3. The Grovstanäs Region.

An Ultra-Basic Gabbro Massif and its Immediate Vicinity.

By

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Preface.

The investigation of the Grovstanäs region accounted for in this paper has been carried out intermittently since 1936, but the main field work could be accomplished first during the summers of 1941—42.

The laboratory work was entered upon in 1941, except for the separate interpretation of the Bönskär bytownite mentioned later on, which attained its completion in January 1941.

The author's most sincere thanks are due to his teacher and friend Dr. H. G. BACKLUND, Professor of Upsala University, whose interest in and support of this investigation have never failed. Furthermore, he is very much indebted to his friend and former teacher of mineral optics, Dr. T. KROKSTRÖM, Lecturer of Upsala University, for a great deal of good advice, and to his friends Dr. W. LARSSON, Geologist of the Geological Survey of Sweden, and Phil. lic. T. TRYGGVASON, for many elucidating discussions.

Dr. H. LUNDEGÅRDH, Professor of the Agricultural College of Sweden, and Director P. E. GRUDE have facilitated the field work in numerous respects.

As to the manuscript, the Rev. C. E. BJÖRK and a friend of the author, Phil. mag. M. MELANDER, have offered various linguistic points of view.

The thin sections — about 160 in number — were prepared by Mr. W. PLAN, whose carefulness as to this task has never diminished.

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I. **Introduction.**

The ultra-basic gabbros within the coast region of Eastern Uppland (the Central and Northern parts of Roslagen) have attracted attention since almost 100 years. In fact, the first mention of them in print appeared as early as 1846, and was one result among many others of a search for rocks containing hornblende or (and) augite. The renowned pioneer of Swedish geology, AXEL ERDMANN, who was the investigator, described at that time the gabbro of Rådmansö in Eastern Uppland, classing it as a »*hypersthenfels*», which in English would be a rock containing hypersthene as a main mafic mineral (A. ERDMANN 1846, p. 225). Later on, the ultra-basic gabbros gave rise to several descriptions, and investigations too, the most prominent of which are those by P. ÖBERG (1872), E. SVEDMARK (1885), and T. DU RIETZ (1929). These authors all concentrated upon the Rådmansö gabbro, perhaps because of this massif being the largest of all gabbro masses in Roslagen. The Rådmansö massif, however, is not the one displaying the biggest number of rock varieties and the clearest proofs as to the origin of the ultra-basic gabbros within Roslagen, and, in recent time (DU RIETZ 1929), this matter of fact has given rise to some wrong presumptions.

When, several years ago, the author of this paper was travelling through Roslagen, his attention was very soon attracted by the Grovstanäs peninsula, situated about 10 km S of the small town of Norrtälje, and about 55 km NE of Stockholm. The fact that the S and larger part of this peninsula consisted of gabbro rocks he already knew from the sketch-map by SVEDMARK (1885) and from the geological map-sheet »Penningby» (A. BLOMBERG 1889). In the description of the latter E. ERDMANN (BLOMBERG 1889, p. 15 ff.) gives a short survey of the gabbro massif, to which he attaches the name »Grovstanäsmassivet» (= the Grovstanäs massif).

E. ERDMANN, however, fails in pointing out the richness of gabbro varieties, which characterizes the Grovstanäs massif. And perhaps this is one of the reasons why it has not been investigated until our time.

II. **General Features of the Grovstanäs Region and its Environments.**

The Grovstanäs region forms a small part of the peneplain of Eastern Uppland. In Central Roslagen this peneplain is very smooth, as shown by Fig. 1, where the fore-ground is occupied by the Grovstanäs region.

Fig. 1. A survey of the Grovstanäs region towards SSE, from a point 200—300 m WNW of the W end of Lake Båtdragsträsket. P. H. L. 1937.

When regarded in detail, the peneplain looses its smoothness, however, and changes into a crude surface, for the most part covered by post-glacial sediments and by water. The rudeness is due to an erosion, which, as the chiefest result of its activity, has given a system of valleys running E—NE- or sometimes NNW-wards. In most cases this direction coincides with the parallel structure of the main rocks of the whole of Roslagen, i. e. the gneiss-granites (see chapter V: 2!), the strike of which, according to H. G. BACKLUND (1936, 1937 and 1941), should be denominated as *Svecofennian.*

As is evident from the sketch-map (Fig. 2), several basite masses are situated in the gneiss-granites of the area around and in the N of the Grovstanäs region. Most of these are concordant and consist of amphibolites; a few, however, in some directions show concordance, in other directions discordance, and are composed of the ultrabasic gabbros already mentioned. The gabbro masses are conformable and disharmonious (terminology according to H. CLOOS, 1936, p. 75).

If the reader looks at the large maps at the end of this paper (Pls. XII and XIII), he will easily notice the reasons for the characteristics of the gabbro masses given above. W—SW-wards the gabbro of the Grovstanäs massif forms wedge- or tongue-shaped protuberances in the strike di-

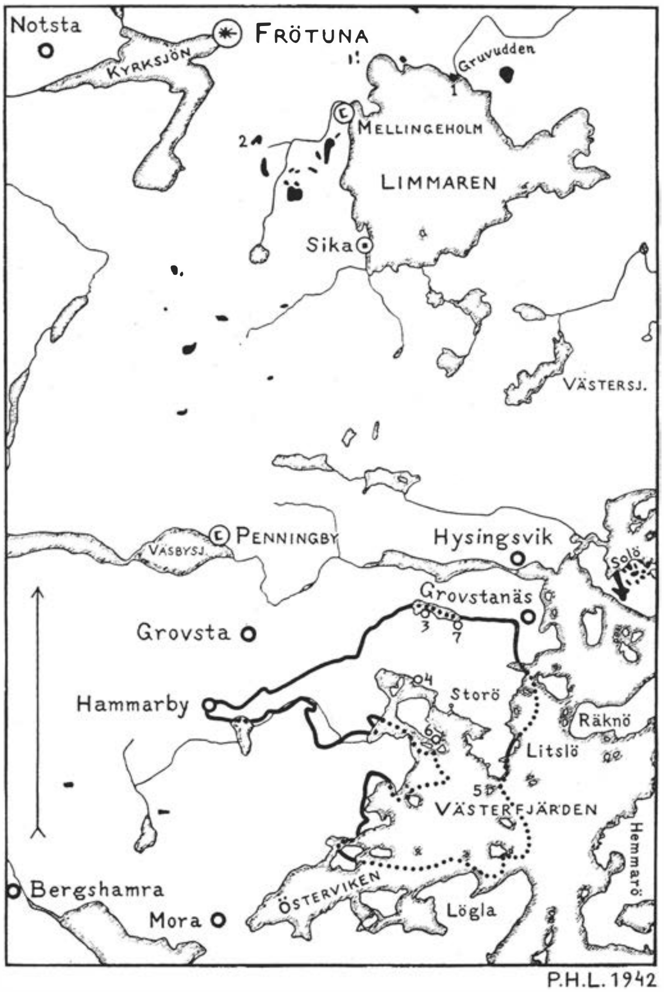

Fig. 2. Map of the Frötuna—Mora area in Central Roslagen. Black = minor amphibolite and gabbro masses (after BLOMBERG 1889), the thick border line = the boundaries of the Grovstanäs massif (incl. border rocks), the numbers = chemical analyses. Scale 1 : 100 000.

rection of the gneiss-granites, towards N and S erosion has concealed the border except in a few outcrops, where concordance between gabbro and wall rock was observed. E-wards, however, the border line exhibits total discordance, with the exception of the change of strike of the wall rock in the immediate vicinity of the gabbro.

Younger dikes, especially of granite-aplites and pegmatites, but also of amphibolites, traverse the region to a large extent. Most of them run parallel to the strike direction of the gneiss-granites.

III. The Ultra-Basic Rocks of the Grovstanäs Massif.

0. Nomenclature and principles of division. Methodological remarks.

When ÖBERG (1872) carried out his investigation of the Rådmansö gabbro, he proposed a new name for these ultra-basic rocks: eucrites. In this he was not followed by SVEDMARK (1885), in spite of the urgency of a clear distinction in nomenclature between the common gabbro rocks with An = 50—80 % and the ultra-basic ones with An = 80—95 %. Perhaps the new use of the name eucrite did not appeal to SVEDMARK because it was invented earlier to indicate meteorites.

As pointed out by DU RIETZ (1929, p. 485), the term eucrite has now been accepted in petrological literature, and in his compendium of nomenclature W. E. TRÖGER (1935) mentions eucrite (no. 358) and quotes an analysis from A. HARKER, showing a gabbro consisting of plagioclase ($Ab_{17}An_{83}$), ortho- and clinopyroxene, some olivine, and a few accessories.

In this paper, however, only olivine-free, ultra-basic clinopyroxene gabbros will be called *eucrites* in order to separate them from rocks containing much olivine together with considerable amounts of clinopyroxene and amphibole, or of amphibole alone. Rocks of the latter type will be classed as *olivine-eucrites*.

The ultra-basic correspondence to troctolite will be called *allivalite*, according to HARKER (1908). Allivalite is mentioned as no. 364 by TRÖGER (1935). In the example given there, the rock to the largest part consists of plagioclase ($Ab_{17}\ An_{82}\ Or_1$) together with olivine.

The ultra-basic norites of the Grovstanäs massif (marked out as norites in Pl. XII) are not in accordance with the definition given by TRÖGER (1935, no. 355). TRÖGER mentions a norite containing 70 % An in its plagioclase. The Grovstanäs norites, however, display a much more anorthic plagioclase (An = 86—87 %). In agreement with the terminology used in this paper, the rocks in question will be classed as *hypersthene-eucrites*.

