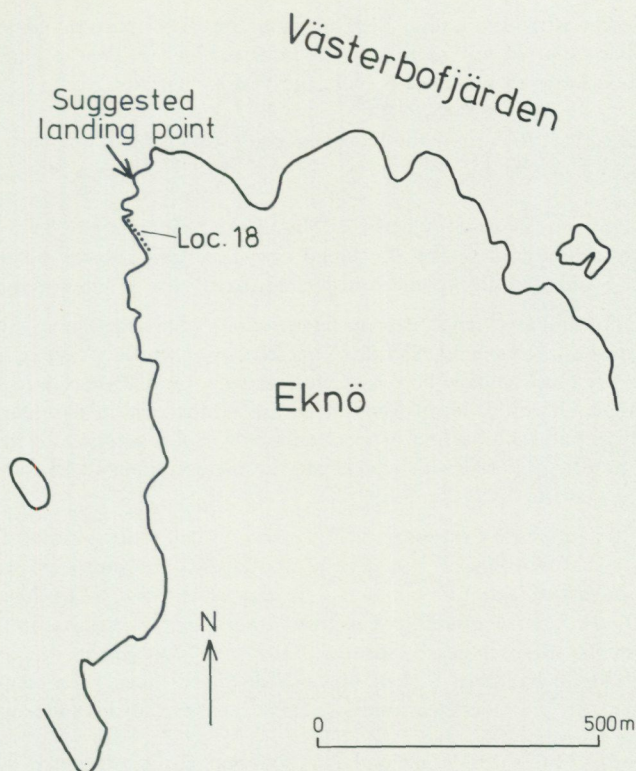


Fig. A:3. Orientation for landing at excursion locality 18.

Loc. 20. Lammholmen. Map-sheet Kråkelund NV, 5a. This locality is an excellent example of *in situ* granitization, where continuous transitions from meta-sediments into homogeneous granitoids can be studied. In the eastern part of the island occur metabasite and beautiful agmatites. It is suggested that the maps and description of Kresten (1971a) have to be followed. Lammholmen should be compared with loc. C80.

It has to be mentioned that some of the passages south-west and south of Älö are very narrow with several under-water skerries—it is preferable to perform this excursion on a sunny day.

Loc. 21. Tvarö, northern shore. Map-sheet Kråkelund NV, 5a. Raft migmatites. Granitoidal, flowable ground masses, in places with relict, sedimentary structures. Metabasite and metasedimentary xenoliths in various stages of metamorphic development are abundant (cf. for example Figs. 57, 58).

Loc. 22. Skavdö farmhouse. Map-sheet Kråkelund NV, 6a. Jetty for landing below the house. In the open area in front of the house there is an exposure with bedded metabasite, porphyritic and massive bands alternating. Fig. 26, analyses nos. 45, 46.

Loc. 23. Skältorpet, north of Skälö. Map-sheet Vimmerby NO, 7j. Jetty for landing. Just east of the jetty there are exposures of fine-stratified, fine-grained me-

tabasite with alternating beds of quartzite. This pattern corresponds very well to that of the map on both sides of the syncline—an intimate alternation between metabasite (volcanics) and quartzite.

With reference to localities from the Congress guide which have not been commented on here, the following can be said.

- Loc. C79. Mjödö, south-east of Västervik. Map-sheet Loftahammar SV, 0a. The features exhibited here are also found elsewhere: red arkosic metasediments in loc. 4 and C80, flecky gneiss in loc. 12, partly loc. 6 and several others.
- Loc. C76. Bondblekeskäret, south-east of Hornsudde. (See econ. map at 1:10 000.) Map-sheet Kråkelund NV, 9b. This locality is worth a visit if time is available. It must anyhow be passed in boat trips from Västervik to the southern islands. One finds an invasion of potash feldspar in coarse quartzite. Deformation and mobilization of metasediments in the presence of small amounts of granitic material which brecciate the metasediments and rotate xenoliths. (See Gavelin 1960, fig. 22.)
- Loc. C72. A very interesting exposure, well worth a visit if time permits. It is situated somewhat outside of the general route, 300 m south-east of Rydeklint, south-east of Ytterhult, immediately east of the bay. Map-sheet Vimmerby NO, 9j. Coarse quartzite has been transected by metabasite. The whole mass has been intensely sheared. Owing to flowage in the quartzite, the metabasite has been broken up and the pieces have been rotated to some extent. In the mobilized quartzite there has been an invasion of plagioclase. (See Gavelin 1960, figs. 16, 17.)
- Loc. C70. Laxholmen, north-east of Hultö. Map-sheet Kråkelund NV, 8a. This stop can be eliminated, since the same phenomenon can be better visualized in loc. 19, 20, and to a certain extent, in loc. C80.
- Loc. C69. Has no particular interest.
- Loc. C73. Mussan. Map-sheet Kråkelund NV, 8b. Feldspathization in quartzite leading to granitoidal or pegmatitic formations. This island is situated quite far from the general routes. The locality is not without interest for studying feldspathization phenomena. Can be visited if time is available.
- Loc. C67. Practically the same as loc. C66.

PROPOSED EXCURSION LOCALITIES ARRANGED ACCORDING
TO OBJECTS OF STUDIES AND LOCALITY NUMBERS

	Rock types
Orthoquartzite	8, 10, 11, C77, C68, 18
Protoquartzite	9, C64
Red metasediments	4
Gray metasediments	C68
Red-gray metasediments	5, 6, C66
Breccia	C74
Metabasite	1, 2 (both gneissic), 3, C74, C65, 22, 23
Gneisses	
flecky gneiss	12, 6, C78, and others
veined gneiss	C80, C77, C74 and others
raft migmatite	21
Older granites	3, 15, 19
Younger granites	13, C81, C80 (smaller massifs). Road cuttings south of Gladhammar and south of Solstadström
Transitional granites	Road cuttings along the road from Olstorp to Överum give a very fine example of transitional granite. (Map-sheet Västervik NO, 5f.)
Gneissic granite	East of the road 200 m north-west of Anneborg, further towards the north and north-east one finds massive, probably recrystallised granites. These localities are given no numbers
	Folding
Regional folding	Excursion around Gamlebyviken (6—12)
Local folding	C71
	Structures
Primary sedimentary structures: cross-bedding (local and distorted), ripple marks, graded bedding, various pre-consolidation deformations	7, 9, 12, C64, C66
Transitions: metasediments → gneisses → granitoids	C80, 20
Deformation of metabasite through flow and feldspathization of granite or quartzite	16, 17, C65, C72

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Box 670

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