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SER C NR 650 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 64 NR 7

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ASPECTS AND PROBLEMS OF PRECAMBRIAN GEOLOGY IN WESTERN SWEDEN

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Editor: P. H. Lundegårdh
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ABSTRACT

Some of the fundamental problems of regional geology in western Sweden are discussed on the basis of recent investigations. Particular attention is given to the position of the "Pregothian" in two critical areas and to the classification of "Gothian" granite plutonics. The diversity of rocks covered by the present use of the term "Åmål-Kroppefjäll granites" is pointed out. A complex of supracrustal and hypabyssal rocks in southern Dalsland is distinguished as an independent formation (the Ellenö complex). It is shown that neither the northern extension of the Göta älv line in the Vänersborg area nor the Klarälven line serve as unique fault-tectonic boundaries between "Gothian" and "Pregothian". Relations between "Gothian" and "Pregothian" geological events and some problems of metamorphism and age are discussed.

CONTENTS

1. INTRODUCTION

Geological maps of western Sweden abound in more or less sharp boundaries which trend approximately north-south and separate bodies of rock supposed to be different in age and origin. The principal feature is the limit between the geological units of the west and the terrains of southeastern and central Sweden. The well-defined boundary drawn in geological maps and indicated in authoritative texts suggests a major dislocation and has an especially straight course to the north of Lake Vänern in County Värmland (fig. 1). Other similar first-order lines are the "mylonite zone" of Magnusson (1937 and 1962, cf. also Larsson 1965) and the Göta älv line (Lundegårdh 1958 and 1959). Published reference indicates that the Göta älv line dissipates in the north into the Gillberga syncline ("Gillbergaskålen", Magnusson 1929 b and 1962, 1963). In the south, however, it is envisaged as a major tectonical discontinuity between "Gothian" terrains in the west and the allegedly entirely different "Pregothian" in the east (fig. 1). Due to frequent shifts of usage and definition terminology is here infested with ambiguity and for the sake of consistency the nomenclature of Magnusson in the description of the Geological Survey Map of Sweden (Magnusson 1962) will be adhered to. The term "Gothian" is consequently used for the supracrustals of Gillbergaskålen and for the Åmål-Kroppefjäll plutonics which intrude them (Magnusson 1929 a and b, 1962, 1963), but does not necessarily imply the acceptance by the present writer of a parallelization of these rocks with other "Gothian" complexes, e. g. in southeastern Sweden, nor a definition of "Gothian" as an absolute age interval in the sense of Lundegårdh (1967). To the east of the Göta älv line is the "Pregothian" of Lundegårdh (1956-7, 1958, 1959) and Magnusson (1962, 1963), a complex of rocks originally described as "jerngnejs" (irongneiss) which term is due to the occasional occurrence of macroscopically conspicuous magnetite crystals in the granulated texture of much of its rocks. To the west of the Göta älv line is the "Gothian" (Magnusson 1962, 1963, Lundegårdh 1958, 1959, 1964, Larsson 1958, Geijer 1963) complex of granites and supracrustals overlain by sediments and volcanics of the Kappebo and Dal formations (Törnebohm 1870 c, 1883, Nathorst 1883, Sandell 1941, Larsson 1947, 1956, van Overeem 1948, Heybroek 1950). Still farther west are the thick metasediments of the Stora Le-Marstrand series (Larsson 1956, 1958, Lundegårdh 1958, 1964) intruded by Bohus granite. Since Bohus granite also cuts the Dal formation (Larsson 1947), its age (Magnusson 1960, Polkanov and Gerling 1961, Parwel and Wickman 1954) must imply the end of major lithogenetical events in this part of the Scandinavian Precambrian basement. Conspicuously the age of the Bohus granite is closely similar to K/A ages throughout the whole of southwestern Sweden and southern Norway which is explained to imply that a "Dalslandian (Riphean) regeneration" affected this whole crustal sector (Magnusson 1960, 1962, Polkanov and Gerling 1960, 1961, Neumann 1960). Because "Gothian" rocks hardly ever appear to the east of the Göta älv line except as slices downfaulted predominantly into the "mylonite zone" (Magnusson 1937, Larsson 1965, Lundegårdh 1958), the Göta älv fault must involve a very considerable throw measurable in kilometers or maybe tens of kilometers. Also, the basement of the "Gothian" in the west is the Stora

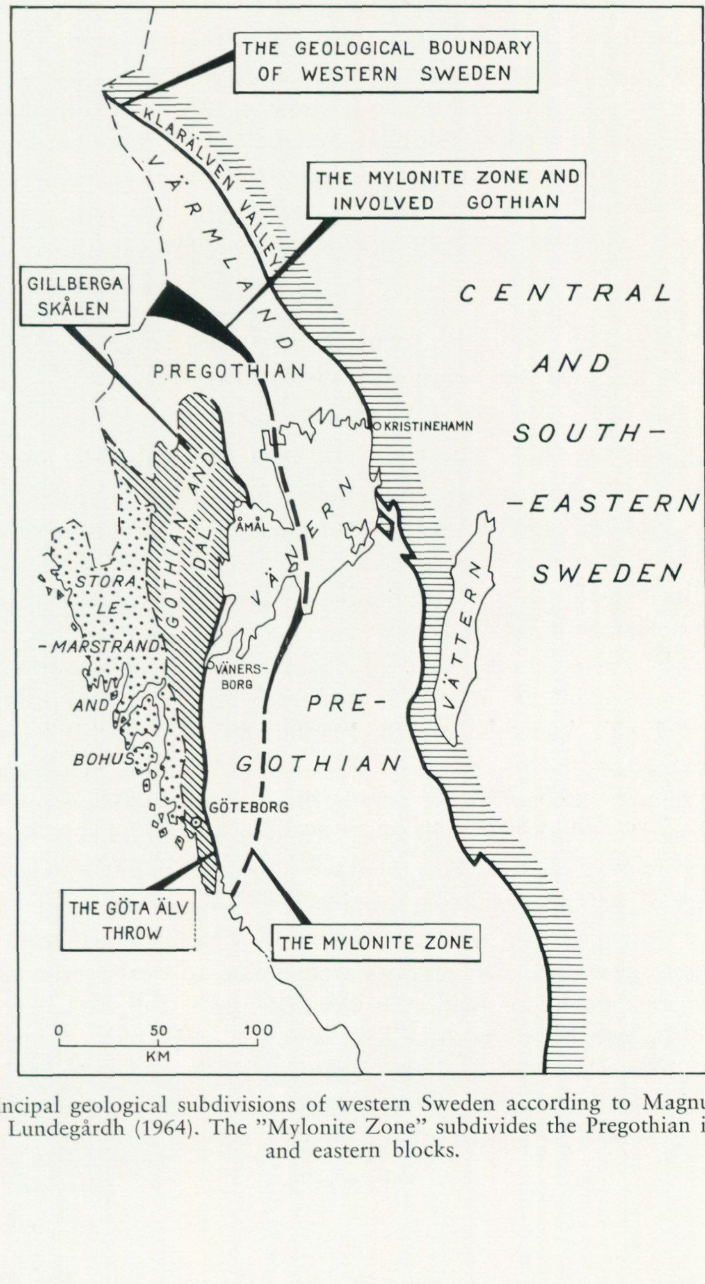

Fig. 1. Principal geological subdivisions of western Sweden according to Magnusson (1962, 1963) and Lundegårdh (1964). The "Mylonite Zone" subdivides the Pregothian into western and eastern blocks.

Le-Marstrand series which allegedly does not reappear in the east. Since the distance between its rocks and the "Pregothian" in the east is not very great, this substantiates the idea of a giant throw on the Göta älv line, which – if prevailing concepts and official maps are correct – must exceed the combined stratigraphical thickness of the "Gothian" and the Stora Le-Marstrand series.

This paper summarizes the results of some recent investigations of the sequence of lithogenetic and tectonic events in western Sweden and discusses the relative positions of the main groups of rocks. To a certain extent the conclusions are tentative and definite solutions will not be proposed for numerous of the discussed problems, but in some of these cases we shall be able to define and specify the existing questions and present evidence eliminating some alternative solutions. Throughout we shall attempt to distinguish between hypothesis and facts established by actual observations. In view of the accelerating pace of new Geological Survey projects in western Sweden this paper is intended to stimulate discussion, facilitate comparisons, and make a number of new facts and suggestions generally available.

2. THE ÅMÅL-KROPPEFJÄLL GRANITES AND ASSOCIATED ROCKS

(a) Age sequence in the Ödeborg area

THE ELLENÖ COMPLEX

In the Ödeborg-Färgelanda-Ellenö area (fig. 2), which forms the northwestern part of the Geological Survey quadrangle map Vänersborg NO, detailed mapping in 1968 and 1969 revealed the existence of a group of supracrustal rocks which is traversed by two generations of granite, but in turn contains pebbles of still another pegmatite-associated red microcline granite. These supracrustals have previously merited short mention by Svedmark (1902) and have later been regarded as "Gothian" which is the position attributed to them int. al. in the latest Geological Survey Map of Sweden (Magnusson 1962). As we have seen, Magnusson's use of this term implies an age earlier than that of the "Åmål-Kroppefjäll" granite. Heybroek (1950) tentatively referred this and other neighboring localities of supracrustal rocks to the Kappebo formation (Sandell 1941). There is much to substantiate this or an analogous relative age classification of the supracrustals in the Ödeborg area. The younger of the two granites traversing these supracrustal rocks probably belongs to a system of dikes related to the Bohus intrusions farther west, while the older one shows textural varieties transitional to porphyry members of the supracrustals. In the following this latter granite and the transected supracrustals will be referred to as the Ellenö complex rocks.

The Ellenö complex can be split up into three main subdivisions: (a) "graywacke" and granule breccias, (b) porphyries, and (c) granite. Lithological characteristics of the supracrustal units are summarized in Table 1.

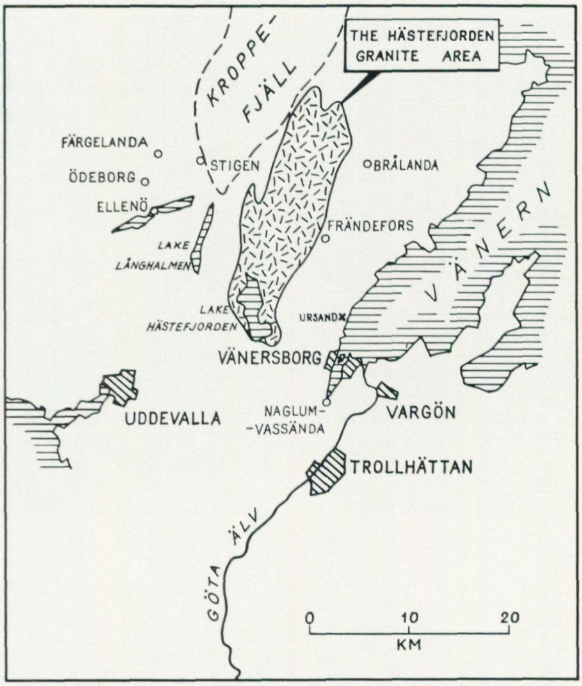

Fig. 2. Sketch-map of the Vänersborg–Uddevalla area showing the localities mentioned in the text.

Table 1. Lithology of Ellenö rocks

GRANULE BRECCIA GROUP:
Composition: Arkosic. Quartz grains set in a micaceous quasi-matrix of dissipating, deformed, strongly sericitized and epidotized ex-feldspar detritus. Unaltered feldspars moderately common. Biotite, chlorite, muscovite, epidote, sphene, opaques, carbonates. Secondary muscovite, epidote, sphene, chlorite, albite, and potassium feldspar. Recrystallized quartz spools. Rock fragments.
Grain size: Gravel to fine sand. *Sorting:* Rather poor
Color: usually gray with, in some types, conspicuous blue quartz and red feldspar insets.
Internal stratification: Usually absent.
Nature of boulders and stones: "Jerbo" gneiss, reddish-gray gneiss-granite with large microcline megacrysts, red microcline granite, pegmatite, vein quartz, amphibolite, paragneiss (rare),

PORPHYRY:
Brownish- or grayish-red rocks with feldspar and feldspar plus quartz phenocrysts (commonly granulated). *Mineral composition:* Quartz, microcline, plagioclase, muscovite, chlorite + sphene/biotite, ores, apatite, zircon, carbonates, fluorite. *Matrix texture:* recrystallized mosaics, average grain-size 0.02–0.03 mm. Inclusions of country-rock are rare. Large inclusions are angular, but show some contact resorption, small inclusions are rounded and corroded.

TECTONIZATION AND RECRYSTALLIZATION:
Thorough postdepositional recrystallization is commonly, but no necessarily accompanied by tectonical reworking producing foliated micaceous pseudoschists with almost obliterated original feldspar-to-feldspar boundaries. Quartz grains may be fractured. Secondary albite develops small fresh crystals or sponge-like larger units ("graywacke") or forms clear rims around potash feldspar (porphyries). K-feldspar porphyroblasts associate with dikes of Ellenö granite. They are essentially predeformational in relation to deformation period (4) of p. 12. Microdislocations of this period are related to the development of regional west-dipping scale-overthrust tectonics which farther east also affect the Dal Formation. From the relations between deformation textures and foliation in the surrounding gneiss-granite and in gneiss-granite boulders in the supracrustals a distinct difference is found between tectonization stages (1) and (3) vs. (4).

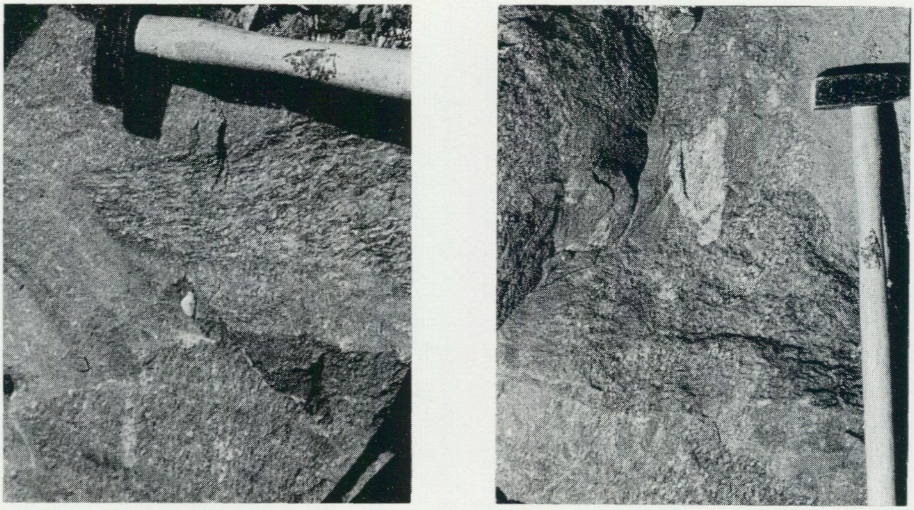

Fig. 3 a and b. Coarse unstratified units of the Ellenö complex. Left photo shows boulder of gray gneiss-granite, the light fragment to the right is a red microcline granite. Road cuttings SE of Ödeborg.

Granule breccias and porphyries constitute the bulk of the Ellenö supracrustals in the area between Ödeborg and Ellenö where they are surrounded by strongly foliated gray gneiss(-granite) or orthogneiss ("Jerbo gneiss") and reddish-gray gneiss-granite rich in large red microcline megacrysts. These older rocks are cut by dikes of pre- and post-Ellenö red granites.

Granule breccias and "graywackes" sometimes show textures indicating a sedimentary or pyroclastic origin, but often recrystallization is strong and some units may be of tectonical formation. The matrix-rich "graywacke" appearance of the rock is essentially a secondary feature produced by postdepositional alteration, tectonization, rewelding, and recrystallization of the altered feldspar/rock fragment detritus. The process produces a quasi-open framework of quartz grains set in a secondary matrix of phyllosilicate-rich material (fig. 5). If sedimentary, the rock is thus actually a very immature lithic metaarkose and the original contents of clay matrix appear to have been moderate. Thus the present macroappearance is deceiving by suggesting a prominence of matrix phyllosilicates which by microscopic examination is shown to be a secondary metamorphic feature. The same also applies to some of the reexamined rocks from the classical Kappebo localities. Consequently the term "graywacke" is inappropriate as a description of the lithology and becomes still more so if we follow Pettijohn (1957) in considering grading to be the decisive criterion in defining rocks of graywacke classification. The present use of "graywacke" in quotation marks is intended to stress the similarity of the Ellenö supracrustals with Kappebo rocks previously

Table 2. Chemical composition of some Ellenö complex supracrustals

	Granule breccias			Red "leptitic" rock	Quartz-porphyries	
	169	436	127	438	166/1	166/2
wt. p. c.:						
SiO_2	73.0	72.3	72.0	79.2	77.6	80.7
TiO_2	0.38	0.57	0.47	0.13	0.12	0.12
Al_2O_3	15.5	15.8	15.0	12.6	12.1	13.3
$Fe{=}Fe_2O_3$	2.6	4.0	3.6	1.1	1.1	1.2
MnO	0.06	0.08	0.07	0.05	0.02	0.02
MgO	1.3	1.9	1.6	0.27	0.13	0.43
CaO	1.8	1.2	2.1	2.2	0.6	0.3
BaO	0.12	0.11	0.15	0.04	0.07	0.05
K_2O	3.1	5.0	3.8	2.4	5.3	5.6
Na_2O	3.9	1.2	2.1	2.4	3.0	2.2

described by this term (Sandell 1941, Heybroek 1950), but strictly speaking the practice lacks lithological justification and should not be continued in other contexts.

Apart from some small dike occurrences of hälleflintoid very fine-grained appearance, the Ellenö porphyries occupy a coherent area just to the north of Ellenö bridge on road 172 between Uddevalla and Bengtsfors. Except for the immediate vicinity of the large Ellenö fault, the rock lacks recognizable macroschistosity. The porphyry is cut by a few veins of Ellenö granite or rock transitional between granite and porphyry and also contains a dike-like body of dark gray rock with schistose contacts. This dike has not been subjected to closer study – it may or may not be an equivalent of the Kappebo "greenstone".