In his description of no. 361, corsite, TRÖGER (1935) uses the term *hornblende-eucrite*, which in this paper will be applied to ultra-basic gabbros with amphibole as the main mafic constituent. Whenever the amphibole is obviously secondary, the prefix *uralite-* will be used instead of hornblende-.

Hornblendite with evidently secondary amphibole will be called *davainite* in agreement with TRÖGER's terminology (1935, no. 702).

The nomenclature of the remaining ultra-basic gabbros needs no special explanation.

The sequence of the rocks accounted for in this chapter is founded on field investigations, microscopical observations, and on chemical evidences. These data will be recapitulated in connection with the description of the rocks concerned. In agreement with common practice the oldest rocks will be dealt with at first.

The field situations of the specimens mentioned in the text will be found on the map, Pl. XII.[1]

The mineral colours reported refer to thin sections.[1]

Most of the measurements of 2 V were carried out by means of the method of characteristic extinction (M. BEREK 1924, p. 91 ff.). Only a few small optic axial angles were determined in accordance with W. W. NIKITIN's method (M. BEREK 1924, p. 103 ff.).[1]

The immersion method was applied in the determination of the refraction indices.

As to the *plagioclase*, the percentages of An $>$ about 80, found from the NIKITIN curve $\perp$ (010) of 1933, have been reduced by 1—2 % (P. H. LUNDEGÅRDH 1941). The NIKITIN $\perp$ (010) values are the ones quoted in the text to be significant for the plagioclase described there.[1]

1. Anorthosites.

The massive anorthosites are concentrated to a huge, curved, band-shaped body situated in the SE part of the Grovstanäs massif, as shown by the petrological map (Pl. XII). They build up the whole of the islet of Bönskär, and run from there S-wards over the isle of Tjuvholmen towards the isle of Träffsholmen.

The massive anorthosites are always medium-grained, xenomorphic (= anhedral), and of a white, sometimes a light gray to a light bluish gray colour.[2] They bear a slight resemblance to marble, and in general contain quite insignificant quantities of mafic minerals. Some varieties, however, grow richer in a green amphibole, in the Tjuvholmen anorthosite often surrounding remnants of clinopyroxene. Very seldom we find olivine as a mafic constituent. In fact, as a rule, the olivine-bearing anorthosites do not occur as masses, but as bands of allivalites and olivine-eucrites. Only in the isle of Tjuvholmen do we find transitions between massive anorthosite and olivine-eucrite: narrow zones with an increasing percentage of olivine.

As narrow bands, anorthosites are spread widely over the Grovstanäs

[1] Applicable to all rock descriptions within this paper.

[2] When nothing else is stated, this will also be the colour of every plagioclase variety mentioned later on.

region. In fact, almost everyone of the strike-and-dip observations represented in the structural map (Pl. XIII) refers to anorthositic bands. They do not only occur in the rocks above mentioned, but also to a large extent in the medium-grained hornblende- and uralite-eucrites. In the hypersthene-eucrites and most of the fine-grained hornblende- or uralite-eucrites, however, the anorthositic banding is badly developed in those cases when it does not lack totally.

The main constituent of all anorthosites is a *bytownite* of a composition (An = 88—89 %) placing it immediately to the anorthite. In other respects, however, the massive anorthosites may vary somewhat from the band ones, and in the following description we shall therefore concentrate upon the former. The characteristics of the remaining anorthosites will be evident from the descriptions of those gabbro types in which they occur as bands.

In an earlier paper the author has carried out a chemical and optical investigation of the Bönskär bytownite (LUNDEGÅRDH 1941), which, as one of its results, has given a relation between Ab and An=12.1:87.9. The arithmetic mean of the poles ⊥(010)[1] of twins measured on the FEDOROW-BEREK universal stage (BEREK 1924) there displayed a somewhat higher percentage of An, and an eccentric situation when compared with NIKITIN's curve ⊥(010) (NIKITIN 1933) after having been represented in WULFF's net as coordinates of the refraction indices. The eccentricity tended towards the line between n_β and n_α (1941, Fig. 1, p. 425).

A certain interest must also be attached to the frequency of different twinning laws as was exhibited by the Bönskär bytownite. Among 25 twins analysed on the universal stage 11 followed the pericline law and 10 the albite law (LUNDEGÅRDH 1941, p. 421).

On the contrary, an examination of 12 twins of three specimens taken from different outcrops in the isles of Tjuvholmen and Träffsholmen has given as a result the fact that no other twinning law except that of albite is represented there. The poles ⊥(010) of these twins have been plotted against NIKITIN's curve (Fig. 26, ch. VII: 1). They scatter well around a point An = 90 % (to be reduced to 88—89 % An), i. e. the pole representing the arithmetic mean of their n_α-, n_β-, and n_γ-coordinates, a point, falling within a most immediate vicinity of NIKITIN's curve (Fig. 26, ch. VII: 1).

The coordinates of ⊥(010), taken from the individuals of the twins recently mentioned, are reported in Tables 1—3. Here we find a distribution in excellent agreement with the normal curve (proposed, as is well-known, by GAUSS). This means that we have to deal with no trend in any direction, i. e. we can trace no indications of any obvious chemical

[1] Explanations here necessary are given in the author's earlier paper.

Table 1. The n_α coordinate of $\perp$ (010) as found from anorthosite plagioclase twins (except for the Bönskär bytownite).

$M = 56°.6 \pm 0°.38$. $\sigma = 1°.84 \pm 0°.266$. $N = 24$

Values	$<2.0 \times \sigma$	$1.0 \times \sigma$	$0.67 \times \sigma$	$>0.67 \times \sigma$	$1.0 \times \sigma$	$2.0 \times \sigma$
Real error distribution . . .	0	4	7	7	5	0
Error distribution according to GAUSS	1/2	4	6	6	4	1/2
Difference	−1/2	0	+1	+1	+1	−1/2
Deviation from M>	3°.68	1°.84	1°.23	1°.23	1°.84	3°.68
Values	<52°.9	54°.75	55°.4	>57°.8	58°.45	60°.3

Table 2. The n_β coordinate of $\perp$ (010) of the same plagioclase twins.

$M = 61°.6 \pm 0°.53$. $\sigma = 2°.61 \pm 0°.377$. $N = 24$

Values	$<2.0 \times \sigma$	$1.0 \times \sigma$	$0.67 \times \sigma$	$>0.67 \times \sigma$	$1.0 \times \sigma$	$2.0 \times \sigma$
Real error distribution . . .	1	4	5	8	4	0
Error distribution according to GAUSS	1/2	4	6	6	4	1/2
Difference	+1/2	0	−1	+2	0	−1/2
Deviation from M>	5°.22	2°.66	1°.77	1°.77	2°.66	5°.22
Values	<56°.4	58°.95	59°.8	>63°.4	64°.25	66°.8

Table 3. The n_γ coordinate of $\perp$ (010) of the same plagioclase twins.

$M = -45°.9 \pm 0°.47$. $\sigma = 2°.32 \pm 0°.335$. $N = 24$

Values	$<2.0 \times \sigma$	$1.0 \times \sigma$	$0.67 \times \sigma$	$>0.67 \times \sigma$	$1.0 \times \sigma$	$2,0 \times \sigma$
Real error distribution . . .	1	4	5	7	4	0
Error distribution according to GAUSS	1/2	4	6	6	4	1/2
Difference	+1/2	0	−1	+1	0	−1/2
Deviation from M>	4°.64	2°.32	1°.55	1°.55	2°.32	4°.64
Values	<41°.25	43°.6	44°.35	>47°.45	48°.2	50°.55

or optical difference within the plagioclase of the three specimens concerned, nor of its localities. An optical difference, however, must be assumed when comparing the anorthosites just now examined with that of Bönskär. But it must be pointed out that there exist no supports of any changes in the relation Ab:An, i. e. differentiation, in the anorthosite mass. And, in fact, anorthosite from the isle of Träffsholmen has given a plagioclase refraction index $n_{\alpha Na} = 1.570 \pm 0.003$. The corresponding value of the Bönskär bytownite was 1.5695 (LUNDEGÅRDH 1941, p. 419)!

The accessories of the massive anorthosites are of no great importance. Alteration products: *sericite* and *clinozoisite* can be traced almost everywhere. These minerals form diminutive grains of irregular shape, and agree in that respect with the secondary *calcite* and *chlorite*, which are much more rarely occurrent. Some grains of *ore* (magnetite—ilmenite), now and then associated with *epidote*, and a few very small plates or lists of secondary *penninite*, most frequently accompanying the green amphibole described below, fills out the picture produced by an examination of several thin sections. In the Bönskär anorthosite single grains of *titanite*, *pyrite* and *prehnite*(?) were observed. The appearance of *quartz*, earlier reported (LUNDEGÅRDH 1941, p. 415), is totally accidental and worth no special attention.

More important constituents are to be found within the green spots of the anorthosite. *Amphibole*, as a rule common green hornblende with the ordinary pleochroism colours, which will be reported in part 7 of this chapter, dominates here, but in the isle of Tjuvholmen we very frequently meet a *clinopyroxene* of the pigeonite-diopside series, surrounded by deuteric or secondary amphibole. On the N shore of the W part of Tjuvholmen a strong alteration to *chlorite* was observed within part of the anorthosite. The kernels of this chlorite contain grains of ore, apparently relics after some primary mafic mineral. The extension of the chlorite alteration shows that it must be due to a chemical reaction between the primary mafic mineral already suggested and the plagioclase.

When getting more common, the spots of amphibole seem to form transitions to hornblende- or uralite-eucrite. These transitions, however, assumed to appear E—N and SW of the islet of Bönskär, are now concealed by the sea.

The amphibole spots always have a distinct orientation in field, and consequently tend to form lines. In this respect they bear close resemblance to those anorthosites (as a rule bands) containing olivine. The lines in question coincide with the general strike-and-dip direction of the banding of the more normal gabbro varieties occurring in these parts of the massif. As to the situations of the plagioclase individuals, however, no special direction is prevailing. In fact, the more narrow plagioclase bands of the gabbro also fail to show such a tendency (Fig. 30).

Transitions between olivine-eucrites and anorthosites are already reported from the isle of Tjuvholmen. *Olivine* will be dealt with further on (ch.-parts 2—3). The almost total lack of transitional rocks in close proximity to the peridotites of the isle of Träffsholmen is striking. This fact, to some extent, seems to contradict the experience from the isle of Tjuvholmen. But in ch.-part 4 most of the peridotites will be proved to be a trifle younger than the allivalites and the olivine-eucrites. That circumstance will perhaps throw some light upon the sharp border lines dividing the peridotites and the anorthosites.

The genesis of the Grovstanäs anorthosites forms a problem not easily interpreted. And this task can hardly be dissolved until we have arrived at a point from which we are able to regard the Grovstanäs massif as a whole.

2. **Allivalites.**

The preserved allivalites of the Grovstanäs massif always occur in connection with the olivine-eucrites as »isles» in, or marginal parts of these rocks. They build up most of the isle of Skarpholmen, and have gained a strong position in the rocky isle of Bergsö; moreover, they are distributed widely in the N and E parts of the massif.

The allivalites in field appear as dark gray to black gray, medium-grained, xenomorphic rocks showing a characteristic brown surface-weathering producing small hollows at those places, where the olivine crystals have once been situated. Anorthositic, or at least plagioclase-rich banding is often prominently developed, but as a rule genuine anorthosite bands occur to a less extent than in the olivine-eucrites. Sometimes the banding winds or has been distorted (Fig. 3). Other outcrops are crossed by straight or only very slightly curved bands.

Plagioclase in general forms the prevailing constituent, but many allivalites grow rather rich in olivine, and thus here and there grade into peridotitic bands. In fact, a great many outcrops show a beautiful alternation of felsic and mafic bands (Fig. 3). But, as a rule, the olivine of these mafic bands has altered in a much higher degree than the olivine of the normal allivalites.

Several banded olivine gabbros now display too large a content of secondary or deuteric constituents, especially amphibole, to be characterized by the term allivalite. They have therefore been classed as olivine-eucrites, and will be dealt with in part 3 of this chapter.

The *plagioclase*[1] (An = 88—89 %) of the allivalites exhibits a fresh physiognomy, which is rather striking when compared with the same component of many other Grovstanäs gabbro varieties. In chemical and optical respects it practically coincides with the anorthositic plagioclase, as shown by the diagrams of pole-⊥ (010)-distribution (Fig. 26, ch. VII: 1). There, and in the error-distribution-tables presented in the next chapter, those plagioclase twins determined on the allivalites and olivine-eucrites are taken together in consequence of the intimate relationship between these rocks.

[1] Frequency of twinning laws is reported at the beginning of chapter VII (Table 27).

Fig. 3. Winding and in part distorted banding at point 156 of the isle of Litslö. P. H. L. 1941.

An examination of a typical allivalite from the S coast of Lake Båtdragsträsket (sp.[1] 52; an analysis shown by Table 4) as to the plagioclase has given as a result a specific gravity of 2.727 (20° C), and an index of refraction $n_{\alpha Na} = 1.569 \pm 0.003$ in excellent agreement (An = 88 %) with the corresponding values found from the bytownite of Bönskär (G = 2.725, $n_{\alpha Na} = 1.5695$; LUNDEGÅRDH 1941, pp. 416 and 419). The more uncertain value of $2 V_\gamma$ is very high, 104° 1/4, in this allivalite. After having noted these data and compared the positions of the poles ⊥ (010) in relation to each others and to the NIKITIN (1933) curve we can class the allivalitic and of course the olivine-eucritic plagioclase, too, as a *bytownite* with the relation Ab : An = 12 : 88—11 : 89.

As was mentioned above, the plagioclase of the allivalites is prominently fresh. A slight alteration, however, can be traced here and there, and has given as its chiefest result several small, irregular-shaped grains of *sericite*. Repeatedly this change is seen to have followed the cleavages, especially the (010) one. *Clinozoisite* ($2 V_\gamma = 80—85°$) is only seldom observed. Sometimes it may grade into *epidote*, especially when minute grains of ore are present. Some grain boundaries, but more frequently those fracture lines, which cross many of the plagioclase individuals, do not only contain the

[1] In the following used as an abbreviation of »specimen».

Table 4. Allivalite from the W part of the S coast, Lake Båtdragsträsket. Specimen 52 (no. 3 in Fig. 2). Analyst = N. SAHLBOM.

	Weight-%	Mol. Prop.
SiO_2	42.00	699
TiO_2	0.12	2
Al_2O_3	25.74	253
Fe_2O_3	1.70	11
FeO	4.07	57
MnO	0.05	1
MgO	8.46	210
CaO	14.14	252
Na_2O	1.06	17
K_2O	0.52	6
P_2O_5[1]	0.22	2
Cl_2	0.15	2
H_2O+	1.66	92
H_2O-	0.14	—
	100.03	

Norm (%)			
Or		3.34	
Ab		2.10	
An		64.25	
Ne		3.13	Σ sal 72.82
Di	$CaSiO_3$	2.21	4.22
	$MgSiO_3$	1.61	
	$FeSiO_3$	0.40	
Ol	Mg_2SiO_4	13.65	17.83
	Fe_2SiO_4	4.18	
Mt		2.55	
Il		0.30	
Ap		0.51	Σ fem 25.41
NaCl (from sea water)			0.23
H_2O+			1.66
			100.12

II:5:5 = *Corsase.*

Or:Ab:An = 4.8:3.0:92.2

Geometric analysis:

	Vol.-%	Weight-%
Plagioclase	69.3	64.3
Olivine	8.3	10.0
Amphibole with spinel-chlorite-»fingers»	11.3	12.5
Orthopyroxene	3.6	4.2
Ore with serpentine	3.3	5.1
Pure serpentine	0.6	0.5
Sericite + chlorite	2.8	2.6
Diabantite	0.5	0.5
Clinozoisite + epidote	0.3	0.3
Calcite	0.1	0.1
Apatite	0.0	0.0
	100.1	100.1

NIGGLI values	
qz	−24.6
al	31.0
fm	35.5
c	30.9
alk	2.6
si	85.8
ti	0.18
mg	0.73
k	0.29
p	0.18

products of alteration just mentioned, but are also marked out by or filled with *chlorite,* rarely accompanied by *serpentine. Talc* was observed together with sericite in one of the thin sections examined.

Particular attention must be paid to the rare occurrence of small rounded grains of plagioclase within the olivine. The reader is recommended

[1] This value seems to be too high, as no apatite was traced in the thin sections examined. But, of course, a little P_2O_5 may be contained within the lattice of some constituent mineral of the rock.

to keep this observation in mind for the future, as we shall return to it when dealing with the peridotites.

The predominant mafic constituent of the allivalites, the *olivine,* perhaps forms the most interesting mineral of all within the Grovstanäs gabbro. This fact, however, does not depend as much on the mineral itself as on its alteration products, which in part are rather peculiar.

DU RIETZ (1929, p. 505 ff.) has already carried out a close investigation as to a phenomenon, by him called »reaction rims», i. e. concentric zones or »coronas» of apparently deuteric minerals, surrounding the Rådmansö olivine grains as well as those of the Grovstanäs gabbro. DU RIETZ has found his olivine to be sometimes embedded in a narrow zone of orthopyroxene, which in many cases is interrupted, but much more frequently to be surrounded by a rim of light-coloured, radiating amphibole. This inner zone is followed by a marginal one of an amphibole, which immediate to the plagioclase is trimmed with small, finger-shaped inclusions of a green mineral, in a few thin sections determined as spinel. After having examined a large number of slides and after having penetrated the earlier literature carefully, DU RIETZ assumes the amphibole part of these rims to be due to chemical reactions between olivine and plagioclase.

In his close study of the olivine-hyperites of the Kragerö region, W. C. BRÖGGER (1935, p. 24 ff.) states that the outer symplectic corona of a commonly bluish-green or green hornblende (actinolite) with spinel there very often present must have evidently originated essentially at the expense of the plagioclase. The inner corona in these rocks consists of orthopyroxene (bronzite, or sometimes hypersthene). To explain the formation of the coronas, BRÖGGER assumes the following chief reactions:

a. The inner zone (1935, pp. 32—33): $(Fe, Mg)_2SiO_4 + SiO_2 = 2(Fe, Mg)SiO_3$, and, when ore is developed in connection with the formation of orthopyroxene: $(Fe, Mg)_2SiO_4 = (Fe, Mg)SiO_3 + FeO$.

b. The inner and outer zones (1935, p. 28): $18MgO \cdot 8FeO \cdot 13SiO_2$ (olivine) + $Na_2O \cdot Al_2O_3 \cdot 6\,SiO_2$ (2 Ab) + $4\,CaO \cdot 4\,Al_2O_3 \cdot 8\,SiO_2$ (4 An) = $9\,MgO \cdot 4\,FeO \cdot 13\,SiO_2$ (hypersthene) + $6\,MgO \cdot 3\,FeO \cdot 4\,CaO \cdot Na_2O \cdot Al_2O_3 \cdot 14\,SiO_2$ (hornblende) + $3\,MgO \cdot FeO \cdot 4\,Al_2O_3$ (spinel).

Within the allivalites of the Grovstanäs massif the ordinary structure of the olivine grains with their coronas is as follows (Figs. 4—5):

a. A kernel of *olivine*, as a rule more or less rounded, but sometimes of quite an irregular shape. This kernel is always crossed by several fissures, filled with a mass of *ore* (in general magnetite) and greenish yellow brown to olive green or greenish *serpentine*, in a few thin sections determined as *chrysotile* ($2\,V_\gamma$ immediate to 0°) accompanied by fibrous *antigorite* (opt. —, 2 V large). Here and there the alteration grows stronger.