The Ellenö granite is a fine- to medium-grained pale red rock which forms numerous dikes and sills in the Ellenö granule breccia. Coherent massifs are found between Ellenö and Stigen, dike networks infest large segments of the surrounding areas. Aplitic or quartzfeldspar-porphyric development transitional into Ellenö porphyries is found in some dikes and in contact varieties, but typically the rock is more or less equigranular. There are a few pegmatitic lenses and schlieren. The Ellenö granite is not affected by the strong regional foliation developed during tectonical deformation stages (1) and (3) of p. 12, but has been subjected to some granulation, recrystallization, and deformation of large feldspar grains during stage (4). In addition there are local restricted zones of crushing and mylonitization. Feldspars are plagioclase and potassium feldspar. The latter shows irregular flecky twinning, but lacks microcline grating. Perthite/antiperthite is rather prominent, but unmixing has

Fig. 4. Bedded refoliated arkosic Ellenö rudite or tectonical pseudorudite. 1 km SSE of Ellenö.

Table 3. Chemical composition (wt. p. c.) of Ellenö complex granites

	500/1	169/2	168/1	168/2
SiO_2	75.0	77.2	76.0	78.1
TiO_2	0.17	0.20	0.12	0.11
Al_2O_3	12.6	13.0	13.2	12.2
$Fe=Fe_2O_3$	0.6	0.9	0.6	0.4
MnO	0.03	0.03	0.03	0.02
MgO	0.48	0.45	0.27	0.13
CaO	1.3	1.0	0.7	0.5
BaO	0.05	0.08	0.03	0.13
K_2O	2.0	4.3	5.3	6.3
Na_2O	4.4	3.1	3.6	3.5
K/K+Na	0.23	0.48	0.49	0.54
Mg/Mg+Fe	0.61	0.50	0.47	0.39
normative An in plagioclase (mol. p. c.)	14	16	10	0 (norm.acmite)

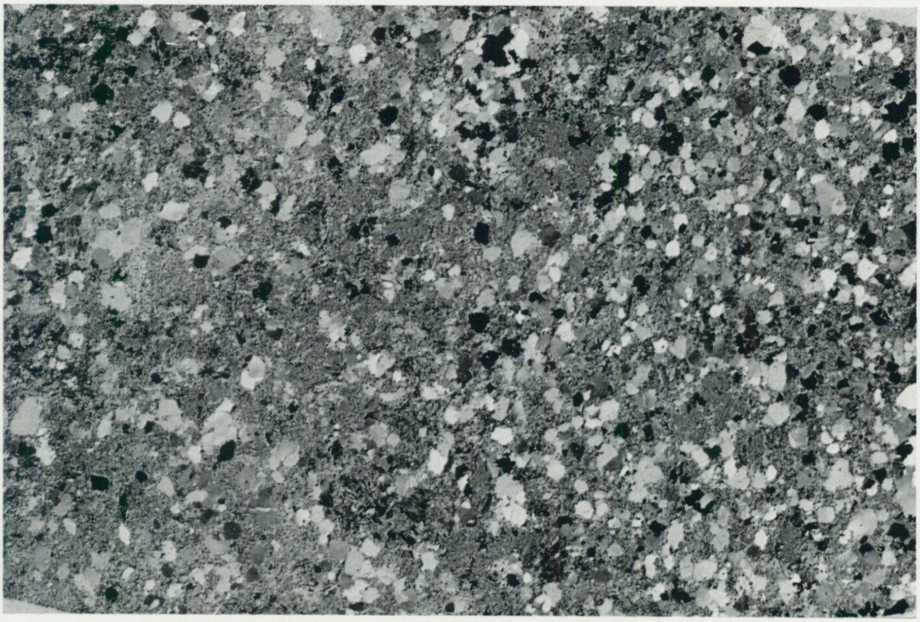

Fig. 5. Micaceous Ellenö arkose. Crossed nicols, linear enlargement 5x.

often proceeded to the advanced stage of rim formation. Sericitized plagioclase contains large secondary aggregations of muscovite flakes. Carbonates are rather abundant. Dark minerals are magnetite and relics of light brown biotite surrounded by secondarily developed aggregates of ore, almost colorless magnesian chlorite, and sphene or rutile. Other minerals are the usual granite accessories zircon, fluorite, and apatite.

THE ENVIRONMENT OF THE ELLENÖ GROUP

Among the rocks which are found as inclusions in the Ellenö supracrustals (Table 1) a gray medium-grained granitic gneiss is by far the most common in the environments of that complex. This rock which has previously been described as Jerbo gneiss (Sidenbladh 1870) is supposed to be a schistose equivalent of the "Gothian" Åmål granite (Törnebohm 1883; Winge 1900; Holmquist 1906) and is, strictly speaking, a foliated granodiorite gneiss. As will be considered later we actually have two distinct groups of gray granitoid plutonics which may aspire for the term Åmål granite and which are somewhat different in age and tectonic position. For the present it suffices to state that the Jerbo(-Åmål) in the Ödeborg area is one of the rocks hitherto accommodated under the Åmål-Kroppefjäll roof. It extends from Ödeborg past the vicinity of Uddevalla (fig. 2) and can in the opposite direction be traced far to

Table 4. Chemical analyses of Jerbo gneiss-granite in the Ödeberg area and of some similar rocks (weight p. c.)

	Ödeberg area				S of Stigen	S of Frän-defors	WSW of Lång-halmen	
	171 B/1	171 B/2	172/2	170	333	225	442	445
SiO_2	66.1	66.2	68.5	64.2	66.2	68.4	76.5	69.3
TiO_2	0.66	0.55	0.60	0.63	0.65	0.49	0.27	0.39
Al_2O_3	15.4	15.4	14.6	15.4	15.5	15.2	14.5	15.1
$Fe_{tot}=Fe_2O_3$	4.7	4.4	4.2	4.9	5.1	4.3	2.1	3.3
MgO	2.6	2.4	2.0	2.6	2.7	1.7	0.8	1.3
MnO	0.08	0.07	0.11	0.08	0.09	0.11	0.05	0.06
CaO	4.3	4.1	2.8	4.4	3.5	3.6	1.9	3.0
BaO	0.06	0.07	0.07	0.08	0.04	0.08	0.12	0.07
Na_2O	3.3	3.5	3.7	3.0	4.8	3.5	3.7	3.7
K_2O	3.0	3.5	3.3	3.6	2.1	3.4	3.1	2.6

the north into hitherto poorly known parts of central Dalsland. With only a few exceptions found in the area W and SW of Lake Långhalmen – which possibly belong to a younger granitoid plutonic (cf. p. 32) – the Jerbo gneiss of the Ödeborg area is very considerably foliated and ranges from distinctly gneiss-textured rock to belts of thorough crushing and mylonitization. The foliation structures generally have more or less north-southerly trends as distinct from limited and much later zones of brecciation and mylonitization which trend both NS and EW to NE–SW and are clearly later than the folding of the Dal formation. The essentially north-southern foliation structures can be subdivided into at least the following groups:

(1) regional schistosity varying somewhat in intensity between different loci and culminating in local veining outside of the Ödeborg area
(2) local zones of foliation and mylonitization
(3) renewed regional foliation which in the area considered here is weaker than (1) and affects rocks which are later than the main period of schistosity development (1). This foliation is missing in some parts of the Ödeborg area. Associated is local granite-pegmatite veining
(4) one or two periods of deformation resulting in local zones of crushing (a few inches to several hundred meters across). Moderate general schistosity and scale tectonics. Faulting.

The foliation textures of the two earliest of these deformation periods have suffered postdeformational recrystallization and local contortion. Instrumental in distinguishing between the different periods of tectonization is their relation to granite textures and to the Ellenö rocks which latter are entirely unaffected by the intensive regional deformation period (1) and the first-mentioned event of localized crushing (2). Regional deformation (1) has in addition to Jerbo gneiss also affected a very prominent system of amphibolite dikes traversing that rock. These dikes can consequently not be parallelized with the porphyrites of Overeem (1948) and presumably represent the source of amphibolite inclusions in the Ellenö complex. Similarly, deformation period (1) has affected the groundmass of a rather homogeneous coarsely microcline-porphyritic granite found to the south of Ellenö. Again, there is a generation of microcline augen which develops in a. o. the Jerbo gneiss and is also found in some contorted metamylonite zones in that rock. Thus it is unambiguously later than both the main regional deformation (1) and the oldest generation of localized foliation (2).

The texture of Jerbo gneiss in the tectonically least deformed areas is finely to coarsly medium-grained equigranular. Color varies from gray over greenish-gray to reddish gray or greenish red. The green element is due to the abundant development of saussurite, sericite, chlorite, and pistacite at the expense of original plagioclase, biotite, and amphibole. Predeformation texture appears to have been equigranular, anhedral, sutured granitic. Mostly there are conspicuous microtextural vestiges of catalastic mineral deformation and we find partial recrystallization, healing, and replacement of these debris by newly formed quartz, feldspar, micas, chlorite, and epidote. The recrystallized elongated quartz grains are sometimes conspicuously bluish. Typically the rock in the Ödeborg-Ellenö area proper is rather homogeneous, showing little interspecimen variation (tables 4 and 5). Reconnaissance mapping suggests that macroscopically more acid varieties are somewhat more prominent W of Ödeborg and farther to the south. Also specimen 333 (western shore of Lake Långhalmen, due S of Stigen) and 225 (S of Frändefors) show compositions deviating somewhat from those in the Ödeborg area. As far as the latter specimen is concerned we are not quite positive that the rock is a chronological equivalent of the Jerbo in the Ödeborg area. The same also applies to specimens 442 and 445 which may belong to a post-Jerbo intrusion W and SW of Långhalmen. Characteristically, traceable variations in the composition of the Ödeborg Jerbo are gradual and slow, exhibiting gamuts of transitional types not describable as well-defined independent units. The Jerbo gneiss-granite contains fragments and resorbed schlieren of older gray gneiss, reddish-gray gneiss, mica gneiss, and metabasites.

As already mentioned the Jerbo gneiss granite is cut by dikes of amphibolite which are commonly boudinaged, foliated, and in extreme cases transformed into biotite-amphibole-chlorite schists. The total amount of these dikes is very considerable. The alignment of the dikes is approximately, but not strictly parallel with the regional foliation (1). Thus it indicates a period of N–S fracturing earlier than the earliest phase of deformation recorded on page 12. Locally the amphibolite dikes are involved in contortive folding which may belong either to a late stage of phase (1) or to phase (3) of tectonization. Still later foliation zones may cut these dikes and folds obliquely, but commonly deformation maxima are found at the contacts between amphibolite and the Jerbo country-rock thus demonstrating the relief of differential strain in zones of preexisting material discontinuities.

Coarse-grained granite-gneisses with rather large microcline megacrysts (1.5–3.5 cm across) occur as a number of rather restricted bodies to the south of Ellenö and to some extent also in the area SE of Ödeborg. Conspicuous about these rocks is the postdynamically partly recrystallized, but still strongly deformed and foliated matrix as contrasted to the usually mono- or oligo-

Table 5. CIPW-norm quartz and feldspars and some other parameters of Jerbo gneiss-granite in the Ödeborg area and of some related rocks

	Ödeborg area				S of Stigen	S of Frän-defors	WSW of Lång-halmen	
	171 B/1	171 B/2	172/2	170	333	225	442	445
Q	21.2	19.2	23.9	18.7	17.6	23.3	36.8	27.8
An	18.4	15.9	13.3	18.1	14.7	15.6	9.8	15.0
Ab	27.8	29.9	31.4	25.2	40.4	29.9	31.4	31.4
Or	17.8	20.6	19.5	21.1	12.2	20.0	18.4	15.6
Cor	–	–	–	–	–	–	1.4	0.6
Normative An in plagioclase	38	33	29	40	26	33	23	31
K/K+Na	0.37	0.40	0.37	0.44	0.22	0.39	0.35	0.32
Mg/Mg+Fe	0.52	0.52	0.49	0.51	0.51	0.44	0.42	0.44
(ionic ratios)								

crystalline, rarely somewhat disrupted megacrysts. Similar textures have been recorded previously in the Dalskog-Dals Rostock area close to the shores of Lake Vänern, NE of the Ödeborg area (Heybroek 1950). Heybroek thinks that the better state of microcline megacryst preservation is due to the higher resistance of these grains to tectonic disruption. As far as the Ödeborg area is concerned there is little to suggest that we should accept this idea for rocks outside of zones of local mylonitization. In some cases the megacrysts have obviously grown as porphyroblasts in originally inhomogeneous preexisting rocks which comprise Jerbo gneiss granite, boudinaged amphibolites, fragments of gneiss and metabasite, and contorted metamylonite. Similar origin is also indicated for numerous diffusely delimited streaks of megacryst-bearing gneiss-granite alternating with Jerbo gneiss-granite in the area W of Ödeborg-Ellenö. These rocks are characterized by the inhomogeneous distribution of megacrysts and rapidly varying megacryst frequencies and sizes. They associate with a reddish gneiss-granite which may or may not belong to the Jerbo-Åmål group and is distinctly more acid and potassic than the gray gneiss-granite described above. To the south of Ellenö there are several small massifs of megacryst-rich foliated gneiss-granite which lacks relics of older rocks except as angular sharply delimited fragments, and which, in spite of locally very considerable foliation, appears to be rather homogeneous. Sometimes microcline megacrysts are found inside the angular gneiss inclusions. As regards macroscopic homogeneity this rock is similar to vast areas of augen gneiss-granite which extend from the Dalskog-Dals Rostock area southward toward Vänersborg and thence far to the east into the "Pregothian". Many of these rocks have passed through repeated stages of metamorphism and foliation and there are textural indications of microcline (re-)formation subsequent to the main regional foliation events, which explains the fresh appearance of the megacrysts as contrasted to the frequently strongly schistose quartz-plagioclase-biotite (-chlorite-muscovite-epidote) matrix. As far as the Ödeborg area is concerned we are still at a loss as to whether most microcline megacrysts are later than the amphibolite dikes, or whether there is an early generation of microcline-porphyritic gneiss-granites with subsequently regenerated recrystallized megacrysts. Frequently high mobility of K is indicated by the formation of potash feldspar megacrysts or microcline lenses in the aureoles of, or in inclusions in equigranular or augen-bearing microcline granites.

Basing his work on an area somewhat farther west Bergström (1963) discusses the formation of megacryst-bearing gneisses and granites. These rocks are found in an environment of metasediments of the Stora Le-Marstrand series and the Geological Map of Sweden (Magnusson 1962) shows them as "Pregothian". However, according to Bergström, they are younger than the metasediments and in this respect similar to the megacryst-bearing gneiss-granites discussed here. In the augen-gneisses and -granites of Bergström's area transitions, relic gneissic structures, and post-folding feldspathization strongly suggest an origin by metasomatic action on sediments. It should be noted that the salient evidence here is the regional context rather than the textural indications of the replacement formation of megacrysts. Textures suggesting late formation of potash feldspar are frequent in gneissic and granitic rocks and have been described in detail by Drescher-Kaden (1948). However, by themselves, and when not referrable to the evidence of deformation fabrics in the rock matrix, they fail to discriminate between formation during late-magmatic or postmagmatic stages immediately succeeding the original crystallization of igneous rocks, and metasomatic action during processes of regional sub-solidus metamorphism. Aureoles of potash feldspar megacrysts and the formation of megacrysts in country-rock inclusions in igneous granites are rather commonplace (e. g. Stone and Austin 1961, Wimmenauer 1963, Emmermann 1968, and references cited in these papers) and do not by their mere existence consti-

Table 6. Chemical analyses of two microcline-megacryst bearing gneiss-granites S of Ellenö

Spec.:	SiO_2	TiO_2	Al_2O_3	$Fe=Fe_2O_3$	MnO	MgO	CaO
127/1	72.2	0.4	14.1	2.3	0.05	0.9	1.9
163/3	70.1	0.5	15.6	3.2	0.08	1.4	2.3

Spec.:	BaO	K_2O	Na_2O	Katanorm An in plagioclase	mg	k
127/1	0.11	5.1	2.8	28	0.43	0.54
163/3	0.12	3.7	3.2	29	0.46	0.43

tute proof of subsolidus in situ formation of granite. Indeed, from the high specific volume of potash feldspar and relative weakness of the K-O bond (e. g. Nockolds 1966), we must expect high susceptibility of potassium to diffusion and "solution transport" in gradients of chemical potential.

Among the analyzed specimens of augen gneiss-granite there are two from the area immediately S of Ellenö (table 6). They show rocks comparatively, but not extremely high in potassium and with rather high Mg/Fe ratios. As would be expected from different macrofrequencies of megacrysts the Na/K ratios are different, which implies that the composition of the matrix does not compensate for differences in the contents of microcline megacrysts. The total amount of Fe+Mg is rather too low to explain these rocks as products of potash or potash-silica metasomatism of the Jerbo gneiss-granite as found in the Ödeborg area (tab. 4). This is further substantiated by the low absolute and relative (vs Fe and Mg) contents of the rather immobile element Ni (30–50 ppm in Jerbo gneiss-granite, < 10 ppm in the augen rock). The nature of the neighboring gneiss-granite has not been investigated in detail and the significance of these chemical characteristics must therefore not be exaggerated.

In addition to stray dikes of Bohus granite we find three main groups of reddish intermediate to acid granites. The oldest of these is tectonically similar to the Jerbo gneiss-granite. The other two form dike networks and massifs associated with aplite and pegmatite. Locally the immediate environments of red granite and pegmatite dikes serve as loci of microcline megacryst (re-)formation. Because fragments of coarsely microcline-porphyric gneiss-granites with untectonized megacrysts are found in the Ellenö rocks, the older of the red dike granites cannot be equivalent to the Ellenö granite and presumably is identical with the balls of microcline granite found in the Ellenö complex.