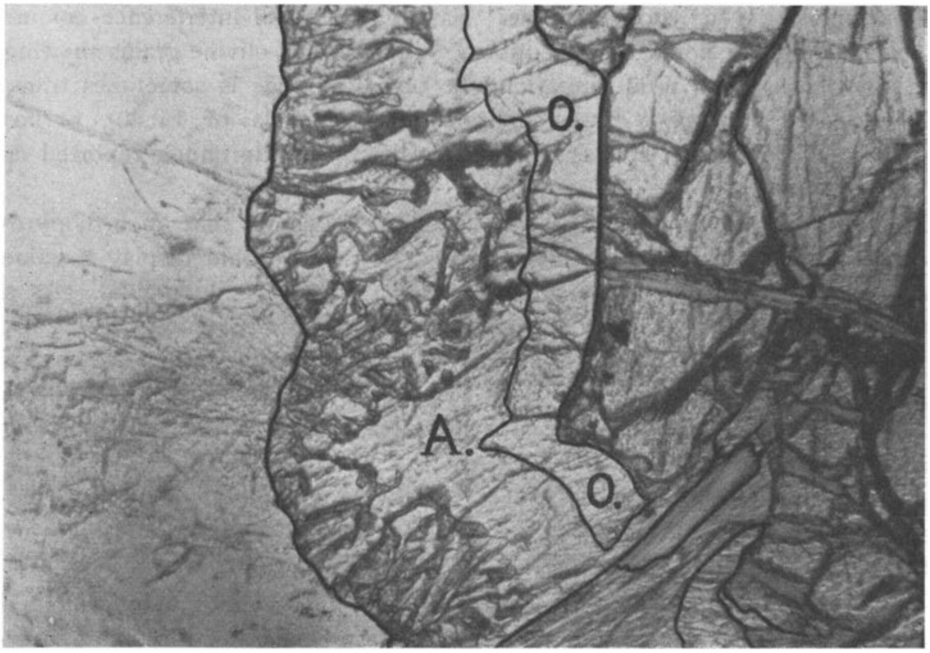

Fig. 4. Part of an olivine corona. From the right to the left: olivine — orthopyroxene (O.) — amphibole (A.) whith chlorite-spinel-»fingers»—plagioclase. Sp. 158, 1 nic., magnified about 165 ×. P. H. L. 1942.

In fact, some kernels form nothing but pseudomorphous serpentine with the ancient fissures preserved as winding lines, rich in ore (for ex. many kernels in sps. 156 and 177). In rare cases it happens that the serpentine is partly exchanged for *chlorite*, in a few cases of the *diabantitic* type (see part 3 of this chapter!). As to its occurrence, however, the diabantite is in general restricted to the boundaries of the kernels. Single fissures contain small grains of deep green *spinel*.

The olivine itself is of a faint greenish colour and displays a chagrin-shaped hue. The (010) cleavages are badly developed or totally absent. (100) cleavages do not seem to occur.[1] $2V_\gamma$ was determined on 7 allivalites: 94° (sp. 47), 95° 1/4 (sp. 52), about 88° (sp. 156), 93° 1/2 (sp. 158), 98° 3/4 (sp. 161), 94° (sp. 179), and 93° 1/3 (sp. 185). According to A. WINCHELL (1933, p. 191), the ordinary allivalite olivine with $2V_\gamma = 94°$ would correspond to a chrysolite with 23—24 mol-% Fe_2SiO_4. BACKLUND's diagram (1909) gives 20 mol-% Fe_2SiO_4.

b. An inner, usually narrow rim of *orthopyroxene*, frequently interrupted, but scarcely ever absent. The orthopyroxene has proved to be optically negative (2 V sometimes immediate to 90°), and, consequently, it should be classed as a *hypersthene* frequently grading into *bronzite*. Its

[1] These characteristics are applicable to all olivine of the Grovstanäs massif.

birefringence is a very low one. Faintly yellowish interference colours $\perp \beta$ can only be noted as exceptions. Within those olivine grains showing a very strong or a total alteration, the orthopyroxene is sometimes transformed into *serpentine* (sp. 156 from the peninsula of Litslö), or has completely vanished (sp. 177 from the islet of Fjärdgrundet, reported as olivine-eucrite).

The diagram of WINCHELL (1933, p. 218) shows that an orthopyroxene corresponding to an olivine with $2\,V_\gamma = 94°$ would display a value $2\,V_\gamma = 102°$ ($Fe_2SiO_4 = 23.5$ mol-%) $- 98°$ ($Fe_2SiO_4 = 20$ mol-%). As a rule this seems to agree with experience. Perhaps the percentage of $FeSiO_3$ of the orthopyroxene is sometimes a little lower than expected (when 2 V goes down to the vicinity of 90°). This fact indicates that BACKLUND's curve 2 V (olivine) would be a trifle more true than the corresponding curve of WINCHELL.

The allivalites of the isle of Skarpholmen frequently exhibit larger reaction rims than these rocks usually do, rims, the hugest of which are combined with a total lack of the outer amphibole zone.

c. An outer zone of pale green *amphibole*, marginally trimmed with finger-shaped inclusions of a green mass, sometimes becoming deep green and then isotropic, too. Most part of the inclusions, however, is faintly birefringent. These »fingers» run inwards from the outer boundary, and may fill most of the amphibole. In a few cases small grains of a deep green *spinel* were found to accompany the »fingers». In one single thin section a scanty number of small plagioclase remnants is included within the amphibole individuals.

The finger-shaped inclusions apparently consist of *chlorite* accompanied by *spinel*, and, consequently, indicate a strong decrease in SiO_2. The amphibole shows normal, though faint, pleochroism with $\alpha =$ yellowish — greenish yellowish — almost colourless, $\beta =$ bluish green, and $\gamma =$ greenish blue — bluish green. $\perp \beta$ as a rule we meet brownish yellow — yellow interference colours. $C:\gamma =$ about 17°, $2\,V_\gamma =$ about 100°. Evidently we have here to deal with a common hornblende, which has got its contents of Al_2O_3 from plagioclase, spoilt by chemical reactions.

When accounting for the development of the spinel-chlorite-»fingers», we must consider the chemical circumstances before an assumed reaction. Only two initial components have apparently occurred: $(\mathit{Mg}, Fe)_2SiO_4 =$ $=$ chrysolite, and $CaAl_2Si_2O_8 =$ anorthite, contamined with 11—12 % $NaAlSi_3O_8 =$ albite (will be put equal to 10 % in the following formulas). The reaction forming the inner corona: $(\mathit{Mg}, Fe)_2SiO_4 \rightarrow (\mathit{Mg}, Fe)_2Si_2O_6$ (hypersthene), needs a supply of 1 SiO_2. In most cases, however, ore is formed, and then the supply decreases (see the computations by BRÖGGER above quoted!). The development of the outer corona: n [18 $CaAl_2Si_2O_8$ +

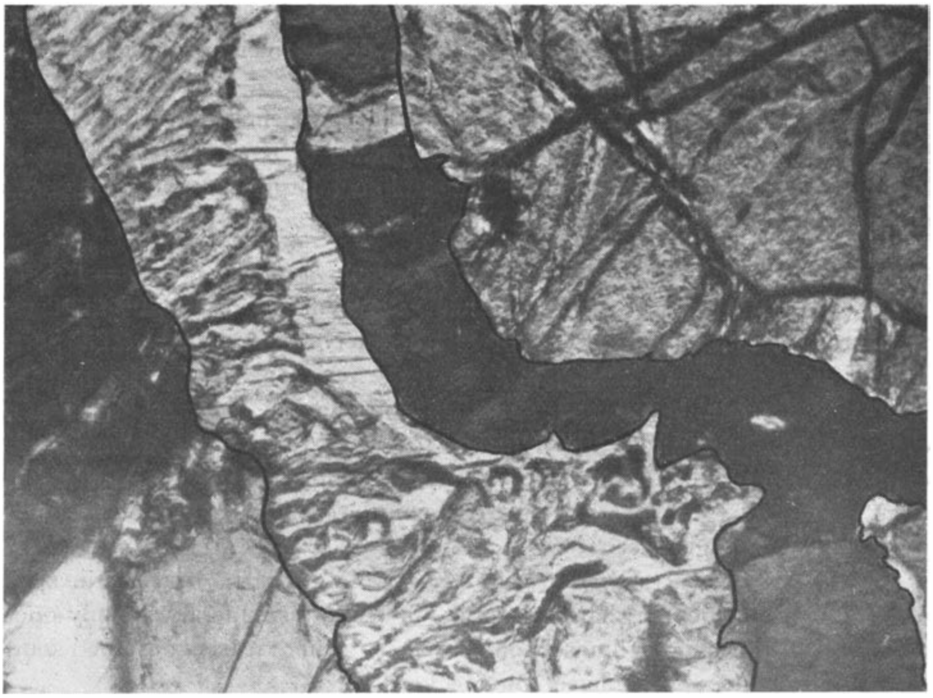

Fig. 5. Part of an olivine corona (expl., see fig. 4!) Sp. 52, + nic., magnified about 165 ×. P. H. L. 1942.

$+ 2\,NaAlSi_3O_8] + m\,(\mathit{Mg}, Fe)_2SiO_4$ (in part perhaps already transformed into hypersthene) $\rightarrow n\,[2\,H \cdot OH \cdot NaCa_2\,(\mathit{Mg}, Fe)_4Al_3Si_6O_{23} + 7\,H \cdot OH \cdot Ca_2\,(\mathit{Mg}, Fe)_4Al_2Si_7O_{23}]$ (hornblende) $+ x\,(\mathit{Mg}, Fe)Al_2O_4$ (spinel) $+ y \cdot H_4(\mathit{Mg}, Fe)_2Al_2SiO_9$ (chlorite), needs no SiO_2 when sufficient amounts of spinel and chlorite are formed, as will be seen from the formula. A computation makes this fact more evident:

When R indicates a monovalent metal-ion, we get: $18\,n \cdot R_8Si_2O_8 + 2\,n \cdot R_4Si_3O_8 + m \cdot R_4SiO_4 \rightarrow 2\,n \cdot H \cdot OH \cdot R_{22}Si_6O_{23} + 7\,n \cdot H \cdot OH \cdot R_{18}Si_7O_{23} + x \cdot R_8O_4 + y \cdot 2\,H \cdot OH \cdot R_{10}SiO_7$.

By transformation of all R_2O into orthosilicate (members preserved), we derive: $(36n + m)\,R_4SiO_4 + 2\,n\,(R_4SiO_4 + 2\,SiO_2) + a = (9n + 2y)\,H \cdot OH + \left(\frac{85}{2}n + 2x + \frac{5}{2}y\right) R_4SiO_4 + \left(2x + \frac{3}{2}y + \frac{37}{2}\right) SiO_2$, where a means the necessary supply, i. e. $(9n + 2y)\,H_2O$.

If we assume the development of nothing but hornblende and disregard from the water component, we get the following inequality after having divided the equation just mentioned by n:

$$\left(76 + 2\frac{m}{n}\right) R_4SiO_4 + 8\,SiO_2 < 85\,R_4SiO_4 + 37\,SiO_2.$$

Here we have a deficit of $29\,SiO_2$ in the left = the initial member. By this computation the reason for the development of spinel-chlorite-»fingers» has become evident.

Moreover, we must consider that we have a deficiency of SiO_2 more pronounced than that of the olivine-hyperites of Kragerö, according to BRÖGGER (1935). Consequently, we must expect larger contents of minerals poor in SiO_2 than were found in those rocks.

As a subordinate mineral *green common hornblende* ($c:\gamma = 16^\circ\,{}^2/_3$, $2V_\gamma = 95^\circ\,{}^1/_2$ in sp. 161 from the vicinity of Gymsan), displaying the usual pleochroic colours (see part 7 of this chapter!), may occur. This hornblende is of another origin than that of the reaction rims. Sometimes it may only be faintly coloured, and then it frequently contains grains of a *diopsidic diallage* ($c:\gamma = 38^\circ\,{}^1/_3$ in sp. 161). In these cases we have evidently to deal with a deuteric or secondary amphibole, as to its development to the largest extent due to chemical reactions between the clinopyroxene and plagioclase.

The existence of a *fibrous amphibole* is of a certain interest, in spite of its totally accidental character. But, in fact, this mineral was only once observed in one single thin section (sp. 156). There it has consumed some of the serpentine of an ancient olivine kernel.

Fibrous amphibole will be dealt with more fully later on, because of its playing an important rôle within some of the remaining gabbro varieties.

The common hornblende above mentioned frequently forms no more than an accessory. No other accessories, however, were observed (except for the alteration products already reported).

3. Olivine-eucrites.

The olivine-eucrites as a rule resemble the allivalites very much. In fact, only larger contents of amphibole, and very often of clinopyroxene, too, do distinguish them from those rocks. The amphibole usually tends to give the olivine-eucrites a faintly greenish hue. Disregarded from this difference, their colour coincides with that of the allivalites (dark gray — black gray).

The olivine-eucrites are in general medium-grained, but here and there they may become fine-grained. In these cases we seem to have to deal with transitions into eucrite, sometimes into olivine-hypersthene-eucrite. The banding, now straight and now winding (Fig. 3), is similar to that of the allivalites, but a trifle more prominent, especially as regards the development of anorthosite bands. Sometimes the xenomorphic texture partly grades into a hypidiomorphic (= subhedral) one.

The *plagioclase* (An = 88—89 %) forms the predominant constituent of the olivine-eucrites. It is only faintly altered with the result of small grains or aggregations, especially of *sericite, calcite* and *clinozoisite* ($2V_\gamma = 85°$ in sp. 153 from the isle of Bergsö), but sometimes of *chlorite*, too. Rarely the alteration may locally grow more extensive (for ex. in sp. 153).

Four measurements of $2V_\gamma$ and G were carried out on olivine-eucrite plagioclase. They will be found in Table 5. The frequency of twinning laws of several allivalite and olivine-eucrite plagioclase individuals is reported in Table 27, at the beginning of ch. VII.

Table 5. Physical, especially optical, properties of the most important minerals contained in the olivine-eucrites.

Sp. no.	Olivine	Diallage				Amphibole		Plagioclase	
		Diopside		Augite					
	$2V_\gamma$	$2V_\gamma$	$c:\gamma$	$2V_\gamma$	$c:\gamma$	$2V_\gamma$	$c:\gamma$	$2V_\gamma$	G(20°C)
3						93° 2/3	17°	101° 1/4	2.740
8	92° 1/2		(40°)		40°		20° 1/2		
10	88° 1/2								
11	90°		39—40°					102° 1/4	2.739
38		59° 2/3	39° 1/3				16° 1/2		
53	95° 1/2			61°	40° 1/2			100° 3/4	2.736
86	98° 3/4	59° 1/3		61° 1/2			15—16°		
96	97° 1/3						17° 2/3	102° 2/3	2.735
112	96° 1/6		⋝ 38° 1/2		⋜ 40° 1/2				
115	94° 3/5	59°	40°		(40°)				
147	97°				42° 1/8		17°		
148	88°			61°	41° 2/3				
149	95°.0		38° 1/3		42° 1/2		(17°)		
153	(95°)					90°			
172[1]	93° 3/4		39°		44° 1/2		(17°)		
175	99° 1/2								

[1] in olivine-bearing hypersthene-eucrite.

In Fig. 26 (ch. VII: 1) the surface poles of all plagioclase twins on (010) measured are represented together with those of the allivalites. The mean coordinates of the poles ⊥ (010) form dot no. 2 in Fig. 26 (ch. VII: 1), and are reported in Tables 6—8, there heading the error distributions of the values having originated them.

Sometimes minute grains, or better rectangles, of *amphibole* were discovered within the plagioclase. In one single slide several diminutive spots of *ore* darken a few plagioclase individuals.

Table 6. The n_α coordinate of $\perp(010)$ as found from allivalite and olivine-eucrite plagioclase twins.

$M = 56^\circ.8 \pm 0^\circ.24$. $\sigma = 2^\circ.18 \pm 0^\circ.170$. $N = 82$

Values	$<2.0\times\sigma$	$1.5\times\sigma$	$1.0\times\sigma$	$0.67\times\sigma$	$>0.67\times\sigma$	$1.0\times\sigma$	$1.5\times\sigma$	$2.0\times\sigma$
Real error distribution .	1	5	13	26	25	16	3	2
Error distribution according to GAUSS	2	5	13	20	20	13	5	2
Difference	−1	0	0	+6	+5	+3	−2	0
Deviation from M> . .	$4^\circ.36$	$3^\circ.27$	$2^\circ.18$	$1^\circ.46$	$1^\circ.46$	$2^\circ.18$	$3^\circ.27$	$4^\circ.36$
Values	$<52^\circ.45$	$53^\circ.5$	$54^\circ.6$	$55^\circ.35$	$>58^\circ.25$	$59^\circ.0$	$60^\circ.1$	$61^\circ.15$

Table 7. The n_β coordinate of $\perp(010)$ of the same plagioclase twins.

$M = 61^\circ.2 \pm 0^\circ.31$. $\sigma = 2^\circ.84 \pm 0^\circ.221$. $N = 82$

Values	$<2.0\times\sigma$	$1.5\times\sigma$	$1.0\times\sigma$	$0.67\times\sigma$	$>0.67\times\sigma$	$1.0\times\sigma$	$1.5\times\sigma$	$2.0\times\sigma$
Real error distribution .	2	3	10	18	21	9	4	2
Error distribution according to GAUSS	2	5	13	20	20	13	5	2
Difference	0	−2	−3	−2	+1	−4	−1	0
Deviation from M> . .	$5^\circ.68$	$4^\circ.26$	$2^\circ.84$	$1^\circ.90$	$1^\circ.90$	$2^\circ.84$	$4^\circ.26$	$5^\circ.68$
Values	$<55^\circ.50$	$56^\circ.95$	$58^\circ.35$	$59^\circ.3$	$>63^\circ.1$	$64^\circ.05$	$65^\circ.45$	$66^\circ.90$

Table 8. The n_γ coordinate of $\perp(010)$ of the same plagioclase twins.

$M = -46^\circ.6 \pm 0^\circ.30$. $\sigma = 2^\circ.69 \pm 0^\circ.210$. $N = 82$.

Values	$<2.0\times\sigma$	$1.5\times\sigma$	$1.0\times\sigma$	$0.67\times\sigma$	$>0.67\times\sigma$	$1.0\times\sigma$	$1.5\times\sigma$	$2.0\times\sigma$
Real error distribution .	1	4	10	17	19	10	3	3
Error distribution according to GAUSS	2	5	13	20	20	13	5	2
Difference	−1	−1	−3	−3	−1	−3	−2	+1
Deviation from M> . .	$5^\circ.38$	$4^\circ.04$	$2^\circ.69$	$1^\circ.80$	$1^\circ.80$	$2^\circ.69$	$4^\circ.04$	$5^\circ.38$
Values	$<41^\circ.2$	$42^\circ.55$	$43^\circ.9$	$44^\circ.8$	$>48^\circ.4$	$49^\circ.3$	$50^\circ.65$	$52^\circ.0$

The prevalent mafic mineral most frequently consists of the *olivine* with its alteration products. In general the coronas are built up in a way similar to that described in part 2 of this chapter, but deviations in several directions may occur. As would be expected, total transformation of olivine into secondary minerals is much more frequently met with in the olivine-eucrites than in the allivalites. *Iron ore* (magnetite, very seldom hematite) and a greenish—brownish yellow *serpentine* of the usual *chrysotile-antigorite* type form the kernel minerals most prominent, but sometimes a highly birefringent *diabantite* occurs, as a rule only as minute quantities, in one of the slides examined (sp. 96 from the islet of Kråkholmen) to a very large extent, however. In single cases the diabantite was seen to accompany *calcite*.