Table 7. Chemical composition (wt. p. c.) of red dike granites to the south of Ellenö

	158/1	158/2	127/2	163/1	163/2
SiO_2	74.5	78.5	76.8	75.4	76.4
TiO_2	0.18	0.18	0.16	0.15	0.13
Al_2O_3	13.9	11.8	12.4	11.7	13.1
$Fe=Fe_2O_3$	1.2	0.8	1.0	1.0	0.5
MnO	0.03	0.02	0.03	0.02	0.02
MgO	0.34	0.32	0.30	0.24	0.22
CaO	1.4	0.7	0.8	0.3	0.3
BaO	0.14	0.11	0.11	0.03	0.14
K_2O	4.9	5.2	5.2	7.1	7.1
Na_2O	3.9	2.9	3.3	2.3	2.6
K/K+Na	0.45	0.54	0.51	0.67	0.64
Mg/Mg+Fe	0.36	0.44	0.37	0.32	0.47
normative An in plagioclase (mol. p. c.)	14	13	12	4	6

From their relations toward the Ellenö complex we know that one granite-pegmatite generation is older and the other younger than the Ellenö "graywacke". Red granite dikes are particularly abundant immediately S of Ellenö where discrimination between the two generations is frequently difficult because of similar macroscopic appearance and since both are post-kinematic in relation to phase (1) of regional foliation. The chemical parameters of dike granites S of Ellenö are not entirely consistent, but many dike granites appear similar to the Ellenö group in being high in both K and Mg and thus distinctly different from e. g. the Hästefjorden granites (tab. 2, 7, and 9). The distribution of some trace elements is of a non-specific type characteristic of acid granitoid rocks in general. Chemical comparisons with inclusions of red granite in the Ellenö supracrustals have not been attempted.

THE ELLENÖ COMPLEX IN ITS REGIONAL CONTEXT

As is evident from the descriptions above the Ellenö complex displays a rock association which is basically different from that of the Dal formation. Nevertheless it is younger than major periods of regional deformation in the area. Incidentally this renders it impossible to attribute all of the strong regional gneissification of the basement of the Ellenö complex to the Dal orogeny. Since the Ellenö supracrustals and hypabyssals are cut by two generations of granite of which only the younger one can be attributed to the Bohus, the Ellenö rocks cannot be later than the Dal. Because of these similarities in relative geological position and because of some common petrological traits, a rough parallelization with the rocks of the Kappebo formation as described by Sandell (1941), Overeem (1949), and Heybroek (1950) appears to be conceivable. According to van Overeem the basement granitoid gneisses of the eastern outskirts of the Dal formation are cut by quartz-porphyries and porphyrites. The deformation which affected the basement gneisses is claimed to be earlier than these hypabyssals. Thus we find a tectonical situation which is obviously similar to that of the Ellenö complex.

van Overeem's work has been severely critisized by W. Larsson (1948) who thinks that van Overeem has made a couple of fundamental mistakes. Larsson remarks that the inland exposures might be easily misinterpreted. Larsson further states that on the bare excellently exposed shore-rocks of Lake Vänern the relations between the different rocks and the deformation are plainly visible and the quartz-porphyry does not occur as dikes in the older mylonitized granite, but is instead cut by the granite. Subsequently tectonic deformation has struck both rocks, the granite showing up the deformation more clearly than the older, red, fine-grained, salic porphyry. This description is in good agreement with the results of a reinspection of both shore and inland outcrops by the present writer.

However, the existence of a late group of hypabyssal rocks appears indisputable from the detailed work of Heybroek (1950) and from observations in the Ödeborg area. Simultaneously, however, the gneiss-granite contains inclusions of leptitoid, commonly porphyric rocks which have sometimes fallen prey to secondary microcline porphyroblast development. Whether all these rocks should be attributed to the Åmål formation or are older, is still an unanswered question. It suffices to point out that petrographically similar rocks are also found as strongly altered inclusions in the "Pregothian" to the east of Vänersborg and as less deformed or intact relics in the western marginal zone of the "Pregothian" which has escaped intense migmatization. It may thus be that there are two or more different groups of supracrustals of porphyric or leptite-like character (for the use of the term "leptite" by the present writer cf. discussion in Gorbatschev 1969 b). In addition to this, the recognition of the Ellenö granite as an intrusive rock which is clearly later than the other plutonics traditionally accomodated in the Åmål-Kroppefjäll group further complicates the situation and provides for porphyries later than the Åmål supracrustals, but still cut by granites other than the Bohus. Presumably these observations do resolve some of the conflict between the views of Larsson (1947, 1948) and those of van Overeem (1948) and Heybroek (1950). Similarly the difference of opinion between Larsson and van Overeem on the issue of tectonics may largely be a pseudoconflict, since, evidently, there are chronologically different groups of similar rocks as well as a complicated sequence of tectonic events leading to cataclastic failure or dynamometamorphic structures (cf. p. 12). It will be found that related field observations date back as far as Törnebohm's description of the Upperud quadrangle (1870 a), where there is mention of a "hälleflinta" which penetrates the bottom cong-

Table 8. Some chemical parameters of Ellenö porphyries and Kappebo effusives

		Ellenö porphyries		Effusives of eastern Dalsland (Kappebo)				
		166/2		Overeem (1948)	Heybroek (1950)			
	K/K+Na	0.63	0.54	0.45	0.21	0.24	0.42	0.37
	Mg/Mg+Fe	0.45	0.13	0.46	0.05	0.15	0.10	0.25
CIPW Norm[1]	Qz	44.8	38.2	28.0	36.5	34.6	34.0	21.1
	An	1.4	3.0	7.8	2.5	5.4	5.6	8.1
	Or	32.8	31.1	25.6	12.1	13.6	23.9	23.4
	Ab	18.9	25.2	29.9	44.7	43.1	33.0	39.4

[1]) Standard katanorm for Heybroek's samples.

lomerate and graywacke of the Dal formation. The term "graywacke" and some other points suggest that the sediment may actually not belong to the Dal, but to what became later known as the Kappebo formation. Sandell (1941) states that quartz porphyries are found in the Kappebo.

The rocks of the Kappebo formation in the Dalskog-Dals Rostock area have been subjected to detailed examination by Heybroek (1950). Discarding the stratigraphy given by Sandell (1941), Heybroek distinguishes between effusive and epiclastic rock units. We notice immediately the similarity between the poorly sorted, conglomeratic, micaceous debris in the granule breccia of the Ellenö complex and the graywackes, "granule breccias", and open-framework conglomerates of the Kappebo in the Dalskog-Dals Rostock area, which suggests essentially similar tectonic-environmental regimes of formation. In both cases we lack clear evidence of transition into typically geosynclinal sedimentary associations. To this is added the similarity of the position of these two rock groups as regards the hitherto recognized regional foliation events.

Amongst the effusive rocks described by Overeem and Heybroek "greenstones" have so far not been identified in the Ellenö complex. Also the rhyolites and particularly the albite-rhyolites in the east are not quite like the Ellenö porphyry. The main chemical differences are considerably more potassic characters of all Ellenö igneous rocks, a tendency for the Ellenö porphyry to be richer in quartz, and somewhat higher Mg in the Ellenö group. The latter difference gains additional prominence if the Ellenö granite is taken into consideration (table 8, cf. table 3, p. 10). For the Ellenö complex there is no basis to suggest a keratophyre-spilite group label.

The eastern region offers no obvious equivalent of the Ellenö granite. A post-Kappebo age has been suggested for a red leucocratic granite known as the Teåker granite (Larsson 1947, the Teåker granite was originally described in Törnebohm 1870 a), but in Larsson's later chronological table (1958) there is no further mention of the post-Kappebo position of this rock. Heybroek (1950) thinks that the Teåker granite is comagmatic with the Kroppefjäll granite, but slightly younger than the latter rock. According to Heybroek all these granites are more cataclastic than the Kappebo rocks and moreover pebbles of aplite-granite are found in the basal conglomerate of the Kappebo formation. Since we know now that there are red granites which are younger and other red granites which are older than the Ellenö complex – and thus presumably also older and younger than the Kappebo formation – the latter piece of evidence is not compelling.

(b) The Hästefjorden granite massif and surrounding rocks

The Hästefjorden granite massif is a characteristical representative of a group of red acid granites situated in the border zone between the "Pregothian" and the "Gothian". Its geographical location is indicated in Fig. 2. Compilative maps by Magnusson (1962) and Gavelin and Magnusson (1935) refer it to the Gothian Åmål-Kroppefjäll group. Its key importance in the regional context of West Swedish geology arises from problems of its tectonical position and the relations to other similar granites, situated deep in what is considered to be the "Pregothian". During the geological reconnaissance of the Vänersborg area the Hästefjorden massif attracted immediate attention by being free from the thorough foliation, intricate folding, and subsequent refoliation which characterizes the terrain north of Vänersborg and similarly from the foliation which befell the Jerbo gneiss-granite found close to the western contact of the Hästefjorden massif. From the latter loci the Jerbo gneiss-granite extends virtually without interruption into the Ödeborg area considered in the preceding section. Prominent foliation characterizes all of this gneiss-granite sector. In its relations towards regional tectonics the Hästefjorden granite is similar to the inferred tectonical position of the red microcline granite occurring as inclusions in the Ellenö complex. Of paramount importance are the relative ages of the Hästefjorden massif plus other plutonics in its environments and a belt of metavolcanic and metasedimentary rocks situated between Hästefjorden and Lake Långhalmen (fig. 2). We are positive in stating that this supracrustal belt is composed of several chronologically different rock groups. Among them is a series of leptites and porphyric leptites which are older than microcline megacryst-bearing foliated gneiss granites and, quite apart from the tectonical pseudoconglomerates of Gavelin (1912), another group represented a. o. by (?Dal) conglomerates which in areas close to the Hästefjorden massif carry pebbles of red granite. The distribution and frequency of these pebbles is such as to make a derivation from other sources than the Hästefjorden massif highly improbable. Our investigations of the supracrustal belt have not yet proceeded far enough to indicate whether all early groups of rocks may be parallelized with the Åmål series. As will be discussed more fully in the final section of the present chapter much of the terminological classification must await strict parallelization with the type localities of the Åmål quadrangle. Thus for the time present we must necessarily leave some very important regional problems without even a suggestion of solution. It is, however, probable that the metasediments and metavolcanics of the Hästefjorden-Långhalmen area do not belong exclusively to the Åmål series as indicated in current compilative maps, nor are they altogether referrable to the Kappebo formation as tentatively suggested by Heybroek (1950). Because of the recognition of several generations of granite in the "Åmål-Kroppefjäll" terrain the mutual relations of the Åmål quadrangle and the rocks described as Kappebo by Heybroek are in urgent need of reinvestigation. From tectonical differences between the Jerbo gneiss-granite plus the red acid gneiss-granites associated with it, and the Hästefjorden massif it is evident that the attribution of one of these groups to the "Gothian" Åmål-

Kroppefjäll granites excludes the other if we are to define the Åmål-Kroppefjäll more strictly than as just comprising virtually any granitic rock in western Sweden except the Bohus. We shall return to these aspects in section (d) of this chapter.

Proceeding along east-west traverses through the central parts of the Hästefjorden massif we find a somewhat asymmetrical development of its rocks. What may be called the western facies is macroscopically virtually without trace of preferred mineral orientation and is a medium- to fine-grained granite decreasing in grain-size as the western contact is approached. Macroscopically the western rocks appear to be slightly more leucocratic than the rest of the granite. Off the western contact there is an aureole of granitic and aplitic dikes in considerably foliated Jerbo gneiss-granite. Inside the western part of the massif there are a few relatively sharply delimited slices of country-rock gneiss and gneiss-granite. Tectonical disruptions in the granite are limited to restricted zones of mylonitization and faulting. From the relation between dikes of Hästefjorden granite and the very prominent zone of dislocation foliation affecting the eastern part of Kroppefjäll, the Hästefjorden massif is older than the principal mylonitizing tectonization in this zone and of course also older than the overthrusts affecting the Dal formation and the subsequent faulting on subvertical planes. To deem from the relative tectonization and the absence of dike amphibolites in the Hästefjorden massif, the Hästefjorden granite is younger than all amphibolite dikes occurring in the area.

The eastern half of the Hästefjorden massif is medium- to coarse-grained and frequently exhibits a more or less pronounced tendency to develop rudimentary unequigranular microcline-megacryst fabrics. Gradually enhanced foliation is the main textural difference in comparison with the west. In a number of eastern localities there are diffuse schlieren and nebulites of older gray gneiss-granites which to some extent are responsible for the "Abbildung"-texture of preferred crystal orientation. This does of course not apply to purely leucogranitic parts where preferred orientation is due to the development of larger feldspar crystals and the elongation of quartz grains. Diffusely delimited relics of older rocks are often infested with a multitude of microcline porphyroblasts or have been subjected to thorough microclinization. On the whole, the difference between the eastern and western extremes of the Hästefjorden massif is so marked as to indicate the possibility of a difference in age. In the summer of 1969 we therefore undertook a thorough investigation of the northern half of the Hästefjorden massif attaching particular attention to the problem of one or two granites. From the results of this survey the transition between west and east is not sharp, and apart from casual small veins of pegmatite, aplite, and extremely leucocratic red medium-grained granite which on the whole are rather insignificant, there are few indications of intramassif age differences. This point is also brought out by the surprisingly great chemical similarity between Hästefjorden granites of very different macroscopical appearance (table 9). We note that the Hästefjorden granite is a leucocratic rock with an average composition close to the eutectic in the Qz-Ab-Or system. The Mg/Mg+Fe ratios are rather low and the distribution of investigated trace elements is typical of an acid granite. Details of Mg and Ca-content variations are not very significant because duplicate analyses indicate that at the low contents of Ca and Mg found in the Hästefjorden massif the error of determination by the employed analytical method is rather large. There are some characteristical differences in comparison with the Ellenö granite and also with most dikes of questionable age found S of Ellenö (tables 3 and 7): one of these is the much higher Mg/Mg+Fe in the Ellenö rocks, another the consistent moderate Be contents in the Hästefjorden massif (average 6 ppm) whereas Be in all investigated acid granites of the Ödeborg area is below 3 ppm. The K/K+Na ratios of the Hästefjorden granite show some variation, characteristically K tends to be slightly higher in rocks developing rudimentary microcline megacrysts. From the textural relations of the microcline we are confident in stating that this is due to a late- or postigneous K-impregnation which is presumably also responsible for the development of microcline megacryst aureoles and megacrysts in inclusions of country rocks.

The rocks bordering on the Hästefjorden massif in the south and east comprise gray gneiss-granites, amphibolites, leptitic rocks, and a medium-grained foliated gneiss-granite with coarse microcline megacrysts which also occupies part of the western contact of the granite massif. Regrettably a great part of the eastern contact towards the augen rock runs along a system of later fault lines, but nevertheless normal contacts are numerous enough to allow a generalized comparison with the west. We find that the development of fine-grained contact granites is much more prominent in the west. In the east there is instead a high frequency of medium-grained migmatizing granite dikes and schlieren and of microcline porphyroblasts.

Incidentally microcline porphyroblasts are more numerous in foliated medium-grained gneiss-granites than in leptitic supracrustals whereas contact amphibolites at the other end of the gamut tend to lack porphyroblasts altogether and instead develop breccias in a matrix of granitic dikes and veins which sometimes have feldspar- or feldspar-quartz-porphyric textures. Altogether, metasomatic action has been more prominent in the east and clean breakthrough contact relations in the west. As regards the microcline-megacryst-rich gneiss-granite there has been formation and redevelopment of megacrysts in the immediate vicinity of the Hästefjorden granite, but there is no indication that the original megacrysts are contemporaneous with the Hästefjorden intrusion.

Table 9. Chemical composition and some other chemical parameters of red granites from the Hästefjorden massif

wt.p.c.		488/1	488/2	229	236	256	482
SiO_2		77.3	78.9	76.9	75.0	77.1	74.6
TiO_2		0.12	0.10	0.17	0.26	0.13	0.17
Al_2O_3		12.8	11.9	10.8	13.3	11.7	13.4
$Fe{=}Fe_2O_3$		1.2	0.9	1.5	2.2	1.6	2.0
MnO		0.01	0.01	0.02	0.04	0.03	0.03
MgO		0.18	0.06	0.14	0.29	0.03	0.06
CaO		0.8	0.5	0.3	0.7	0.7	0.6
BaO		0.01	0.01	0.02	0.04	0.01	0.01
K_2O		4.5	4.4	5.3	5.4	4.1	6.1
Na_2O		4.1	3.7	3.0	3.3	3.1	3.4
ppm:							
	Be	8	7	4	5	7	3
CIPW norm	Qz	34.0	38.8	38.1	32.3	41.0	30.4
	Or	26.7	26.1	31.1	31.7	24.5	36.0
	An	3.3	2.5	0.6	3.6	3.6	3.1
	Ab	34.6	31.4	25.2	27.8	26.2	28.8
	Cor	–	0.1	–	0.7	0.8	–
Mg/Mg+Fe		0.23	0.12	0.16	0.21	0.04	0.06
K/K+Na		0.42	0.44	0.54	0.52	0.47	0.54

Key:

488/1 Fine-grained granite
488/2 Medium-grained leucocratic granite
229 Coarse almost equigranular massive granite
236 Medium-grained grayish-red gneissic granite, faint tendency to develop megacrysts
256 Coarsely medium-grained, submassive granite
482 Coarsely medium-grained, submassive granite with very faint tendency of megacryst development

In the part of the Vänersborg area close to the Pregothian/Gothian boundary in the Geol. Map of Sweden there are two additional bodies of red medium-grained acid granite which are similar to the Hästefjorden massif. One of these is situated a few kilometers north of Vänesrborg (W of Ursand), the other in the Vassända-Naglum area between Vänersborg and Trollhättan. In the development of their core parts both remind of the Hästefjorden granite. The main difference is in the contact relations. Granite and pegmatite dikes and break-through contacts occur in all three instances, but the limits of the Ursand and the Vassända-Naglum granites are commonly of a diffuse migmatization/feldspathization type producing broad vein- and/or megacryst-rich aureoles preserving nebulitically the original textures of the country rock. In the Ursand case this is a foliated slightly veined medium-grained (granite-)gneiss with or without phenocrysts, and in the Vassända-Naglum area a veined migmatite – a more migmatized equivalent of the Ursand country rocks. The cores of all three granites typically have textures which are clearly postkinematic in relation to the main areal foliation/folding/migmatization. Even if similarities thus are great and point toward an eastward gradually increasing infrastructure aspect of the red acid granite bodies, we do not at present venture to consider this to be proof of a strict contemporaneousness of the Hästefjorden, Ursand, and Vassända-Naglum massifs. A close scrutiny of the area between the Ursand and Hästefjorden massifs is in progress and we prefer to await its results before proposing a definite opinion on the age relations. However, we wish to point out the inconsistency of the tectonical position of the Hästefjorden massif with the concept of a single Åmål-Kroppefjäll granite group embracing all rocks referred to the Gothian in the generalized maps of western Sweden.