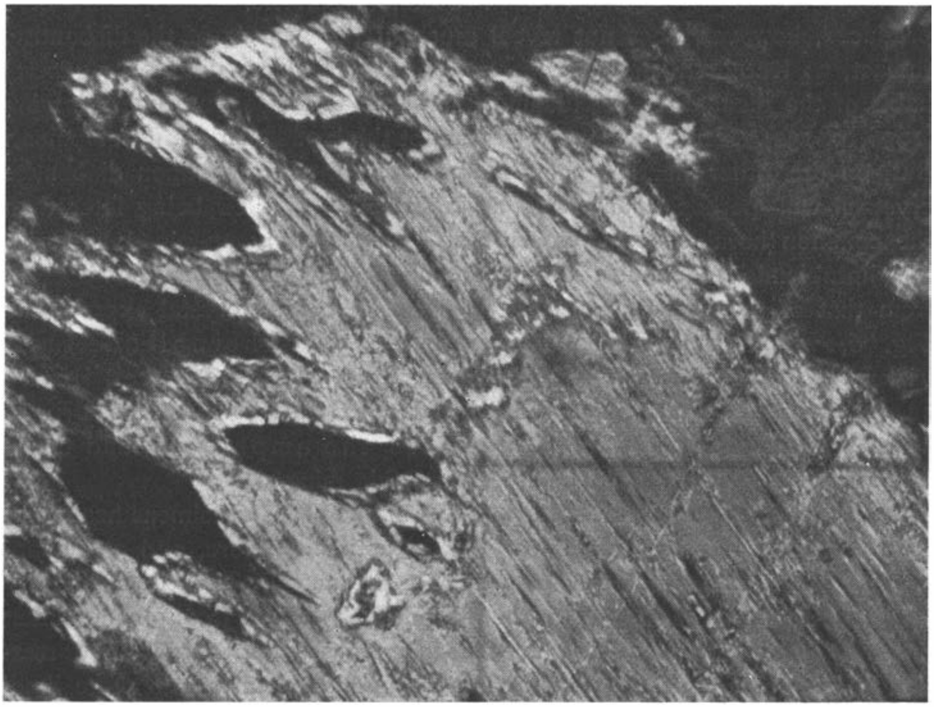

Fig. 6. Diabantite, penetrating amphibole (= black). Sp. 96, + nic., magnified about 165 ×. P. H. L. 1942.

T. KROKSTRÖM reports diabantite from the Hällefors dolerite dike (KROKSTRÖM 1936, p. 131 ff.). Also here it occurs among the alteration products of olivine. KROKSTRÖM gives the following optical properties of this peculiar chlorite mineral: $n_\gamma = 1.634$, $n_\alpha = 1.621$, $n_\gamma - n_\alpha = 0.013$, $2 V_\alpha$ small, γ = deep green, α = colourless (1936, p. 132). The Hällefors diabantite is said to resemble delessite.

The diabantite from the islet of Kråkholmen forms large crystals, almost totally filling most of the former olivine kernels. This diabantite penetrates or is penetrated by *amphibole* (Fig. 6). Unchanged olivine does only remain to a less extent in the odd Kråkholmen olivine-eucrite.

The Kråkholmen diabantite displays a well-developed chloritic appearance. A closer examination, however, gave as its chief results an extraordinary high birefringence, $n_{\gamma Na} - n_{\alpha Na} = 0.034 - 0.043$, but medium indices of refraction, $n_{\alpha Na} = 1.615 \pm 0.003$ and $n_{\gamma Na} = 1.649 \pm 0.003$. $2 V_{\alpha} = 6^{\circ} \frac{1}{2}$. The pleochroism is a very faint one, most frequently impossible to get aware of. A few crystals show the following colours: $\alpha = \beta =$ greenish, $\gamma =$ colourless.

Repeatedly the diabantite individuals contain small flakes of *sericite*, indicating a slight alteration to that mineral. Once diabantite was seen to form beams or lamellæ within common chlorite. The picture here produced, however, does not reveal much of the genesis of the diabantite. In fact, as KROKSTRÖM, too, reports from the Hällefors dike, »the general habit of the diabantite individuals often seems to suggest a primary origin» (1936, p. 132). Here, of course, we cannot think of so early a development. But, on the other hand, a short look at the large Kråkholmen diabantite crystals will perhaps contradict an assumption of their being later than the common hornblende there occurrent. When closely examined, however, the hornblende individuals do never fail to show an orientation different from that of the diabantite. And the large diabantite crystal exposed by Fig. 6, within its marginal parts, contains several hornblende individuals, parted from each other, but all orientated in the same or at least almost in the same direction. Evidently the present diabantite crystal penetrates the amphibole, and therefore we must consider it to be later than this mineral.

Outside the olivine kernel KROKSTRÖM in one of his specimens has found the following zones: 1) talc + iron ore, 2) actinolite + ore, and 3) diabantite + a little actinolite (1936, p. 132). He presumes: »Thus it can hardly be doubted that at least some of the diabantite is derived from olivine. Most probably, when the supply of lime became too scant to permit the formation of actinolite, iron and magnesia were bound to enter into some lime-free compound and the result was the formation of diabantite» (1936, p. 132).

In a much more obvious way this hypothesis is applicable to the Grovstanäs and especially to the Kråkholmen diabantite, which actually occurs instead of serpentine. And, indeed, it seems to suit the chemical circumstances within the olivine kernel better than the latter mineral, because of the disappearance of iron ore always accompanying the development of diabantite, especially large crystals.

Fig. 7 (sp. 153 from the isle of Bergsö) gives an extreme example of the common mode of occurrence of diabantite within the Grovstanäs olivine eucrites. Here the olivine kernel is surrounded by a rim of *chlorite*, carrying small grains of *iron ore*, and accompanied by diabantite. The extremity of this case is the two zones following outside the chlorite rim. The inner of these zones consists of *iron ore*, the outer one of *talc*. And first then we meet a very narrow variety of the orthopyroxene corona. In everyone of the remaining slides examined the ore and talc zones lack, however, and there, too, the diabantite-chlorite rim is badly developed and very occasional as to its appearance.

The rarest component of the Grovstanäs olivine eucrites is a red brown *iddingsite*, in fact only found within one single olivine kernel (sp. 81 from the isle of Tjuvholmen).

The orthopyroxene rim of the olivine-eucrites is in most cases preserved, but now and then it has been transformed into *amphibole* or *serpentine*.

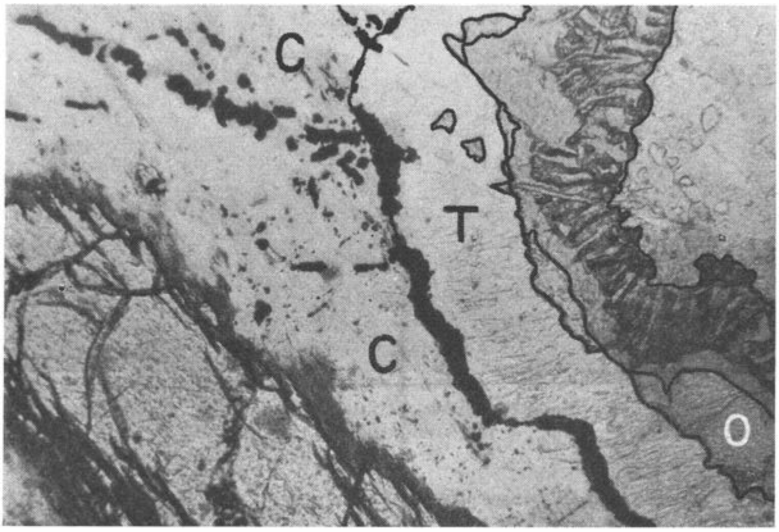

Fig. 7. Part of an olivine corona. From the left to the right: olivine—chlorite (C), accompanied by iron ore and diabantite — iron ore — talc (T) — orthopyroxene (O) — amphibole with chlorite-spinel-»fingers»—plagioclase. Sp. 153, 1 nic., magnified about 150 ×. P. H. L. 1942.

In one of the thin sections examined *clinopyroxene* has originated in close proximity to the olivine, but there are no certain indications at all of its being a reaction product of this mineral.

The outer amphibole corona has sometimes grown very extensive, and in connection with that, the spinel-chlorite-»fingers» have almost always disappeared. In fact, some of these penetrating amphibole individuals were seen to contain single clinopyroxene and a couple of plagioclase crystals, many of which have preserved their orientation in grains parted from each other (Fig. 8). The hugest amphibole individuals may contain more than one single coronated olivine grain, and within the peridotites, dealt with in the next chapter-part, they almost as a rule contain several olivine grains. When turned against light, the penetrating amphibole gives rise to reflections broken off by nearly every grain of the included minerals. In Swedish we call such

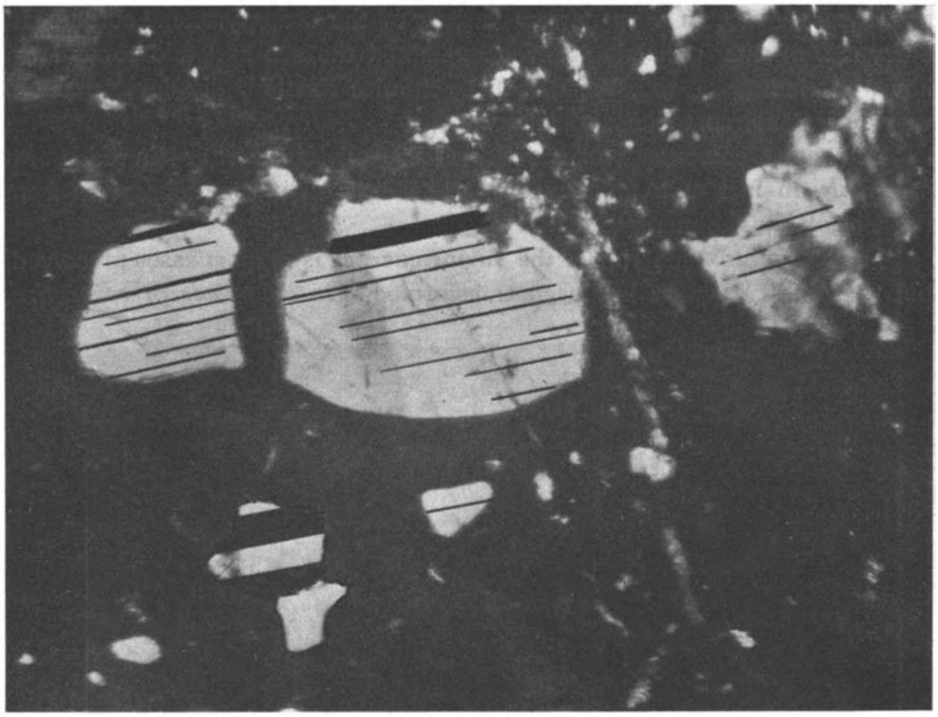

Fig. 8. Penetrating amphibole (= black), containing corroded and divided plagioclase individuals. Sp. 153, + nic., magnified about 165 ×. P. H. L. 1942.

a mineral, as was now described, »ett (= a) skillrande mineral». »Skillra», or, in English, »schiller» forms the contrary to »scintillate». A scintillant mineral originates sparkles in reflected light because it is divided in several separate minute parts, everyone of which is reflectant in the same directions, a schillering mineral has got its reflectant surfaces interrupted by several dark spots.

But the schillering amphibole now discribed, which should be classed as common hornblende, will alone be able to distinguish very few olivine-eucrites from the allivalites. Indeed, the penetrating hornblende individuals are too occasional as to their appearance to become classing constituents. Only within the peridotites, dealt with in the next part of this chapter, they will prove to be of the greatest importance.

Frequently we find solitary grains of *common hornblende*, repeatedly forming a main constituent of the olivine-eucrites examined. This amphibole can sometimes be designated as secondary, or at least deuteric. More often its genesis cannot be interpreted, however. When secondary, it originates from clinopyroxene. As is in part shown by Table 5, $c:\gamma$ usually varies from 15 to $20^\circ\ {}^1/_2$, and $2\,V_\gamma$ between 90—*95*—100°. The pleochroism is rather constantly: α = yellowish green — yellow green — almost colourless,

Fig. 9. A large hypersthene individual surrounding serpentine, accompanied by iron ore, and crossed by several fissures, filled with chlorite, serpentine, and ore. Sp. 153, 1 nic., magnified about 160 ×. P. H. L. 1942.

β = green of various shades, very frequently grass or olive green, γ=blue green. This amphibole may sometimes grade into a *fibrous* variety, which seems to be of a different age (See p. 335!). Rarely a brownish, undoubtedly primary hornblende was observed.

In one slide dense flocculations of *iron ore* were discovered within several amphibole individuals. This mode of occurrence very much resembles that of the spinel-chlorite-»fingers». The flocculations bear clear evidence of being formed by an act of alteration of a mineral poor in SiO_2 and rich in Fe.

The second wide-spread mafic constituent, disregarded from the olivine, is *clinopyroxene*. This mineral occurs as individuals, more or less changed into amphibole, usually marginally and frequently centrally, where then the amphibole forms spots. Part of it displays a green colour, and it should be classed as a *diopsidic-augitic diallage* because of its optical properties (given in Table 5) and its well-developed parting on (100). Rarely a faint pleochroism was seen: α = green, β = brown red — red brown, γ = green. Sometimes pigeonitic varieties appear ($c:\gamma = 28—28° \frac{1}{2}$). Within a few diallage crystals needle-shaped microlites of *ore* have originated. These are all orientated in two certain directions, the most important of which as a rule shows small angles at [001] and the parting on (100). SVEDMARK

(1885, p. 45) reports a great many similar microlites from the »olivine gabbro» of Rådmansö.

Solitary *hypersthene* occurs in a few cases (especially in sp. 174 from the shore NW of the isle of Skarpholmen). But even here it is almost always intimately related to olivine (look for instance at Fig. 9, where serpentine evidently secondary after olivine occurs at the centre of a large hypersthene crystal!). The following optic axial angles ($2 V_{\gamma}$) of ortho-pyroxene were determined on olivine-eucrites: 93° (sp. 3, *bronzite* related with olivine), 112° ½ (sp. 53, solitary hyp.), and 107° ¼ (sp. 174, solitary hyp.).

A few accessories not already mentioned appear now and then: *pen-ninite* (secondary after amphibole), *spinel* (single deep green grains within the plagioclase), and *magnetite* with *ilmenite*.

4. Peridotites.

The utmost contrary to the anorthosites of the Grovstanäs massif is formed by the peridotites and by the rare hornblendites (with davainites) dealt with at the end of this chapter.

The Grovstanäs peridotites are black, xenomorphic, as a rule more or less schillering rocks. Disregarded from the penetrating amphibole in-dividuals, the hugest of which were seen to occupy areas larger than 25 cm^2, they are medium-grained. Very frequently they contain plagioclase, partly or totally altered, but in spite of this fact they have nearly never been seen to grade into olivine-eucrites or allivalites. Narrow fissures, filled with serpentine and chlorite, may sometimes cross them. Banding very seldom appears, and where it is expected to be found, it can hardly be discovered, owing to its bad development. The plagioclase, however, uses to be placed out as to form faint lines, and may give occa-sion to strike-and-dip measurements.

Peridotitic bands very frequently (Fig. 3), and lens-shaped inclusions (»fishes») of peridotite (Fig. 10) in general more seldom, were observed within the allivalites and olivine-eucrites (»lenses» or »fishes» almost only within the latter). The »lenses» or »fishes» are rather peculiar. They may be surrounded by concentric salic and mafic bands (Fig. 10). In fact, this banding seems to indicate that the peridotite lumps should be older than the olivine-eucrite outside them. Of great importance as to the genesis of the peridotite inclusions are also a few small, rounded grains of plagio-clase found within the olivine crystals of some allivalites. In spite of their roundness the plagioclase in question has probably become surrounded by the growing olivine crystals when being in the solid state.

The largest occurrences of massive peridotites are situated in the isle of Träffsholmen, where they form huge bands, or better »lenses», seen to fade S-wards. These »lenses» alternate with anorthosite, but there exist

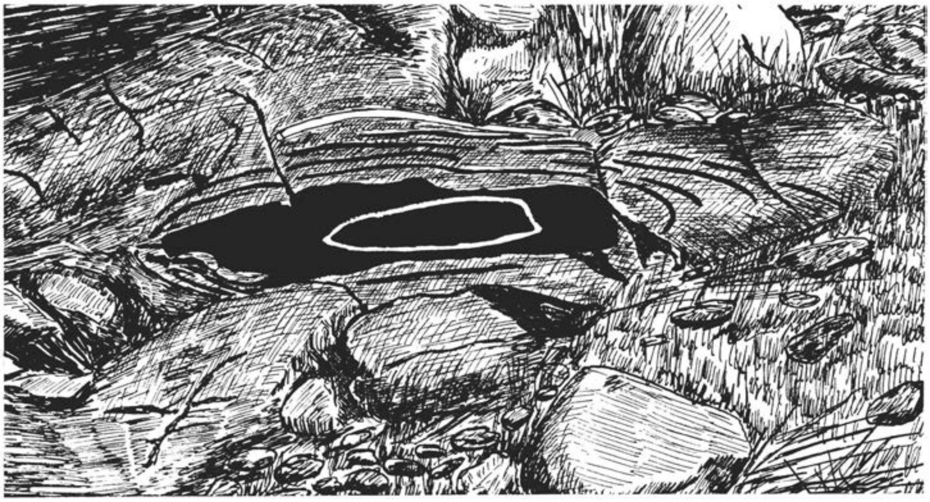

Fig. 10. Elongated peridotite inclusion (= black), parallel to the gabbro banding, and surrounded by anorthositic (= white) and peridotitic (= black) bands. Olivine-eucrite (= gray) outcrop at photo-point I at the shore of Storö. Scale of the inclusion = 1 : 27. Drawn by W. PLAN after photo P. H. L. 1941.

no transitions between the two rocks, as was mentioned in part 1 of this chapter. Peridotites also build up the whole of the islet W of Träffsholmen. Here an intact remnant of allivalite (of a minor size = 1 $^{1}/_{2}$ dm^{2}) was discovered. The remnant is of an irregular shape, and shows distinct borders upon the peridotite. Hence we must assume the latter rock to be younger than the olivine-eucrites and allivalites, at least when it forms large masses. The presence of a few bands of allivalite within the peridotite of this islet shows, however, that, in general, the difference of age cannot be a great one and that it may sometimes be totally wanting.[1]

The main constituents of the peridotites are the *olivine* [$2\,V_\gamma = 93^\circ\,{}^{1}/_{5}$ (sp. 81), $93^\circ\,{}^{1}/_{8}$ (sp. 106), 94—$94^\circ\,{}^{1}/_{3}$ (sp. 180—179), and $93^\circ\,{}^{2}/_{3}$ (sp. 182)], and the *penetrating*, *secondary amphibole*. Apparently the olivine from the very beginning must have occupied a larger area than it is found to fill now, but we cannot get away from the fact that there must have existed another primary mafic mineral of the greatest importance, too. This constituent has now vanished completely, and we can form no certain assumptions as to its character.