(c) "Pregothian" migmatites and the nature of the Göta älv line in the Vänersborg area

Mapping in the Göteborg area in the forties and fifties demonstrated the importance of the Göta älv line as a limit between the Gothian granites in the west and what is now called the Pregothian in the east (Lundegårdh, 1958, 1959). In emphasizing the significance of tectonic dislocation along the Göta älv fault zone Lundegårdh links in with the work of Holmquist (1906) who described the Göta älv-Byälven line as the first-order limit between gneissic rocks in the east and granites in the west. Holmquist thought that the transition between these rocks is gradual and caused by different degrees of metamorphism and deformation. In the northern – the Byälven – part of this line Magnusson's investigations (1929 a and b, summaries 1962, 1963) do not suggest a major dislocation-type tectonic boundary. According to Magnusson the rocks of the Åmål supracrustal formation instead rest concordantly on Pregothian gneisses.

The northern end of the conceivable Göta-älv-line-limit between the Gothian and the Pregothian has been reinvestigated in the Vänersborg area. This work was conducted in the summers of 1968 and 1969 with the particular aim of defining a limit of the "Pregothian" and of ascertaining the role of the Göta älv dislocation in this area. Close to its outflow from Lake Vänern Göta älv

Fig. 6. Gray gneiss(-granite) with "layer granite", amphibolite (right), and thin late veins. Just to the right of the compass an inclusion of gray fine-grained gneiss is cut by a granitoid "layer". Korseberg, 2 km to the south of Vänersborg.

describes a bend toward the east and the fault does not follow the course of the river. The zone of strongest beltiform foliation in the area is the Vassända depression passing through Vänersborg. The solid basement is not exposed in the central parts of this depression, but the rocks adjoining in the west are strongly foliated, mylonitized, and have subsequently been subjected to brecciation. The nature of the "Pregothian" in the Vänersborg area and its transition into the "Gothian" are considered in the present section.

The predominant rock in the Vänersborg area is a gray or less frequently reddish-gray to grayish-red medium-grained gneissic plutonic of mostly approximately granodioritic-tonalitic composition. It varies in texture from migmatized gneiss in the east, over medium-grained strongly schistose gneiss immediately S and W of Vänersborg, to pronouncedly gneissic gneiss-granite in the area SE of Hästefjorden (fig. 2). Similarly to the gneiss-granite of the Ödeborg area this rock is traversed by dikes of what is now fine- to medium-grained amphibolite or biotite(-garnet) amphibolite. These dikes align more or less strictly with the foliation of the gneiss(-granite). In the area NW of Vänersborg this implies NNE directions of strike. Because there are inclusions of still older amphibolite in the grey gneiss(-granite) the amphibolites concerned here cannot be other than dikes. Inclusions in the gray gneiss-granite also comprise fine- to finely medium-grained gray and brown gneisses ranging from mica-gneiss over leptitoid gneiss to amphibolitic gneiss. Locally, as for instance in part of the area between Vänersborg and Vargön, these rocks predominate over the gray gneiss(-granite). In regions of very strong foliation, e. g. in the area N and NE of Vänersborg, tectonic elongation of small fragments of gneiss enclosed in the gray gneiss-granite may be extreme and we find shortest to longest diameter ratios of 1:10–1:30. Younger than the gneiss-granite and the amphibolite are "layers" of fine-grained gray or seldom grayish-reddish granitoid to aplitoid rock with have orientations controlled very strictly by the direction of pre-migmatization regional foliation. These fine-grained "layers" are themselves appreciably schistose (fig. 6). The width of the "layer granitoids" ranges from close to one centimeter to usually less than a few meters, thicknesses between 3 and 20 cm being most common. This development of the gneisses and strongly gneissic gneiss-granites is exceedingly common throughout the western block of the Pregothian which occupies the area between the "Gothian" and the "Mylonite Zone". It has been observed at so widely different localities as e. g. the areas of Vänersborg-Trollhättan, Arvika (close to the N margin of Gillbergaskålen), Sunne, and Charlottenberg (close to the Norwegian border, SW of Magnusson's Mylonite Zone). So far we have no observations of larger massifs of granitoid rock which can be undisputably parallelized with the "layer granite".

The following features are relevant in a discussion of the origin of the fine-grained gray granitic "layers":

The orientation is strictly controlled by regional foliation, this alignment may have been accentuated by subsequent very strong compression of the enclosing rocks. The delimitations of the "layers" are always very sharp and clean-cut. In spite of very strict control by foliation there are a few observations of low-angle crosscutting in relation to composition inhomogeneities in the enclosing rock. The "layers" may occasionally wedge out, branch, and enclose short lensoid segments of the surrounding rock. They never occur as short isolated lenses, there are usually no biotite "stringers" or similar inclusions in the "layer granites". Except for areas of later small-scale folding and migmatization there is no meandering of the "layers". Grain-size is usually different (finer) from that of the enclosing rock. From stray thin-sections the composition is approximately normal granitic; the contents of dark minerals (biotite) are low to moderate, pegmatitoid lenses may occur in the "layer granite", but are extremely uncommon and may be of later date. The "layer granite" occurs both in gneiss-granite and its equivalents, metasupracrustal gneisses, and amphibolites; as far as can be ascertained now the composition of the "layers" is independent of the kind of enclosing rock. The frequency of "layers" appears to have been controlled by the metamorphic (and stratigraphic ?) "depth" level of the different localities – as the "Gothian" of the Vänersborg area, the "Gothian" of Gillbergaskålen, and "Gothian" of the Mylonite Zone in the Sunne area are approached the "layer" frequency decreases gradually and finally drops to nil. Simultaneously the enclosing rocks pass from veined migmatites over strongly foliated gneiss into moderately schistose rocks with local zones of strong crushing. Thus in spite of different timing, the "layer granite" formation is correlated with the zoning of regional deformation and metamorphism. The frequency of "layer granite" also appears to drop "downwards" in areas of intense veining, migmatization, and small-scale contortive folding. This may, however, be an illusion since the different original rock components may be rendered unrecognizable by migmatization and later veining.

These observations warrant the following conclusions:

The "layer granites" cannot be beds of different composition in an originally supracrustal, subsequently granitized sequence.

The "layers" must be later than the formation of the enclosing rocks and later than the introduction of dike amphibolites.

The "layers" – and at that the amphibolites – have been emplaced after the initial development of the regional tectonic pattern which determines the principal schistosity and foliation. Part of the apparent strict control of "layer" orientation by foliation is due to the post-formational elongation compression of the whole rock sequence. The virtual absence of ptygmatic-type folds in the "layers", which due to differences in mica contents probably were more rigid than the gneiss-granite, nevertheless suggests good original tectonic control of "layer" shape. Also boudinaging of amphibolites is rather modest in the presently exposed surface section.

A plausible mode of "layer granite" origin is formation by segregation under control of well-developed foliation surfaces. Whether material has been added from the outside remains an object of further investigation.

In the veined-gneiss-migmatite areas immediately S and E of Vänersborg there are in addition a few small bodies of fine- to medium-grained plutonics belonging to two different types. One has an approximately granitic composition, is moderately gneissic and carries small fragments of grey gneiss. It can perhaps be equivalent to the "layer" granites. The other type which is dark grey dioritic or monzonitic occurs as a few boudinaged bodies some tens of meters across. It has not been subjected to closer examination. Both rocks appear to be older than at least the last manifestation of migmatization, but nevertheless and presumably because of their fine grain-size and poorly developed foliation they contain few migmatic veins.

The thorough migmatization around and to the east of Vänersborg postdates the formation of all the rocks considered above. In general terms its intensity increases toward the east.

Proceeding along a NW–SE section through Vänersborg the sequence of rock development may be described as follows (fig. 7–12):

– Approximately 5 km NW Vänersborg: supracrustal gneisses, amphibolites, and gray gneiss-granite with dikes of amphibolite. Usually large- to moderate-amplitude folding. Good prefolding foliation in the gneiss granite. local postfolding foliation. Frequency of "layer granite" moderate to nil. Dikes and diffusely delimited lenses of red granitoid rock and pegmatite which are cross-cutting or conform with the folding pattern. They may be associated with augen development in the enclosing rocks and have together with these been subjected to postfolding schistosity and lineation development.

– 2–3 km NW Vänersborg: increasing prominence of small-amplitude folding. Very strong pre-folding foliation, moderate to strong post-folding foliation. High frequency of "layer" granite. Red medium- to fine-grained vein/dike granites associated with pegmatite have compositions varying from normal granitic to extremely potassic. These have been involved in the folding, but appear to be free from pre-folding schistosity. The shapes of the red granite "dikes" are irregular, alignment with folded schistosity surfaces is moderate to good. Outright cross-cutting is rather common. Variability in composition, thin stringers of biotite derived from the enclosing rocks, and occasional basic rims indicate prominence of formation by replacement and segregation (fig. 13). Inhomogeneous distribution, association with aggregated small bodies of red granite, and compositional criteria suggest introducing of part of the material from outside of the presently exposed area. There is no general vein development in the gneiss granite.

– WNW part of Vänersborg town and area immediately S of Vänersborg: Locally very intense small-amplitude contortive folding. Post-, syn-, and prefolding foliations are prominent. Incipient development of general veining. The characteristics of the different original rocks are still well recognizable. Several types of veins can be distinguished:

– veins developing by small-scale segregation of the dark and light components of gneiss-granite and metasupracrustals

– "veins" forming by recrystallization of the "layer" granites

Fig. 7. Incipient segregation veining in amphibolite. The broad lighter bands (bottom left and top right) are "layer granites". 2 km SE of Lake Hästefjorden.

Fig. 8. Folding and foliation in an unveined mixed gray gneiss-granite – "layer granite" sequence. To the left is a pegmatite nodule. Korseberg, 2 km S Vänersborg.

Fig. 9. Incipient vein formation in a mixed gray gneiss-granite – "layer granite" sequence. The "layer granites" tend to recrystallize into "veins". Southern outskirts of Vänersborg close to Korseberg.

Fig. 10. Close-up of incipient veining in gray gneiss-granite. Same locality as in fig. 9.

Fig. 11. Veins formed by segregation and by recrystallization of "layer granite" in gray gneiss(-granite). Location of large pegmatite vein is controlled by fold geometry (lower part of the photo). Southern outskirts of Vänersborg near Korseberg.

Fig. 12. Veining complete. The original lithology can no longer be identified in detail. Veined gneiss at the Vänersborg water-tower.

Fig. 13. Schlieren of red microcline granite in foliated composite gray gneiss. Note thin biotite stringers projecting from the gneiss into the granite lenses. Periphery of the Ursand granite body between Ursand and Frändefors.

– veins which from total composition must depend on material introduced from outside of their immediate environment.

– veins and dikes of granite and pegmatite which cut across the folding. These may locally be accumulations of segregated alkali-silica-rich material, but apart from that they form vein/dike aureoles around local bodies of red granite (the Vassända-Naglum massif and other smaller units). We can generally discern two groups of these granite veins. One is ptygmatically folded, boudinaged, or develops foliation and lineation. The other is massive, undeformed, and unfoliated. When both occur together in the same outcrup the latter is always recognized as the younger one.

– Area between Vänersborg and Vargön: Small-scale folding in a terrain of veined gneiss-migmatite. The individuality of various original rock units may be rendered unrecognizable. Different types of veins merge. There is locally a tendency for the leucosome and melanosome of the veined gneiss to coalesce into homogeneous units with well-developed microcline megacrysts. Microcline augen also grow in relic bodies of less migmatized rock and to a great extent the loci of vein and megacryst formation are mutually exclusive. Nevertheless, in the Vargön area previously veined rock is overridden by subsequent formation of microcline porphyroblasts. Here the long axes of the megacrysts show preferred orientation (NNW) which is independent of still recognizable small-scale contortive folding and veining. Passing through Vargön there is a belt of somewhat foliated rather homogeneous augen gneiss-granite with large monocrystalline megacryst units.

From the relations just mentioned it is evident that a period of microcline porphyroblast formation is contemporaneous with or somewhat later than the development of migmatite – veined gneiss, and is another aspect of metasomatic action in terrains dominated by the transition from gray gneiss-granite to "Pregothian" veined gneiss. Still, as far as megacryst-bearing rocks are concerned, there remain numerous unanswered questions. Two of the most important ones are: (1) is there a pre-migmatization augen-granite in the area? and (2): Have any augen rocks formed subsequent to the principal folding and migmatization period of the Vänersborg area, but earlier than the "second generation" granite clan considered below? Because some medium-grained acid granites, e. g. the Ursand body, develop aureoles of megacryst formation and regeneration of previously granulated megacrysts in what appears to be older augen rocks, these problems are also of cardinal importance in the classification of red acid granites as a means of investigating the relations between "Gothian" and "Pregothian". Mapping of the Vänersborg quadrangle shows that megacryst-bearing gneiss-granites are not restricted to a certain segment of migmatite areas, but occur as large coherent bodies between Vänersborg and Ödeborg in areas which are inferred to be at very different positions in the sequence of metamorphism as sketched above. For instance, the augen rock around Frändefors is found in an environment where metamorphism of the gray gneiss-granite is still very far from the veining stage. This also applies to identical rocks west of the Hästefjorden massif and to the Ödeborg area. Of key importance in the dating of augen gneiss-granites is their relation toward the amphibolite dikes traversing the gray gneiss-granite e. g. to the south of Ödeborg. As far as the area N of Vänersborg is concerned our evidence so far is negative: we have only a few dikes of plagioclase-porphyritic metabasite in the augen rocks and these dikes are different and strike differently from the NNE-aligned schistose amphibolites in the gray gneiss. There are inclusions of amphibolite in the coarse megacryst-bearing gneiss-granite S of Frändefors, but they associate with leptitic supracrustals and thus may belong to a supracrustal group which was found to be even older than the gray gneiss-granite. We are at present not prepared to embark on a further consideration of the problem of acid granite-augen gneiss granite-amphibolite relations.

Geological reconnaissance carried far into the Pregothian to the east of Vänersborg shows that there is no essential difference between that area and the rocks on either side of the inferred northern continuation of the Göta älv line. The principal unit is still the medium-grained gray gneiss-granite of the area to the north of Vänersborg. There are considerable amounts of leptitic gneisses and micaceous metasediments. The latter are somewhat more prominent here than around Vänersborg. The development of "layer granite" is similar to the areas considered previously. The pattern of veining and migmatization belongs to two somewhat different types:

– Areas of migmatization associating with bodies of medium-grained red granite and pegmatite, and

– Overall veining without evident relations to particular granite bodies. In the latter case vein frequency and composition depend on the character of the mother rock: while the veining of leptitic gneiss, metaargillites, and granitic rocks is leucogranitic, the veins in granodioritic or still more basic varieties of the grey gneiss(-granite) tend to be rather poor in quartz and carry amphibole. This composition control indicates an essentially local derivation of the vein material. We can thus distinguish between veining depending on the segregation of material from the enclosing rocks vs. local centra of granitization drawing on material derived from the outside. In addition, and similar to the Vänersborg area, there are independent cross-cutting intrusions of fine- to medium-grained reddish granites which are post-tectonical in relation to folding and migmatization. We may recall that similar differences in the composition of migmatite veins have been recorded from the Göteborg area where Lundegårdh (1958) distinguishes between a "Pregothian" generation of sphene-bearing syenitic veins and a granitic "Gothian" veining. We find that the development of veins poor in quartz is more or less strictly related to "basic" metaplutonics. The abundance of sphene is here a predictable consequence of the replacement of plutonic amphiboles and biotites by hornblende in segregation veins. Similar phenomena are common in other areas of regional metamorphism, e. g. the Black Forest in Germany (Mehnert and Büsch 1966, Büsch 1966). In the Vänersborg area we find that the "second generation" granites shortly referred to above, cut across the folding in the gray gneiss-granite and also are younger than the principal microcline megacryst-bearing gneiss-granite of the area. Even though we have no undisputable "second generation" granites traversing the Vänersborg veined gneiss, this suggests that migmatization which is later than the "second generation" Gothian (?) granites may not be represented in the Vänersborg area at all. This problem is still not definitely solved. Of interest in this context is the mention by Lundegårdh (1958) of a serorogenic "Gothian" granite generation in Göteborg which had not been previously recognized as such. We have thus no a priori reason to assume that our "second generation" and the Åmål-Kroppefjäll group as described from the Göteborg area must be identical.

What is here termed "second generation granites" form numerous elongated bodies of varying extent in the area between Vänersborg and Hästefjorden. Farther to the north the "second generation" is restricted to fine-grained dikes in older rocks. Generally speaking these dikes are aligned subparallel to the regional direction of foliation, but especially in areas of moderate-scale folding there are numerous uncomplicated cross-cutting contacts which show that the "second generation" group is younger than the gray gneiss-granite, the coarse microcline-megacryst-bearing gneiss granite between Vänersborg and Frändefors (fig. 2), the "layer granites", and all kinds of schistose amphibolite found in the area between Vänersborg and Hästefjorden (fig. 14).

In the area to the west of Vänersborg the "second generation" comprises a diversified rock series ranging from gray intermediate and basic granites

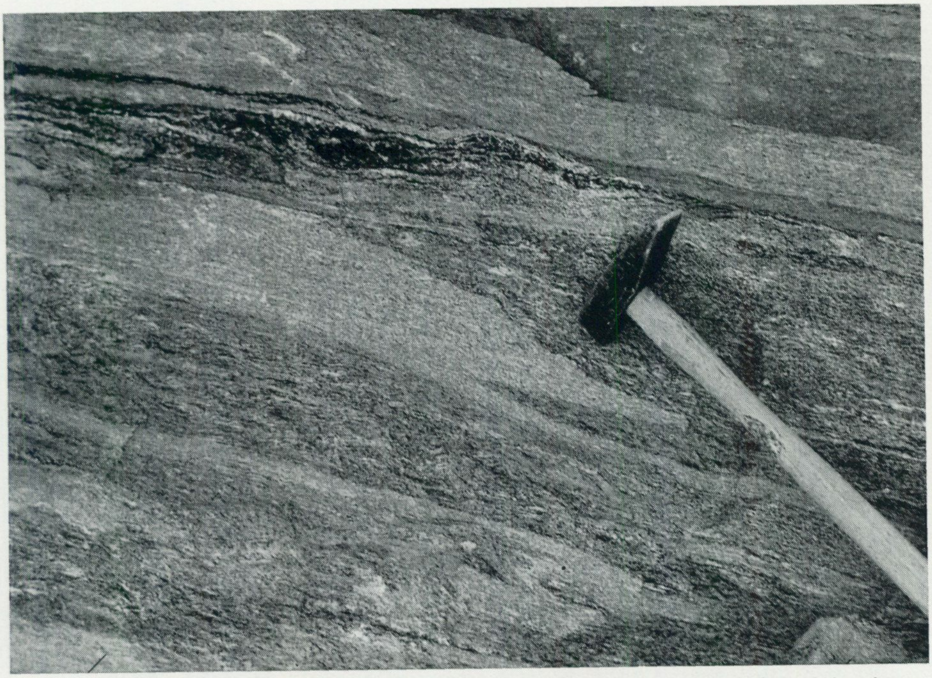

Fig. 14. Older gray gneiss-granite ("1") with relics of gray gneiss and slight veining is cut by subconformous lighter "second generation" gray gneiss-granite "2". 2.5 km WNW Vänersborg.

over microcline-porphyritic reddish-grayish granites to reddish rather acid granites. Still it appears from cursory examination that there are few rocks quite as moderate in quartz contents as the older gray gneiss-granite. From the absence of "second generation" granite intrusion into the Hästefjorden massif it appears that this unit may also be a late member of the group. Foliation and schistosity in the second generation granitic rocks is considerably more irregular in intensity than the regional foliation of the older gray gneiss-granite in immediately neighboring areas. We also have a few instances of intrusive contacts between gray granites of "second generation" relative age classification where the intruding rock is massive whereas the intruded unit is moderately schistose. Foliation in "second generation" rocks ranges from almost imperceptible to zones of very strong cataclastic deformation and schistose foliation which may be several hundred meters across. Much of the deformation structure of the second granite generation appears to be similar to the post-folding foliation in the older rocks to the north of Vänersborg. Its direction coincides with the regional strike which thus is rather invariable all the way from the earliest recognizable foliation of the oldest "Pregothian" unit to the strikes of the folded and thrusted sediments of the Dal formation. In connection with the problem of microcline megacryst development it is important to note that "second generation" gray granites with microcline megacrysts carry fragments of an older gneiss-granite which contains large megacryst microclines.

As far as the western part of the Vänersborg NO quadrangle is concerned we have as yet no definite indications as to whether the gneiss-granites in the Ödeborg area are "first" or "second" generation plutonics. As mentioned previously compositional and some tectonic and relative age features suggest that quite apart from the Ellenö granite we may have to reckon with two different groups of gray intermediate to basic granitoid plutonics hitherto included in the "Gothian".

Returning finally to the significance of the Göta älv line in the Vänersborg area we find that neither the Vassända depression nor any other alternative zone of mylonitization, faulting, or brecciation west of Halle- and Hunneberg qualify as "The Boundary" between the "Pregothian" and the "Gothian". Instead the contacts between terrains dominated by either gray gneiss-granite or "second generation" are usually normal intrusive ones. We can thus definitely discard the Göta älv line of the Vänersborg area as the unique boundary between the "Gothian" and the "Pregothian". Its role as such a limit in the Göteborg area must depend on a much greater amount of throw than what is found around Vänersborg or else the continuation of the Göta älv throw must be sought far to the east of Vänersborg.

It appears that in the Vänersborg area the limit between Gothian and Pregothian as interpretable from Gavelin and Magnusson (1935) is a fair generalization of the boundary between areas dominated by older gneiss-granite and our "second generation" rocks. It must, however, be emphasized that units of both classifications interfere on either side of that boundary and that "Pregothian" units reappear far to the west.

(d) The status of Kroppefjäll granite

In the preceding sections of this chapter we have considered several plutonic rocks which enter what has hitherto been regarded as the Gothian Åmål-Kroppefjäll group. As far as the Vänersborg area is concerned we cannot escape the conclusion that the "Åmål-Kroppefjäll" group comprises several disparate elements starting from gneiss-granites which are unmigmatized better preserved equivalents of units labeled "Pregothian" farther east and finishing with the Ellenö granite which has considerable extent in the Ödeborg area and may also reappear in other sectors allegedly occupied by "Gothian" plutonics (cf. e. g. Törnebohm 1883). These observations suggest the urgent need of a reinvestigation of the type localities around Åmål and step-by-step correlation of the Åmål chronology with other areas of supposedly "Åmål-Kroppefjäll" granites. We know for instance that "second generation" rocks clearly cut previously foliated gray gneiss-granites with microcline porphyroblasts, a rock type which not only extends into the "Pregothian" in the east, but can also be traced northward into areas considered by Overeem (1948), Larsson (1948), and Heybroek (1950), where all three writers find or consider that these rocks are of what is at present known as "Gothian" age. Similar rocks also associate with the migmatites of Vänersborg-Trollhättan. A photograph by Lundegårdh of the Trollhättan veined migmatites is brought in Magnusson's review (1962, fig. 3) as a characteristical instance of "Pregothian" rock development. However, the latter migmatites are also found together with red granites which not only petrographically, but also texturally are identical with rocks of "Kroppefjäll" classification. Some of the arising confusion is amply illustrated by Heybroek's discussion of the stratigraphical position of the Åmål series (Heybroek 1950). While it is well-demonstrated that the Åmål supracrustals are cut by granites (Törnebohm 1870 b, Winge 1900, Holmquist 1912, Magnusson 1926, 1929 a and b, Larsson 1947, 1948, 1956), Heybroek found that at Örnäs to the south of Åmål "feldspar-quartzites" of the Åmål series rest normally on "Kroppefjäll" granite. Heybroek concluded from this and other related observations that the Åmål series was actually younger than the "Åmål-Kroppefjäll" granite group. It will also be remembered that fragments of granite – not "jerngnejs" – have been found in rocks of supracrustal Åmål classification (Törnebohm 1870 b; Hummel and Erdmann 1870; Holmquist 1912). While we must consider it evident that there is a clan of granites which cut the Åmål supracrustals, it may be suggested that the existing contradictions are due to the ambiguity of the "Åmål-Kroppefjäll" concept rather than to the misinterpretation of the actual field relations by some of the involved geologists. Another circumstance to be reckoned with is the possible confusion of Åmål series supracrustals with "Kappebo" rocks. As we have already seen in section (a) of this chapter Ellenö supracrustals and similar rocks occur in the area NW of Vänersborg which according to the Geol. Map of Sweden (Magnusson 1962) comprises a belt of rocks belonging to the Åmål series. A factor contributing to difficulties in the interpretation of the situation is the scarcity of observations of relative age of subsequently foliated plutonics in the original descriptions of the Dalsland geological maps. Most of Dalsland has not been subjected to detailed comprehensive reexamination after the original Survey mapping. The neglect of contact relations in the older quadrangle descriptions is due to neptunistic concepts which dominated the reasoning of Survey geologists during the eighteen-sixties (cf. Gavelin 1921). Attention was thus naturally concentrated on the determination of up-down relations, a task a priori doomed to failure when it comes to originally intrusive or metasomatic plutonic rocks. These aspects, and later on the assumption of liquation differentiation in situ of giant magma, left their imprint also on the investigation and rock classification of the "Pregothian" (Johansson 1918). We find that as late as the thirties animated discussion was devoted to the latter model (Johansson 1928 and 1931, Magnusson 1926, 1929 b, 1949). It is imperative to consider this background to avoid anachronism when basing evaluations and compilations on the geological relations as described in older publications.

Confusion of classification and shifts of terminological practice have been especially prominent in the description and definition of the Kroppefjäll group. We find that the term "Kroppefjäll" was originally applied to rocks grouped as "Kroppefjällsgnejs" in the Geological Survey descriptions of the Dalsland quadrangles (Hummel and Erdmann 1870, Karlsson and Wahlqvist 1870, Sidenbladh 1870, Törnebohm 1870 a, etc.) In agreement with the development of the rocks in the type locality, the Kroppefjäll hills NNW of Brålanda (fig. 2), the rock is described as a reddish or greyish "gneiss" with large, usually red, feldspar megacrysts. The application of the term was not restricted to what we now think of as the "Gothian" granite terrains to the west of Lake Vänern, but was petrographically – and presumably also chronologically – entirely adequately extended to comprise identical or similar rocks in the present "Pregothian", as for instance in the area to the east of Vänersborg (Sidenbladh 1870 a. o.). It is worth noting that e. g. the Hästefjorden granite was at that time not thought of as any form of "Kroppefjäll". The pronouncedly red acid rocks were called by Karlsson and Wahlqvist (1870) either red granite or red gneiss, a very suitable terminology indeed, which refers the locality term "Kroppefjäll" to rocks not easily described in two words. The employment of the term "Kroppefjäll" to describe coarse augen-granites or -gneisses in the present "Gothian" areas has never been discontinued and is the usage of a. o. Overeem (1948) and Heybroek (1950). Heybroek writes that the Kroppefjäll in its typical development is an augen-gneiss sometimes transformed into granite-schist/mylonite and occasionally losing its augen texture by suppression of the matrix in acid varieties of rock.

A different development in the application of "Kroppefjäll" is inaugurated during the genetical interpretation of part of the Dalsland gneisses as foliated originally plutonic igneous rocks (Nathorst 1883, Törnebohm 1872–74, 1883, Winge 1900, Holmquist 1906 a. o.). Törnebohm (1872–74, 1883) emphasizes the transitional relations between granite and Kroppefjäll gneiss or rocks previously described as Kroppefjäll gneiss (1872–74). Thus for the first time we find equigranular rocks brought into relation with the term "Kroppefjäll". We also note that Törnebohm (1872–74) distinguishes between Kroppefjäll gneiss and coarse augen-gneiss in eastern Dalsland, both these rocks evidently containing feldspar megacrysts. This important distinction did regrettably not attract the attention it deserves and a reclassification of the augen rocks in Dalsland according to Törnebohm's subdivision was never made in the field. The transitions between "Jerbo" gneiss, "Kroppefjäll" gneiss, and different kinds of granites as considered by Holmquist, Törnebohm, and Winge imply the accomodation of petrographically inhomogeneous units under the "Kroppefjäll" label. Again Winge (1900), Holmquist (1906, 1912), and other authors also recognize intrusive relations between granites and some gneisses. According to Holmquist (1906), a granite sensu stricto group which penetrates the "Åmål" plutonics is an unmetamorphosed equivalent of "Kroppefjäll gneiss". By alternatively calling the latter rock augen gneiss Holmquist nevertheless emphasizes the prominence of feldspar megacrysts. He finds that Kroppefjäll gneiss passes by granulation into red "jerngneiss" with red gneiss (often with augen) as an intermediate variety. This period finally sees the application of "Kroppefjäll" in the form "Kroppefjällsgranit" to rocks supposed to be unfoliated parts of the "Kroppefjällsgnejs". As applied by Svedmark (1902) the term still preassumes a prominent development of feldspar megacrysts, but the granite is acid. Since some authors, notably Holmquist (1906), think that the difference between at least some kinds of "jerngneiss" and granites is one of degree of metamorphism, the original application of the term "Kroppefjäll" to rocks in the present "Pregothian" is usually not expressly discarded.

Because of certain similarities of general lithology the rocks of the Åmål area have by Gavelin (1921) and Magnusson been parallelized with granites and porphyries of south-eastern Sweden. This is the presently prevailing opinion (Larsson 1947, Lundegårdh 1964, 1967, Magnusson 1962, 1963, Geijer 1963 etc.). In contrast to among others Holmquist, Magnusson (1926, 1929 a and b) considers that there are sharp contacts and a great difference of age between the "jerngneiss" regions (Pregothian) and the granites of western Sweden (Gothian). Magnusson applies the term "Kroppefjäll" to a group of what we now know as Gothian granites and thus by definition cancels its potential application to "Pregothian" rocks. According to Magnusson's work in the Säffle area (1929 a and b) field evidence shows clearly that the Åmål and Kroppefjäll granites are congenetic, formed from the same magma. This would indicate that there are continuous transitions between the two kinds. Still Magnusson refers all encountered granite types to either of these two groups and only between them he mentions "sharp boundaries" suggesting some difference of age. In spite of being genetically related they have to a certain degree independence of occurrence. For instance, in the area of By church, Kroppefjäll granite intrudes a gneissic variety of Åmål (the Sjögerås "granite") in numerous dikes which follow the foliation (Magnusson 1929 b, p. 30).

Magnusson (1929 b) describes the Kroppefjäll granites as pronouncedly red ,quartz-rich, younger granites rather poor in dark minerals. This is a very substantial difference in comparison with the former employment of the term, because feldspar megacrysts are no longer essential in the definition, whereas acidity has previously not been emphasized quite as much. Nevertheless, the Kroppefjäll granites may carry feldspar megacrysts and the coarse varieties are reported to be gneissic. From Magnusson's description we find that augen rocks proper are defined as typical Åmål granite (1929 b, pp. 17–18). According to Larsson (1947, 1956) the Åmål-Kroppefjäll group ranges in composition from diorite to acid granite and was intruded while folding was in progress. Folding, however, ceased previous to the emplacement of the latest acid varieties, the Kroppefjäll granites. In the description of the geology of Göteborg and surrounding areas Lundegårdh (1958) subdivides the Gothian ("younger Gothian") granites into gray basic Åmål and red acid Kroppefjäll while the term "Askim granite" is applied to rocks rich in feldspar megacrysts. According to that writer Askim granite is a rock of inhomogeneous igneous-metasomatic provenance and carries several generations of microcline augen. Thus we find that the term Askim granite is applied to rocks closely similar to the original "Kroppefjäll" and that the term "Kroppefjäll" has entirely changed its scope. From having been a rock defined by its microcline megacrysts "Kroppefjäll" expanded to embrace an array of petrographical types comprising among other things megacryst-bearing rocks and red semiequigranular granites and was then anew reduced to eliminate most of the megacryst-bearing units. Some of the latter are now called "Askim" (Lundegårdh 1958) while others pose as "Åmål" (Magnusson 1929 b). Since in the process the term "Kroppefjäll" has without expressly stated redefinition been used for rocks of very different character, terminological confusion and misunderstandings have been inevitable.

Our recent investigations in Dalsland, Värmland, and Bohuslän show conclusively that the term "Kroppefjäll" has previously been applied to rocks which are dissimilar both in age and in petrology. Referring to the Kroppefjäll hills, the original home of the term, we find that the regionally foliated megacryst-bearing rock of the locality is typologically identical with homogeneous augen rocks found in the "Pregothian" around and to the east of Vänersborg-Trollhättan. This, we note, is in complete agreement with the application of the term "Kroppefjäll" by the first geological investigators of the area (Hummel and Erdman 1870, Sidenbladh 1870). In addition there is the megacryst-bearing element in the "second generation" granite group and, finally, porphyroblast-infested inhomogeneous parts of the grey gneiss-granite which are obviously continuous with the "Pregothian" grey gneiss-granite. The latter rock cannot be considered part of the Åmål-Kroppefjäll group if the term is to be applied to "Gothian" granites only, i. e. unless we chose to consider some of the type localities of "Pregothian" veined-gneiss development as being actually "Gothian" in age. At least this is not in harmony with established terminological practice. In noting the inhomogeneity of the megacryst-bearing rock group we agree with Törnebohm's (1872–74) distinction between Kroppefjäll gneiss proper (= our "second generation"?) and the "augen gneisses of eastern Dalsland".

Chosing the other petrographical alternative and following Magnusson, Lundegårdh, and Larsson in applying "Kroppefjäll" to red acid granites in the Gothian terrain we run into similar terminological ambiguity. According to Hummel and Erdmann (1870) there is in Dalsland a "late" red or reddish-grey fine-grained granite which, as found by Törnebohm (1883) and Larsson (1947, 1956, 1958), must be older than the Dal formation. Larsson conclusively disproves earlier claims of post-Dal granites other than the Bohus (Hummel and Erdmann 1870, Winge 1900, Backlund 1931, Malmqvist acc. to Ljungner 1927). Similarly we find mention of some throughbreaking granites – e. g. the Bodane granite of a. o. Holmquist (1906) – in other parts of the Dalsland--Värmland region. Apart from the Bohus, these granites have hitherto not been identified as a post-Gothian group and thus evidently are comprised in the "Kroppefjäll" which leads to obvious inconsistencies. Thus if the throughbreaking granites of Hummel/Erdmann and Holmquist are Kroppefjäll granite, Kroppefjäll gneiss cannot possibly be a foliated equivalent of Holmquist's Kroppefjäll granite which is one of his "arkeiska massivgraniter". The two groups evidently belong to two tectonically entirely different regimes of development. We ventured to show in section (a) of this chapter that there are at least three different red rather acid granites in what the Map of Sweden shows as "Gothian" in the Ödeborg area. In the Vänersborg area we similarly find several generations of red granite of which some are migmatizing, others throughbreaking, while the granite units of Ursand and Vassända-Naglum which are situated in or close to the "Pregothian" conform with what we may term the classical behavior of the Kroppefjäll by passing gradually into augen-gneiss-granite. We note, however, that in these cases the transition is one of microcline porphyroblast formation and granitization, not of subsequent partial foliation of originally massive units. It is evident that the application of "Kroppefjäll" to either of these groups eliminates at least some of the others. Thus we find that the present status of the term "Kroppefjäll" is somewhat unsatisfactory and in need of stricter definition. An obvious path is to follow Larsson and Magnusson in letting "Kroppefjäll" be a group of plutonics which are younger than the Åmål supracrustals of the Åmål-Säffle area and also younger than the Åmål granites. Whether this application of the term in a chronological sense requires further terminological refinement to eliminate similar rocks which are neither red nor acid is not entirely clear at present. This definition probably also implies disconnection of term and original type locality. A prerequisite for strict application outside of the Åmål-Säffle area is the definite settlement of the problem of Åmål/Ellenö (-Kappebo ?)/"Pregothian" classification of pre-Dal supracrustals in Dalsland. This task still requires much detailed work. Pending strict redefinition we must realize that the terms "Kroppefjäll" and "Åmål-Kroppefjäll group" do not provide an unequivocal chronological characterization and basis for strict correlation of many of the rocks to which they are applied at present.

3. THE BOUNDARY OF THE "PREGOTHIAN" IN COUNTY VÄRMLAND

(a) The Klarälven valley

In the Klarälven valley area compilative texts give the boundary between the greater geological units of southwestern and southeastern Sweden as an uncomplicated line proceeding just west of the upper Klarälven river (Magnusson 1962). More detailed reference is found in Magnusson's paper on the "Mylonite Zone" (1937 a), where the boundary is traced from Klarabro to just west of Stöllet and further between lakes Gröcken and Busjön (fig. 15). As Magnusson has it, the boundary of the granite complex of eastern Värmland toward the gneisses is a tectonical line with an unusually straight ("rätlinjigt") course. The gneisses are everywhere plunging in under the granites and the granites are strongly schistose close to the boundary. Here and in the "Mylonite Zone" of Magnusson schistosity is said to affect the granites only (Magnusson 1937 a). Similar conditions prevail also in the Unden area between lakes Vänern and Vättern (Johansson 1915, cf. Holmquist 1934, Magnusson 1962). It is however not always evident whether "plunging in under" concerns the structure of the gneisses or the foliation of the alleged semilinear tectonic limit. In a summary of 1949 and in numerous earlier papers, e. g. 1934, Magnusson depicts the boundary as a zone of gradually intensified foliation which is complicated by movements on lines of tectonic dislocation. This is in keeping with the previously prevailing view of one single Gothian (Wahl 1936, Magnusson 1936, 1949) or Gotho-Carelidic (Backlund 1936) revolution in this part of Sweden. Hence the difference between the rocks of the "jerngneiss" complex and their eastern granitic neighbors was not, or was not necessarily envisaged as one of age, but rather as one of tectonics. A gradual transition between Filipstad granite areas and "jerngneiss" is also suggested by the maps of Törnebohm (1880, 1881, cf. Holmquist 1906). The original descriptions by Magnusson have most commonly been interpreted as indicating a single throw line (e. g. Sundius 1944). In recent compilative reviews and summaries Magnusson as well as other authors (Magnusson 1962, 1963, Geijer 1963, Lundegårdh 1964) envisage the jerngneiss area as belonging to the "Pregothian" which is said to be very much older than the Filipstad granites of eastern Värmland reckoned as "Gothian" and parallelized with the "Åmål-Kroppefjäll" group (Magnusson 1929 b, 1937 a, 1962, Larsson 1958). In view of this alleged large difference in age – the "Pregothian" is reckoned as being even older than the 1650–1950 m. ys. of the Svecofennian, while the "Gothian" is dated as around 1450–1650 m. ys. (Magnusson 1960, 1963, Lundegårdh 1964, 1967) – it is indeed remarkable that the bedding or foliation of the folded older mass everywhere in Värmland conforms to plunge in under a straight throw or overthrust line separating it from the younger granite complex. It will be remembered that according to Magnusson (1937 a) tec-

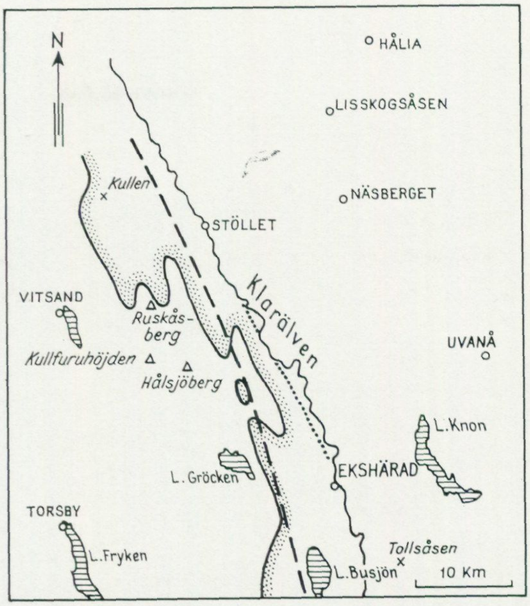

Fig. 15. The "Pregothian/Gothian" boundary in the central Klarälven area. Shaded solid line is the demarcation between coherent areas of strongly and moderatly foliated rock. Local zones of strong schistosity and granulation to the north and east of Ekshärad have been omitted. Broken line shows the approximate course of the gneiss/granite boundary acc. to Magnusson (1937). Stippled line indicates the main Klarälven fault where not coinciding with the river valley.

tonic throw foliation affects the granites only, i. e. not the gneisses. As described by Magnusson (1937) and Larsson (1958) the folded structures in the eastern "jerngneiss" block sometimes strike EW, while the limit toward the granite runs an undiverted NNW. It is difficult to see how this could be the case without a truncation of the older folds at the border toward the granite. Since the granites are reported to be essentially unfolded, possible post-Gothian metamorphism or Dalslandian regeneration can hardly be material in basically mitigating this contradiction.

The first leg of our investigations in the Klarälven valley area concentrated on the sector between Torsby, Vitsand, Näsberget, and Uvanå (fig. 15). The terrain in the east is predominantly occupied by diverse granitoid rocks. In addition there are numerous areas of porphyries and supracrustal metaargillitic, metaarenitic, and "leptitic" units. The lithology is essentially similar to the continuation of the granite belt into Kopparberg county (Hjelmqvist 1966), but metasupracrustals appear to be somewhat more important on the Värmland side of the county border. A prominent member of the granitoid group is a syenitic to granitic rock with medium-grained greyish matrix studded with

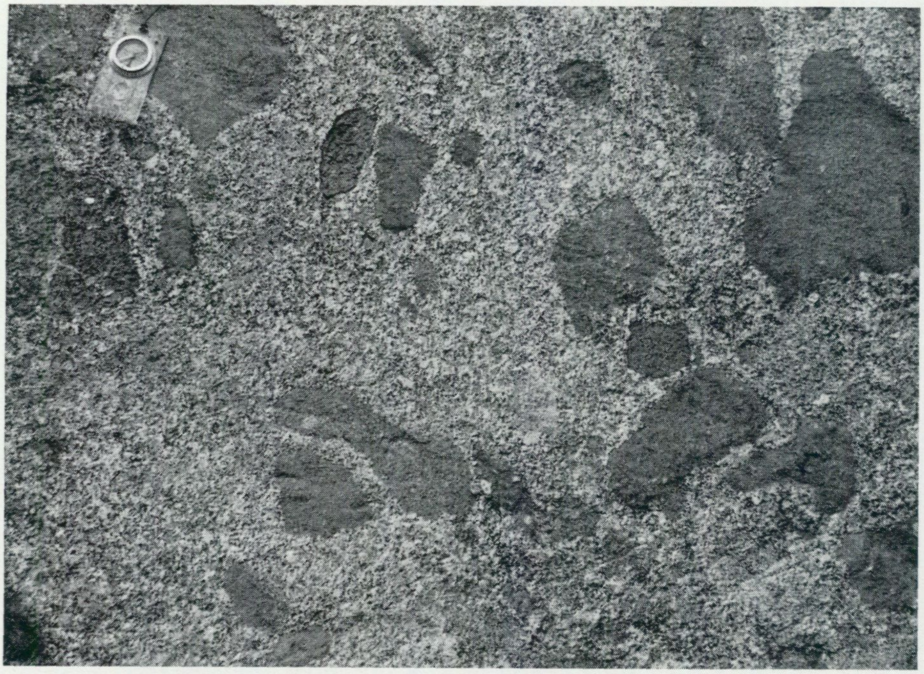

Fig. 16. Kullen type granitoid with abundant inclusions of amphibolite and gray fine-grained gneiss. 3 km S of Kullen hill.

well-zoned violet feldspar megacrysts which become reddish in color when affected by foliation. Associated with this rock are more basic members of syenite to monzonite composition, dark in color, with or without violet feldspar megacrysts. Characteristic of almost all loci of the megacryst-bearing granitoid are abundant inclusions of the monzonitic members of the suite, of supracrustal (unveined-) gneisses, and amphibolites (fig. 16–17). In a few cases some of the amphibolite fragments show traces of original ophitic texture. We have so far no instances of inclusions of older granitic rocks or of strongly foliated or veined gneisses of "Pregothian" type. Rocks similar to the violet-greyish granitoid are often labelled "Kristinehamn granite", but since the areas intervening between the Torsby-Uvanå area and Kristinehamn are not yet remapped we prefer to use "Kullen type" as a provisional denomination. Different from the Kullen type is a coarse to coarsely medium-grained, usually more or less acid group of rocks which may or may not be microcline-porphyritic. This rock appears to be an equivalent of the Filipstad granites. Both granite types are traversed by essentially NNV to NS-trending belts or zones of very intense to moderately strong foliation which gradually decrease in prominence toward the east. Within the "Filipstad" group there are several subunits. There are numerous instances of dikes of red granite in darker gray granitoids. Epidotization and chloritization of contact localities of the gray rock are common. Epidote also develops in belts of foliation. The contact facies of the red granite is commonly developed as a (quartz-) feldspar-porphyry and may occupy considerable areas (e. g. east of lake Knon, fig. 15). In the Näsberget-Lisskogsåsen area we similarly find relics of strongly foliated epidotized gneiss-granite included in and transected by dikes of "feldspar-porphyry". This gneiss-granite appears to pass into megacryst-bearing gray granitoid. In addition there exists a different group of porphyries which are older than the dark "Filipstad" group granitoid. Because of, among other things, differences in regional tectonization between different members of the granite and porphyry groups we find it difficult to accept Ljunggren's idea (1954) of a formation of virtually all of the above-mentioned rocks from metasediments by a process of regional granitization in situ. Instead we suggest a series of emplacements by intrusion – not necessarily igneous intrusion – with intervening stages of tectonical deformation between the different intrusion events.

Younger than the Filipstad granite group are fine- to medium-grained greyish to reddish granites which show clearly cross-cutting relations toward the older rock. They are sometimes developed as microcline-porphyric varieties. The latest member of this suite is a red acid fine- to medium-grained granite occurring as systems of dikes and numerous small massifs. These

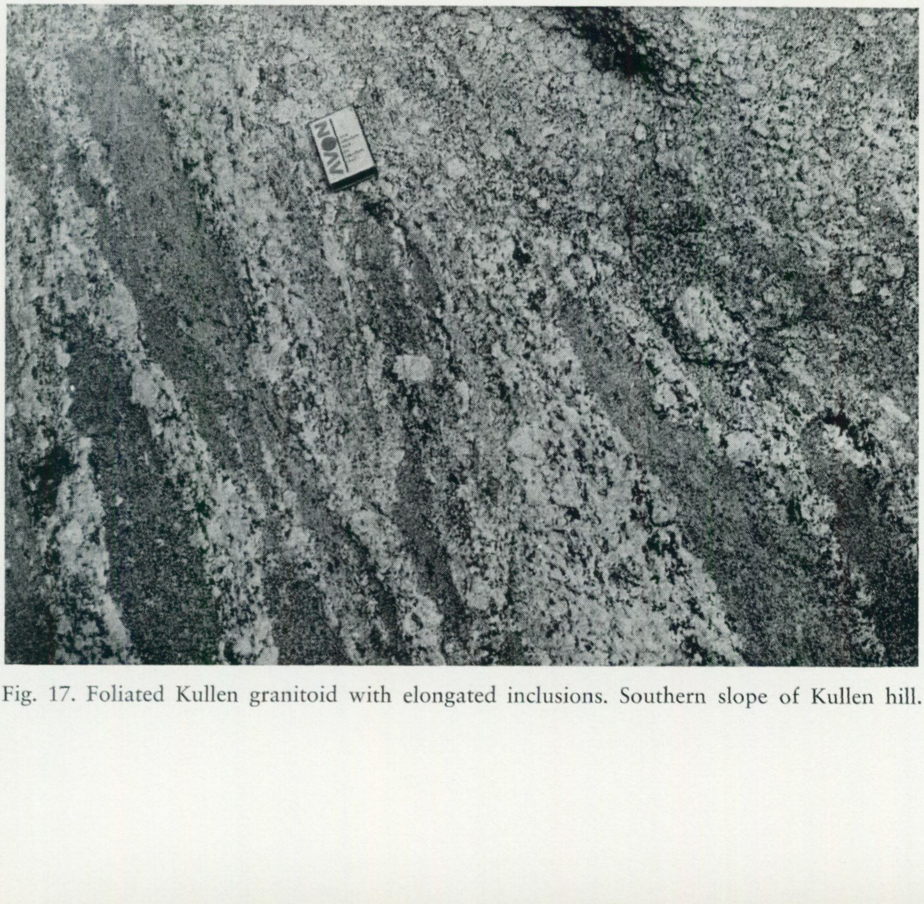

Fig. 17. Foliated Kullen granitoid with elongated inclusions. Southern slope of Kullen hill.

rocks commonly associate with pegmatites and are sometimes accompanied by local migmatization and formation of feldspar phenocrysts in the older rocks. The Kullen and Filipstad granites very often exhibit weakly to moderately well developed parallel textures even outside of the beltiform zones of strong schistosity. The late granite group is in contrast mostly macroscopically massive. This applies especially to the central segments of the area to the east of Klarälven. The frequency of late fine-grained granites decreases eastward. Unknown are their relations with massifs of medium-grained brightly red or white-red mottled leucocratic acid Dala-type granites (Hjelmqvist 1966) which are restricted to the area east of Uvanå. To the east of Klarälven we have so far not been able to identify granitoid rocks which are unambiguously older than the "Filipstad" group. The supracrustal rocks in the Värmland granite belt have previously been described by a. o. Törnebohm (1881), Magnusson (1925), Ljunggren (1954), and Hjelmqvist (1966). In addition we may especially point out the prominence of greyish micaceous and greyish or reddish leptitoid supracrustal gneisses in the area between Kullen, Stöllet, and Ruskåsberg. These rocks are intruded both by the Kullen and the younger red or greyish-red granites; they are locally migmatized, but have with the exception of restricted zones of crushing not been affected by foliation and granulation of "Pregothian" type.

The hitherto recognized succession of rocks in the eastern Värmland granite belt is in order of decreasing age:

Supracrustals and hypabyssals (quartzite, metaargillite, "leptite", amphibolite, porphyries)

Kullen and red and gray Filipstad granites plus associated porphyries

Younger granites

This compilation omits the Dala granites and porphyries, and the Jotnian sandstone found only close to or inside Kopparberg county.

In the "Pregothian" area between Torsby-Vitsand and the Klarälven valley we recognize numerous distinct groups of rocks. The "Pregothian" gneisses may be subdivided into the following principal units:

– Grey commonly somewhat garnetiferous fine-grained gneisses

– Red fine- to finely medium-grained gneisses of granitoid composition.

In a few instances there are relics of quartz- or feldspar-porphyric texture in this group.

– A prominent group of equigranular or originally feldspar-megacryst-bearing medium- to coarse-grained gneisses or gneiss-granites varying in color from red to reddish-grey. In spite of strong foliation the contacts of these rocks toward the preceding groups can commonly be recognized as originally intrusive. Rocks of this kind carry very elongated fragments of the fine-grained gneisses.

– Metabasites, often transformed into biotite/chlorite-amphibole schists are generally not very abundant and appear to belong to at least two groups of which one is older and the other younger than the originally medium-grained gneisses.

All these rocks are very thoroughly foliated and granulated. Granulation is thorough also in the originally medium-grained gneiss group, but what is inferred to have been pregranulation medium- to coarse-sized mineral grains still form coherent lenticular mono- or oligomineralic units. Except in zones of renewed crushing the present mineral grains are products of postdeformational recrystallization. Bent and deformed crystals are not very common and e. g. mica streaks in macroscopically very strongly foliated rocks may develop groups of divergently orientated grains. From these features we draw the conclusion that the present mineral assemblage is much later than the rocks proper and at least in part posttectonic in relation to the principal phase of granulation. In the foliated "Pregothian" gneisses there are several types of (former-) feldspar megacrysts: one is completely granulated and transformed into streaks or lenses of small feldspar grains, the second kind are granulated assemblages of small crystals and the original megacryst outlines are deformed, but still macroscopically coherent. The third type are augen which still consists of one or a few megaunits of microcline, which sometimes have deformed twinning lamellae and usually granulated rims. Postdeformational recrystallization or formation of new microcline megacrysts is found in some areas. These late megacrysts may develop at the expense and in the loci of groups of small grains which appear to be granulated lensoid megacryst relics of an older generation.

Clearly intrusive contacts toward the fine- and formerly medium- to coarse-grained "Pregothian" gneisses are exhibited by a group of finely medium-grained to fine-grained red granites. The contacts of these rocks are not quite as much deformed to align with the general direction of foliation as those between the oldest (supracrustal-) gneisses and the granulated ex-medium/ex-coarse-grained gneisses. Indeed the contacts may be outright crosscutting and fragments of older rocks are not as elongated as those in the earlier metaplutonics. Though there are instances of marked foliation and granulation also in the late red "granites", we sometimes find a very distinct difference in the degree of deformation between these rocks and the older gneisses.

A special kind of "Pregothian" rocks are quartzites of the Hålsjöberg (Horrsjöberg) type. The type locality is well known in literature as an instance of kyanite-lazulite-rutile mineral association (Igelström 1854, Sjögren 1877, and numerous later works). Two other somewhat smaller similar occurrences are Ruskåsberg and Kullfuruhöjden (fig. 15). In Ruskåsberg the mineral assemblage is quartz-muscovite (-hematite)-magnetite. Kyanite is present only as a few relics surrounded by muscovite rims, rutile is rare, there are a few grains of zircon and sphene. All three localities comprise isolated large lumps of quartzite and are not coherent. The contacts outwards are usually unexposed and we have at present no basis to suggest whether the quartzites are tectonically disconnected formerly continuous beds, inclusions in the granulated, formely medium-grained gneisses, metasomatic formations as suggested by Geijer (1963 b), or rocks resting normally or tectonically on the surrounding gneisses. Associated with the Hålsjöberg quartzite is a minor occurrence of mica-schist and numerous units of a grey feldspar porphyrite probably of dacitic or andesitic composition. The quartzites are not necessarily chronological equivalents of the oldest recognizable red and fine-grained gneisses. At least they do not enter coherent belts of supracrustal rocks as shown in some maps. The porphyrite of Hålsjöberget is intruded by, and contains dikes of a granite similar to the Filipstad granite. From macroscopically weakly foliated varieties the porphyrite passes into extremely schistose and granulated grey gneiss in the outskirts of the Hålsjöberg locality. In these loci the Filipstad-type granitoids are transformed into what looks like a typical granulated "Pregothian" gneiss. Dikes of "hyperite" diabase are clearly younger than the Hålsjöberget quartzite and also carry fragments of foliated gneiss and gneiss-granite similar to the surrounding "Pregothian".

Notwithstanding considerable textural differences between granulated rocks of "Pregothian" type and typical Värmland granites, the establishment of a coherent well-defined boundary proved much more difficult than expected on the basis of previously published data. An approximate demarcation between "Pregothian" and "Gothian" types of rock is given in fig. 15 and disregards some very prominent zones of extreme foliation and granulation found in the Gothian area. In spite of some uncertainty of classification of transitional types and difficulties due to the heavy cover of Quaternary deposits, it is clear that the "Pregothian/Gothian" boundary in the central Klarälven area is not a straight line. Deviations from a straight course are at most $\pm$ 5 kilometers and thus not very great, but still significant enough in eliminating the possibility of a single fault throw. As has been shown previously by Magnusson (1937 a) the Klarälven valley throw has nothing to do with the "Pregothian/Gothian" boundary and is in the area studied here entirely within the "Gothian" granites. Rocks of the Klarälven dislocation are accessible for investigation only where the fault leaves the river depression proper (stippled line in fig. 15). They are found to be fault gouges and extremely foliated and in part mylonitized crushed granitic rocks. There are a few evidently posttectonical microcline porphyroblasts and some feldspar-quartz schlieren inside these rocks.

In a group of outcrops SE of lake Gröcken the transition between submassive "Gothian" granite and "Pregothian" gneiss is effected over a distance of approximately 50 meters and implies a gradual intensification of foliation and simultaneous granulation of the constituent minerals, particularly the microcline megacrysts which change from reddish-violet to red and then pale pink. Similar, though somewhat more gradual transitions are also found to the south of Gröcken and NW of Ekshärad. In these areas it appears that some of the Värmland granites have been involved in a tectonization process which makes them indistinguishable from varieties of "Pregothian" gneiss.

In contrast, in the area NW of Ruskåsberg "Pregothian" extremely granulated formerly megacryst-bearing gneiss and the "Kullen type" granite which occupies the tongue of "Gothian" between Ruskåsberg and Vitsand come within a few meters of each other without recognizable change of macroscopical character. The contact line proper is not exposed and it is not clear whether it is an intrusive or a fault or overthrust boundary. The conspicuous absence of fragments of unequivocally "Pregothian" gneiss in the "Gothian" granites and of "Gothian" dikes in the "Pregothian" has been mentioned previously, but mutually conflicting evidence is provided by the evidently rather sharp contact of the "Kullen type" granite to the east of Vitsand and by the presence of a granulated, but otherwise moderately foliated megacryst-rich rock in the southern continuation of the "Kullen type" bulge ESE of Vitsand. In this area there is sometimes conspicuous regeneration of microcline megacrysts in "Pregothian" gneisses.

So far the most important results of the new survey are the discoveries that the "Gothian/Pregothian" contact in the central Klarälven area is strictly speaking not a straight line and that "Gothian" granites in the Stöllet-lake Busjön sector have been involved in at least the latest stage of "Pregothian" foliation. The latter in a way implies a return to earlier concepts (Magnusson 1934). The contact line between chronologically speaking possibly different "Pregothian" and "Gothian" rocks must thus be sought somewhat to the west of the demarcation zone between the tectonically different gneiss and granite areas. So far the Torsby-Uvanå sector has not provided an unequivocal solution of the problem of "Pregothian/Gothian" age difference.

(b) The Kristinehamn area and the hyperites

The critical "Pregothian/Gothian" boundary area on both sides of the central Klarälven valley and its continuation farther southward are heavily covered by till, peat bogs, and glacifluvial deposits. The better exposed environments of Kristinehamn thus attract attention as possible localities of unambiguous "Pregothian/Gothian" relationships. The Kristinehamn area also appears superior to the central Klarälven valley in offering greater contrast between "Pregothian" and "Gothian" lithologies. Whereas the proportions between (meta-) plutonics and supracrustals on either side of the "Pregothian/Gothian" boundary are not very different farther to the north, the Geological Survey map-sheets Kristinehamn, Väse, and Nyed show a compact mass of granite in the east and an almost as compact unit of variegated gneisses in the west. Particular attention is also attracted by the abundance of basic hypabyssals in the Kristinehamn sector. As mentioned in the previous section we find that the diabases known as "hyperite" probably cut across all members of the central Klarälven "Pregothian" recognized hitherto. In analogy with the late red granites the hyperites appear to have escaped much of the general granulation of the other "Pregothian" rocks including the earlier amphibolites. The hyperites thus appear foreign to part of the "Pregothian" development. We note also that in spite of strong foliation and extreme elongation of, for instance, inclusions of older rocks in the "Pregothian" metaplutonics, the hyperites of central Värmland have generally escaped boudinage. Strong dislocative and foliating movements have nevertheless affected the hyperite/gneiss contacts. The general late postgranulation recrystallization which may be associated with the latest period of folding in the "Pregothian" has adapted the igneous mineral association of the "hyperite" diabases to mesograde metamorphic PT-conditions in producing the parageneses feldspar-garnet-amphibole-pyroxene and feldspar-garnet-epidote-biotite/chlorite-amphibole. In the central Klarälven valley the "hyperites" very often form subvertical or steeply inclined dikes, whereas further to the south Magnusson (1929 c, cf. also Wiman 1961) found that the hyperites appear to belong to one single or a few folded layers (sills). Multiphase-intrusion relations are found in the north and the hyperites of the Torsby-Hålsjöberg area contain intradike diabases and breccia networks of plagioclase-porphyrite, fine-grained diabase, leucodiabase, and albitite (cf. Brøgger 1935, Wiman 1961). From the shape of the hyperite bodies we conclude that they have been involved in the latest folding of the "Pregothian" and are also affected by one of the late periods of zonal schistosity development which appears common to the "Pregothian" and the eastern "Gothian". Literature reference (Magnusson 1933, Wiman 1961) suggests that in southern Värmland hyperites are older than (segregation-) pegmatites and other acid or hybrid rocks possibly associated with regional metamorphism. The relations between the hyperites and the granites of the east are of paramount importance in establishing the sequence of metamorphic, intrusive, and deformational events in the "Pregothian/Gothian". The relative position of hyperites and granites must also be instrumental in deciding at what period of relative chronology the megaunits of western and central/southeastern Sweden started partaking in a common geological development. The ideal case would of course be localities where the hyperites are either truncated by granite, cut the granites, or terminate against major lines of tectonic dislocation. In the central Klarälven valley the hyperites of the "Pregothian" nowhere come close to ungranulated eastern granites. The Kristinehamn area appears to offer much better possibilities in this field and hyperites are for instance by Magnusson (1929 c) reported to occur inside the granite belt. In that particular case the contacts were unexposed. In the central Klarälven area the basic hypabyssals of the granite region mostly comprise diabase dikes classed as Åsby (olivine-) diabase and inclusions of amphibolite which associate with relics of grey or red gneiss and, if anything, remind of the older amphibolites in the ”Pregothian”. The Åsby diabases form more or less straight, clearly cross-cutting dikes which range from a few decimeters to more than hundred meters across. Dikes of diabase in Värmland granites are found as far west as the vicinity of lake Gröcken, where a 30 m thick diabase dike strikes in a direction carrying it toward the local ”Pregothian/Gothian” boundary. Regrettably till cover prevents further tracing outside of the ”Gothian” granites.

Beside these rocks there are a few instances of basic dikes younger than the granites, but involved in zones of granulation and partly or wholly altered to amphibolites. A characteristic locality is Musåsberget hill just to the northwest of Lake Knon (fig. 15), where a swarm of NNW-striking dikes some tens of meters across shows fine-grained chilled ophitical border facies against the surrounding rock which is a subsequently moderately foliated and thoroughly granulated Värmland granite. The central parts of the dikes have recrystallized into (pyroxene-garnet-) amphibolite. In addition to granulation and recrystallization, both the dikes and the granites are traversed by obliquely cross-cutting NS-trending zones of foliation which transform the granite into a gneiss with completely granulated lenticular relics of originally coarse-grained quartz and feldspar grains. A cursory examination permits no conclusions as to whether the basic hypabyssals were originally Åsby diabases. Nevertheless it demonstrates the existence of ”post-Gothian” basic dikes transformed into amphibolite rocks. Instances of obvious alteration of diabases are also found in the northern outskirts of Kristinehamn where there is a swarm of Åsby-type diabase dikes and sills (strictly speaking subhorizontal dike intrusions). These rocks are in part transformed into schistose amphibolite. Alteration is especially prominent in rather narrow zones of foliation and along some diabase-granite contacts. It merits special attention that the recrystallization products are amphibolites, not the chlorite-ore-epidote-sericite ”sköl” rocks of dislocation zones in the Jotnian diabases of central Sweden (Gorbatschev 1961). In addition to dikes of diabase the granite area to the east of Kristinehamn contains several large lenticular bodies of basic medium- to coarse-grained rock, which in spite of their more or less lenticular dike-like configurations carry veins of granite and exhibit contact breccias of basic rock in a matrix of granite. Some of these bodies associate with leptitic or other gneisses and may represent pre-granite amphibolites. Others may be intrusive into the granite, but have been invaded by granitic material during some later stage of metamorphic-tectonic reworking. These problems need further investigation. We find that Wiman in a description of some rocks in the Kristinehamn area (1961) applies the term ”hyperite” to numerous diabase intrusions into the Kristinehamn granites. It is not entirely clear on what grounds some rocks, but not others are classified as ”hyperites” and not referred e. g. to the Åsby or other groups of diabases. Similarly it remains obscure what actually constitutes the chemical difference between ”hyperites" and other types of diabase. In areas subjected to diverse degrees of metamorphism, mineralogical differences like those described by Törnebohm (1877) and other investigators are not needs very significant in defining chronologically different groups of rocks. We gather for instance that orthopyroxene is not very prominent in some of the Värmland "Pregothian" areas (Magnusson 1929 c, Wiman 1961). We find that the mineral often occurs either as unmixing products of pigeonite, alteration rims around olivine, or associated with garnet. The first two varieties are by no means uncommon in "Jotnian" diabases (e. g. Gorbatschev 1961), while the occurrence of orthopyroxene together with garnet is expected in metamorphosed diabases. It is of great importance in providing means for the determination of PT-conditions of metamorphism, but is no indication of an igneous petrology different from that of, for instance, the Jotnian diabases. As concerns chemical composition, analyses of intact core zones of "hyperites" in the "Pregothian" and diabases and metabasites in the Värmland granites are neither numerous nor systematic enough to allow consistent comparisons and definite conclusions. Neither is it entirely clear which of the "hyperites", "hyperite-diabases", and "amphibolites" of southern Sweden are equivalents of the Värmland hyperites (cf. Magnusson 1962). Comparisons with either of these groups and their chronological relations are thus not necessarily relevant.

As a potentially significant feature we may note that as far as the writer is aware, there are with a few questionable exceptions (Magnusson 1937 b) no Åsby diabase dikes in the granulated and foliated "Pregothian". Since diabases are fairly common farther east even the hypothesis of enormous block movements at the "Pregothian/Gothian" boundary can hardly provide a very plausible explanation of this fact. Thus the question arises if the Åsby diabases are actually present in the "Pregothian" in a metamorphic disguise. The relation between K/A ages of the latest "Sveconorvegian" regeneration (1000 $\pm$ 100 m.ys.) and the radioactive ages of Åsby-type diabases ($\leq$ 1300 m.ys., Welin, Blomqvist, and Parwel 1966, Kouvo 1958, Eskola 1963, Magnusson: lecture at the April 6th, 1967 meeting of the Geological Society of Stockholm) do not contradict this possibility. We may also ask if the "Pregothian" hyperites can correspond to some of the granite-penetrated lenticular dike-like metabasites in the granites to the east of Kristinehamn. Any work aiming at the understanding of orogenic developments in western Sweden must necessarily concern itself with these problems. One of the most important steps must be a thorough survey of the relations between tectonics and metamorphism in the "Pregothian/Gothian" borderzone, another, examinations of the relative position of the "hyperites" in the sequence of metamorphic events, and of the intrusion-tectonic and chemical factors which are similar or dissimilar to those of the mafic rocks in the eastern "Gothian". In both these contexts the Kristinehamn region appears to offer singular possibilities.

4. SOME PROBLEMS OF METAMORPHISM AND AGE

Despite the large number of papers dealing with the geology of western Sweden available data on mineral associations of the metamorphic rocks do not permit the establishment of a consistent concept of paragenetic development and are in some cases contradictory. In many instances we find mention of localities with uncommon or potentially indicative minerals, but new surveys are required to establish critical characteristics of the particular associations and their relations to the less spectacular minerals and crystals of the surrounding rocks. In particular the reports of kyanite from several localities in western Sweden possibly indicate the P- or PT-conditions of metamorphism in this particular "orogenic environment". However, scrutinizing more closely the available literature reference it is by no means clear that kyanite is a mineral of regional significance in the area. Considering the stability field of kyanite as it emerges from modern experimental data (Althaus 1967, and others) we find that the occurrences of kyanite in the rather special environments described hitherto (Västanå-Dicksberget-Hålsjöberg: cf. Geijer 1963 b, pegmatite: Bergström 1960, and close to the "mylonite zone" of Värmlandsnäs: Johansson 1920) do not necessarily indicate either regionally high pressure or a steep P vs. T gradient. As mentioned cursorily in the preceding chapters sillimanite has during the present survey been reported from several localities of the western "Pregothian" block, e. g. at Arvika and in the Vänersborg area. Other instances include the andalusite-sillimanite gneisses of the eastern fringe of the "Pregothian" (map-sheets of the western Vättern region, cf. Holmquist 1934).

In the "Pregothian" areas proper metaargillites do not appear to be very common and bulk composition is therefore in general not very favorable for the development of mineral associations comprising aluminosilicates developed at temperatures below the upper stability limit of muscovite which at $P_{total} \approx P_{H_2O}$ is indicated to be approximately 700 degrees C at pressures of infracrustal regional metamorphism (Crowley and Roy 1964, Velde 1964), but must be considerably lower in nature since p_{H_2O} is estimated to be much lower than P_{total}. Similar aspects also apply to the scarcity of cordierite. The development of this mineral is not only depending on the availability of excess alumina and sufficiently low water fugacity, but also a. o. on the Mg/Fe proportions of the rock. The importance of the Mg/Fe ratio is evident from the very conspicuous preference of the cordierite lattice for Mg in comparison with the alternative ferromagnesian silicates garnet, biotite, chlorite, and amphibole (Folingsbee 1941, Gorbatschev 1968, 1969 a, 1970, Saxena and Hollander 1969 b). While there are indications of limited stability of cordierite in environments of high pressure (Chinner 1959, 1962, Hirschberg and Winkler 1968, cf. however Schreyer 1965 a and b) and high water fugacity (Winkler

1966), the element distribution data show that the role of Mg/Fe proportions is paramount in determining the stability field of cordierite vs. biotite/chlorite plus muscovite and still more so vs. garnet. This is in accordance with a comparison between experimental data given by Hirschberg and Winkler (1968) and von Platen and Höller (1966). Availability of Mn and Ca must be important in destabilizing cordierite and biotite in relation to garnet (Gorbatschev 1968, 1970). We are thus by no means entitled to treate these minerals in complete analogy with stoichiometrically constant species in defining their PT-stability fields and must consider the chemical particulars in each special paragenetic case. An obvious task of first-rank importance for the understanding of metamorphism in West Sweden is consequently the investigation of mineral associations and crystal chemistry of the scarce metaargillites in the "Pregothian". Fortunately, virtually all areas of the "Pregothian" and associated rocks hitherto inspected by the writer comprise garnetiferous biotite-bearing members and thus enable us to investigate the temperature conditions in a semiquantitative way. The temperature dependence of biotite-garnet element distribution is prominent and fairly well investigated, it is indeed one of the few geothermometers employing common minerals which can be said to be in an operational condition (Kretz 1959, Albee 1965, Perchuk 1967, 1968, Saxena 1968 a, Gorbatschev 1970). Complications arise from crystal-chemical influences which are as yet not entirely satisfactorily known and evaluable, and reference is mutually somewhat incompatible (Albee 1965, Sen and Chakraborty 1968, Saxena 1969, Dahl 1969, Gorbatschev 1968, 1969 a). These complications nevertheless do not appear to be very serious, provided variations in the composition of the involved mineral phases do not exceed certain limits. In addition the number of uncertain variables can be reduced by cross-checking with other ferromagnesian mineral pairs involving garnet, as has been demonstrated by Gorbatschev (1968) for garnet-biotite and garnet-cordierite. Mineral-chemical investigations of some parts of the "Pregothian" are in progress.

Another feature of the West-Swedish gneisses is the development of their characteristic "jerngneiss" iron-oxide crystals. It is yet unknown whether this is a result of textural readjustment allied to granulation/recrystallization, or of oxidation and consequent extraction of iron from the silicate lattices as elaborated quantitatively for biotite by Wones and Eugster (1965). From the textural relations of magnetite porphyroblasts surrounded by leucocratic rims in rocks of the Vänersborg area oxidation is involved in the process (fig. 18). Similar rocks occur also in areas which are shown as "Gothian" in the latest map of Sweden (Magnusson 1962), but have previously – probably on the "evidence" of magnetite crystals – been classed as "jerngneiss" by Sidenbladh (1870) and Karlsson and Wahlqvist (1870). The inferred oxidation process is comparatively late and affects all rocks older than and including at least part

Fig. 18. "Jerngneissification" of fine-grained granitoid rock ("layer granite"?). Note that the magnetite grains tend to be surrounded by leucocratic aureoles. 2 km W of Vänersborg.

of the "second generation" granites (cf. p. 32). Presumably closely related in time is the development of sodic amphiboles and pyroxenes described by Lundegårdh (1958) from the Åmål supracrustals of the Göteborg area. The areal extent of this process and its relation to granitic intrusions is not known in detail. Neither is it clear whether the concerned Åmål supracrustals are peralkaline nor whether peralkaline compositions are characteristic of these rocks in other areas.

The interpretation of metamorphic phase relationships in the "Pregothian" may be complicated by polymetamorphic conditions resulting from the superposition of several metamorphic cycles. Of considerable importance is the relation between the high-grade rocks described by Quensel (1951) and Larsson (1966) from the southern part of the "Pregothian" and the lower grade rocks of the north. The crystal chemistry and mineral associations of the charnockitic units have been investigated by Saxena (1968 a), and Saxena and Hollander (1969 a). The mineral association of the "hyperite" diabases is an obviuous starting point in tackling the problem of whether there may be possibilities to distinguish between several phases of metamorphism on grounds of mineral-chemical geothermometry. The ubiquitous "hyperites" of the eastern block are inferred to be relatively late units in the "Pregothian" (p. 48) and the crystal-chemical parameters of their garnet-amphibolitic margins thus probably reflect the conditions and temperature distribution pattern of the latest "Pregothian" phase of metamorphism. Whole-rock K/A ages are closely similar throughout much of southern Norway and all of western Sweden (Magnusson 1960, Neumann 1960, Polkanov and Gerling 1961). Some minor deviations pointed out by Bergström (1963) may well depend on differences between almost wholly micaceous and essentially feldspathic rocks (Afanasiev, Kojina, Starik 1960, Wetherill, Aldrich, Davis 1955, Meier 1966) or are within the limits of determination error. The close similarity of the radioactive age of Bohus granite to K/A datings of the "Pregothian" suggests that the "Gothian-Pregothian" rocks have experienced loss of argon (the Sveconorvegian or Dalslandian regeneration, Magnusson 1962, 1963). The complicated geological development of western Sweden ("Pregothian" supracrustals and granites, Åmål supracrustals and granites, Kappebo, and Dal) is thought difficult to crowd into the age interval suggested by the K/A ages and militates against considering all of its rocks as developed at 1000 ± 100 m.ys. A "Gothian" age (Lundegårdh 1958) reported by Parwel and Wickman (1954) for the Högsbo pegmatite near Göteborg finds no further support in the datings by Welin and Blomqvist (1964). The question is then whether and to what extent the Sveconorvegian phase is responsible for the present petrographical development of the "Pregothian". We may recall that post-Dal metamorphism has been evoked by Larsson (1947, 1956) and that sillimanite is reported to occur in the Dal formation (Larsson 1956).

A new development of our concepts of the bedrock of SE Sweden is heralded by datings of Småland granites and associated pegmatites which give Svecofennian U/Th/Pb and Rb/Sr ages (Welin and Blomqvist 1966, Welin, Blomqvist, Parwel 1966, Priem et al. 1969). Since investigations of "Gothian" granites in SE Sweden show that the Småland group is not chronologically homogeneous the entire significance of these datings is difficult to estimate, which particularly concerns the rather uncertain parallelizations between SE Sweden and the similarly ambiguous "Åmål-Kroppefjäll" group (p. 32 and 39). As discussed by Welin (1966) the recent datings in SE Sweden indicate the necessity to discard the "Gothian" of that area as an independent "orogenic cycle". As far as western Sweden is concerned interest concentrates on the problem of a pre-Sveconorvegian petrogenetic development. Experience from other areas (Jäger 1966, Meier 1966) suggests that whole-rock Rb/Sr datings may be helpful in discriminating between chronologically different units in subsequently (re-) metamorphosed regions. Very roughly our investigations suggest that among the most promising areas may be the moderatly metamorphosed rocks of the Vänersborg-Uddevalla sector which are continuous with the "Pregothian", rather than the "Pregothian" core areas subjected to possibly late post-hyperite metamorphism.

5. SOME GENERALIZATIONS

We have in the preceding chapters discussed the rocks and geological contexts of some areas at the border of the "Pregothian" complex of western Sweden. In doing so we have hitherto avoided considering the relations between the Stora Le-Marstrand series and the "Gothian" and "Pregothian". Investigations of these problems are planned in a westward extension of the mapping in the Vänersborg area, but at present we cannot contribute new aspects in this field beyond the statement that as far as we can recognize now all the rocks considered above are younger than the Stora Le-Marstrand series and the period of metamorphism leading to the migmatization of its rocks. In particular this applies to the age relations between the Stora Le-Marstrand and all granites and gneiss-granites of the Vänersborg area which we have discussed above. Still the established age differences are relative and we have at present no basis to suggest hypotheses for their translation into intervals of time. As we have described above there are continuous transitions of some rock groups of the "Pregothian" into the "Gothian" as found in Dalsland and Bohuslän. In addition we find petrographical similarities between the Stora Le-Marstrand and certain relatively early rock groups in the "Pregothian" complex. Nevertheless it remains unresolved whether this implies equivalence of the Stora Le-Marstrand and some of the early rocks and metamorphic events of the "Pregothian". We can only state that a continuity of the Stora Le-Marstrand with certain elements of the "Pregothian" is not expressly contradicted by the stratigraphical-tectonical context emerging from our work.

As to the relations between the "Pregothian" terrains and the Dalsland-S. Värmland "Gothian", many problems, particularly those concerning the relative timing of intrusive and metamorphic events, remain obscure. Still we consider that we have even at the present early stage of our survey sufficient evidence to establish some geological relations and provide a limited number of feasible alternatives concerning others. In particular we wish to point out that our mapping of parts of the "Pregothian" demonstrates that in spite of intense and repeated metamorphism this group of rocks is liable to treatment in analogy with areas outside of the "Pregothian". Thus it appears that the alleged petrological-distributional contrast between areas on either side of the Gothian/Pregothian boundary is to some extent a matter of defining mappable geological units. In the "Pregothian", changes in color, acidity, type and frequency of pegmatite/migmatite veining, feldspar megacrysts, and frequency of amphibolite beds and dikes have been employed to establish different gneiss units. Some of these features as for instance amphibolites and megacrysts and to a certain extent also variations in color and acidity are not taken as reason to split the "Gothian" granite group. These differences in mapping practice are largely due to H. E. Johansson's definition of gneiss types in the "Pregothian". Johansson's classification was based on the chemical rating of "megaschlieren" in his giant differentiating "gneiss melt", whereas differences in "Gothian" areas were suppressed by the assumption of one single group of congenetic granitoid rocks. In contrast, age relations between the granites and supracrustal rocks in the Gothian-Dalslandian have merited attention for almost a century, whereas similar relations in the "Pregothian" have prior to Magnusson's work in the late twenties often been regarded as genetically and chronologically unimportant differences between magma schlieren solidifying at slightly different times, or have been tackled on the basis of up-down concepts rooted in neptunism. Naturally there are actual differences between the "Gothian" and "Pregothian" particularly as concerns intensity and type of deformation and metamorphism, but e. g. throughout most of the western "Pregothian" block we find that gneiss classification according to different frequencies of amphibolites, migmatite schlieren, and feldspar porphyroblasts tends to obscure the fact that a grey gneiss/gneiss-granite is the ubiquitous main constituent element. In spite of very intense polymetamorphic alterations close scrutiny of the relations between this gneiss-granite and different other constituent rocks offers firm basis for the subdivision of much of the "Pregothian" gneiss into metasupracrustal, plutonic, and hypabyssal units.

Concerning the "Pregothian" and "Gothian" we have arrived at the following conclusions:

– The boundary between the "Gothian" and "Pregothian" in the Vänersborg area cannot be described as a zone or a system of faults.

– Rock elements continuous with the "Pregothian" occur in the "Gothian" area as it is shown in the Map of Sweden (Magnusson 1962).

– Rocks hitherto covered by the term "Åmål-Kroppefjäll granites" belong to at least two different groups with intervening amphibolite hypabyssals and major tectonical events.

– The transition from the "Pregothian" to the "Gothian" in the Vänersborg area is one of decreasing intensity of regional metamorphism. In additoin "second generation (p. 32) plutonics make their appearance in the west. Their contact relations are normally intrusive.

The relations at the contact between the "Gothian" and the western block of the "Pregothian" are closely similar in all surveyed areas (Vänersborg, northern and northeastern edge of Gillbergaskålen, and southwestern edge of the "mylonite zone" between Sunne and Arvika). In all three cases there is a gradual transition from small-scale contortive folding in migmatites to large-scale folds in unveined rocks, and finally to zones of foliation deformation. This suggests that veining cannot be older than a hypothetical "pre-Åmål" land surface carved into the "Pregothian" and subsequently covered by "Gothian" sediments. In the Gillbergaskålen area our preliminary survey confirms the correctness of the basic tectonic pattern as described by Magnusson (1929 b). Further investigations are required to elucidate the chronology and the relations between different groups or rocks and events of metamorphism. In the western block of the "Pregothian" one of the main chronological problems concerns the relations between the red submassive granites of the "Pregothian" and the red "Kroppefjäll" (= Hästefjorden) granite farther west, and similarly the relative age of migmatization and the "second generation" Åmål granites in Dalsland. There are indications of two different periods of regional metamorphism in some parts of the "Pregothian". "Pregothian" and "Gothian" periods of metamorphism have been described by Lundegårdh (1958), but we differ in the classification of syenitoid veining as "Pregothian" and granitoid veining as "Gothian" and suggest a distinction between veins depending on local segregation and veins associated with material transport and granitization. Granitic veins may belong to both groups.

In the eastern "Pregothian" block we have indications of a similar polymetamorphic development. Reconnaissance in the Ulricehamn-Borås area demonstrates the probable existence of an amphibolite generation intervening between two periods of veining and folding. Since we found that members of the "Gothian" Värmland granite group (cf. Hjelmqvist 1966) are involved in at least the last period of regional deformation of the "Pregothian" in Värmland, they cannot be regarded as entirely segregated from the "Pregothian" development. Future attention must be focused on a. o. three unanswered questions which can be put thus:

– Which if any of the granulated augen-gneisses of the eastern "Pregothian" are older than the foliated western facies of the Värmland granites?

– Do the quartzitic supracrustals and associated dacite porphyrites of the Hålsjöberg group represent relics disconnected by metaplutonics or do they rest on an ancient erosion surface. The solution of this problem will be instrumental in the classification of different augen-gneiss metaplutonics in the eastern "Pregothian".

– What is the relation between the "Pregothian hyperites" and other diabases outside of the "Pregothian"? Our investigations demonstrate that the hyperites are hypabyssals which are much younger than the surrounding rocks and also younger than the general granulation of the "Pregothian" rocks to the west of the Klarälven valley. Thus in conflict with a commonly held opinion we wish to stress that the hyperites cannot in this respect be considered integral parts of the surrounding "Pregothian" gneisses.

A new development in our concept of "Gothian" geology in the Bohuslän-Dalsland-S. Värmland region is indicated by the recognition of several different groups of granitoid plutonics in the areas previously described as "Gothian", and by the present investigation of the relation between some of these rocks and the Ellenö complex of chapter 2. While the results of the new survey resolve some difficulties and contradictions in previous work, they necessitate at the same time a thorough reconsideration of the supracrustal

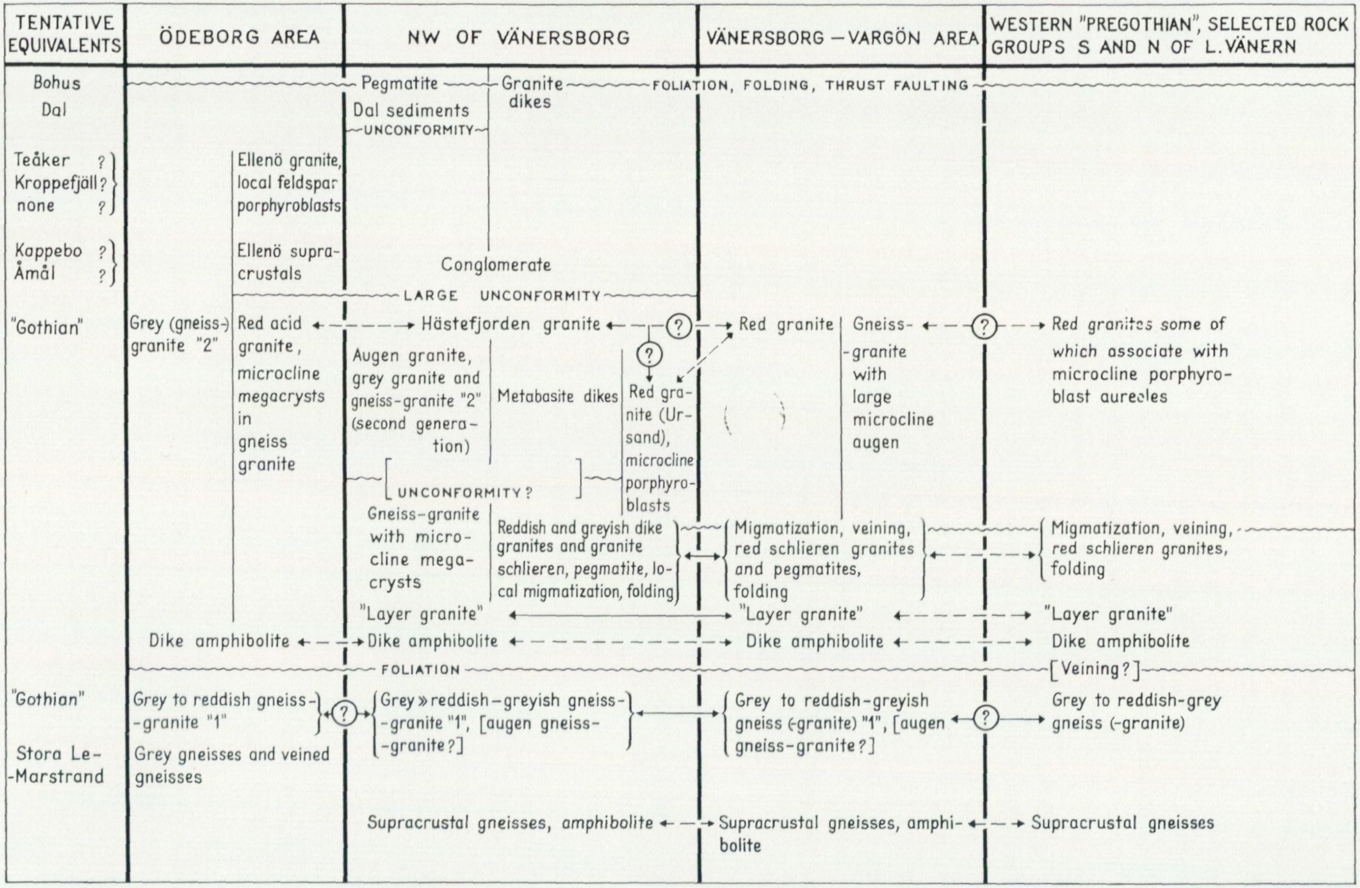

Fig. 19. Local stratigraphies of the Vänersborg region and the "Pregothian". Vertical thin lines are drawn between rocks of the same area when mutual age relations are not unequivocally established. Solid arrows show correlations observed in the field, broken-line arrows connect rocks which can be parallelized on petrographic-tectonic grounds. Arrows with interrogation marks indicate questionable conceivable age correlations. Youngest rocks at the top.

rocks in Dalsland. No longer can we take it granted that if a pre-Dal supracrustal rock rests on granite(-gneiss) it must be "Kappebo", and if it is transected by a pre-Bohus granite it must be "Åmål". As far as the Ellenö complex is concerned similarities in lithology suggest the possibility of a parallelization with "Kappebo". In this case we must necessarily reckon with an important group of post-Kappebo "Kroppefjäll granites". Again if the Ellenö complex be classified as "Åmål" much of the granites and granite-gneisses of southern Dalsland, including some "Kroppefjäll-type" rocks must be "Pregothian" in the sense of being older than the Åmål series supracrustals. It is anticipated that future investigations of the relations between supracrustals and "second generation" granites in the Vänersborg area will provide definite answers. A survey of local chronologies and some tentative correlations between rocks of the Vänersborg area are given in fig. 19.

Our investigation provides no new contributions toward a parallelization of the rocks of western Sweden with orogenic groups in central and southeastern Sweden, but if anything it illustrates the risks arising from the complexity of lithogenetical events and from the existence of rocks of similar lithology, but different chronological position. The intricacy of chronological problems in West Swedish "Gothian-Pregothian" areas demonstrates the urgent need of checking the geological correlations and basing the definition of distinct orogenic events on polymethod isotopic dating. The complicated areal distribution pattern of chronologically different, but lithologically similar rock units makes it imperative that future radioactive-dating projects be conducted in close association with investigations of regional geology. In particular we wish to emphasize that the present "Åmål-Kroppefjäll group" classification provides no unambiguous definition of the geological age of plutonics in the Dalsland area and that the location of a rock in the "Pregothian" region is no indication that it is "Pregothian" in a lithogenetical and chronological sense.

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SGU – Sveriges geologiska undersökning

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