In the plagioclase-bearing peridotites (for instance sp. 81, taken from an outcrop of peridotitic olivine-eucrite, and in part sp. 182), to a certain extent, we meet coronas similar to those of the olivine-eucrites. As a rule, however, we have to deal with quite another development of secondary

[1] BRÖGGER (1931, pp. 52—53) reports similar, intricate circumstances (essexite contra pyroxenite) from one of the preserved parts of the large Hurum volcano S—SSW of Oslo in S Norway. Transitional rocks there also occur, however.

minerals within the peridotites. The olivine kernels are strongly altered and at the present time partly or totally exchanged for a green — olive green — green yellow — green brown *serpentine* accompanied by *iron ore*. The serpentine is optically negative, with a very small $2V$ (sometimes about $0°$). It assumes more frequently a fibrous than a lamellated appearance, and seems to consist of members of the *jenkinsite-antigorite* series. *Spinel* and *chlorite* may be found together with it. In sp. 182 a red brown *iddingsite* occurs as an accessory.

In the plagioclase-free peridotites we usually meet *penetrating amphibole*, seldom *hypersthene* (sp. 182), immediately around the olivine kernel. The amphibole is in most cases colourless or almost colourless, with $c:\gamma = 15°$ (sp. 106) — $20°$ (sp. 81) and $2V_\gamma = 86° \, ^1/_3$ (sp. 81) — $87° \, ^1/_2$ (sp. 106). A faint pleochroism could very frequently be traced: α=colourless, β = colourless — pale grass green, γ = very slightly—pale blue green — green blue. $\perp \beta$ yellow (1st order) — blue interference colours are produced. Sometimes, however, the birefringence is seen to be much lower. In sp. 182 a brown-pleochroic, penetrating amphibole predominates ($c:\gamma = 13°$, $2V_\gamma \geq 90°$). It carries a great many microlites, and is sprinkled with aggregations of irregular-shaped *calcite* grains. In contradistinction to the pale variety it evidently contains some alumina and lime.

As a more advanced state of metamorphism of the olivine with its coronas, BRÖGGER (1935, p. 89) describes an exchange of the spinel-pigmented, light-coloured amphibole for »a granular, darker green, rather strongly pleochroic hornblende without spinel». This development bears resemblance to the circumstances in sp. 182.

The almost colourless amphibole seems to have formed at the expense of an earlier mineral, suspected to have been *orthopyroxene*. In fact, the latter mineral occurs as large, penetrating crystals in sp. 182. There a minor part of it has been locally transformed into a *cummingtonitic* amphibole with that high birefringence pointed out by B. ASKLUND (1925, p. 21) to be characteristic of the cummingtonite occurring as an alteration product of the hypersthene of his Stavsjö norites. In sp. 81 a *fibrous* and *highly birefringent amphibole* was seen to originate from the hypersthene along cleavages and fissures. Perhaps this variety forms an earlier state of the alteration just mentioned.

In sp. 106 the penetrating amphibole frequently contains flocks of microlitic spinel and ore grains. The spinel, however, is nowhere finger-shaped, nor associated with chlorite. In this slide, and sometimes in sps. 180 and 182, large, deep green *spinel* grains have developed within the amphibole (Fig. 11), indicating a pre-existence of olivine and some mineral containing alumina. Most often these grains (for instance every grain of sp. 106) do not display any serpentine-and-ore-filling of the numerous fracture lines crossing them. But, for the rest, they bear close resemblance to the olivine occurring in the allivalites and olivine-eucrites. As to the genesis of the spinel, we have apparently to deal with an exchange of the silica of the probably pre-existing olivine for alumina. Perhaps we may assume the alumina necessary for the development of spinel to have originated from accessoric plagioclase grains or (and) from a *clinopyroxene* of an augitic composition. For, in fact, evidences of an alumina metasomatosis do not exist at all within the Grovstanäs massif.

Fig. 11. Spinel within penetrating amphibole. Sp. 106, 1 nic., magnified about 70 ×. P. H. L. 1942.

Rarely the pale amphibole was seen to be strongly altered into *serpentine* (along fracture lines and narrow fissures in sp. 81), more frequently into *penninite* ($2V_\gamma$ very near to $0°$; occurring in sp. 106, and seldom in sp. 180), following the cleavages and a few of the fracture lines. Minute grains of *ore* repeatedly accompany the penninite.

The *plagioclase* grains of the peridotite forms no more than a subordinate constituent, and in most cases they seem to be wanting, as was touched upon above. As a rule they are strongly or almost totally altered, with the result of *calcite*, *sericite*, and of some *chlorite*, frequently grading into a mass of an almost *saussuritic* appearance.

Finally, an account for the remaining accessories found within the peridotites will follow: *Calcite*, as a rule minute, irregular-shaped grains, not to be seen merely within the plagioclase, and, only in sp. 106, *diabantite*, there occasionally occurring as rather large crystals.

Calcite was also observed to fill part of the narrow and minute fissures of sp. 81.

5. **Eucrites.**

Very seldom we find real eucrites within the Grovstanäs massif, for, in general, the clinopyroxene is accompanied by predominant olivine, hypersthene, or amphibole. The two largest areas occupied by eucrites are situated in the peninsula of Litslö and in the isle of Bergsö. Only two small occurrences were discovered (at the N cape of Gymsan and in Hornsholmen).

The normal eucrite is medium- to fine-grained, black gray to gray black and xenomorphous. The felsic and prevailing one of its main constituents, the *plagioclase*[1] (An = 88—89 %), as a rule exhibits a fresh appearance. Minute grains of secondary *clinozoisite*, sometimes *sericite* and *calcite*, too, were repeatedly found, however.

The plagioclase of sp. 155 from Gymsan shows an alteration more

[1] Frequency of twinning laws is reported at the beginning of chapter VII (Table 27).

pronounced, however, the products of which most frequently concentrate to fracture lines and cleavages. Here the sericite, together with the inferior clinozoisite, may be accompanied by *chlorite* (opt. —, $2V = 80—90°$). Sp. 166 from the isle of Hornsholmen locally (along fissures) displays a red plagioclase, owing its colour to an impregnation with a couple of aggregations of minute, rounded *hematite* grains (a supply of Fe; see chapter VII: 1!). Similar grains of a green mineral (probably chlorite) occupy large areas within the red plagioclase, too. The common alteration to sericite, accompanied by much clinozoisite and some calcite, predominates, however.

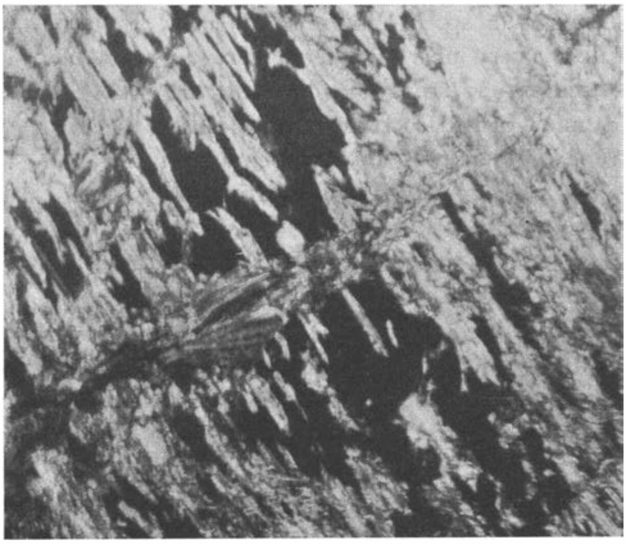

Fig. 12. Plagioclase (= black), to the largest extent changed into sericite, in general following (010). Sp. 166, + nic., magnified about 150 ×. P. H. L. 1942.

Also within this rock the change has begun along the cleavages, especially the (010) one (Fig. 12).

The main mafic mineral would be expected to consist of *clinopyroxene* alone, but, in fact, amphibole occurs in equal amounts in almost every specimen examined. The clinopyroxene usually occurrent is a green, *diopsidic diallage* [$2V_\gamma = 59°$ (sp. 16), $59° \frac{1}{3}$ (sp. 98), $59° \frac{1}{3}$ (sp. 166); $c:\gamma = 39° \frac{1}{2}$ (sp. 16), $38° \frac{2}{3}$ (sp. 98), $38°$ (sp. 155), $39°$ (sp. 166)]. In sp. 98 its indices of refraction are: $n_\alpha = 1.672 \pm 0.003$ and $n_\gamma = 1.702 \pm 0.003$. Lamellar twinning (frequently polysynthetic) accompanies the parting on (010) in sp. 166.

Augitic ($c:\gamma = 40° \frac{1}{2}$ in sp. 155) and *pigeonitic* ($c:\gamma = 33°$ in sp. 98) varieties sometimes appear.

Marginal alteration to *amphibole* is a rule. Minute, central spots of this mineral were found in a great many crystals, too. The amphibole is a greenish — green hornblende of the same type as will be described later on. In a few specimens it exchanges for a *fibrous* variety (sps. 98 and 155), as a rule showing a low birefringence.

From the Breven dolerite dike, KROKSTRÖM (1932, p. 275 ff.) describes a similar fibrous amphibole, which, according to his opinion, seems to have originated from a compact amphibole, secondary after pyroxene. The fibrous variety of the Grovstanäs eucrites, however, may also appear as a primary alteration product, following the parting on (100) of the diallage (sp. 155).

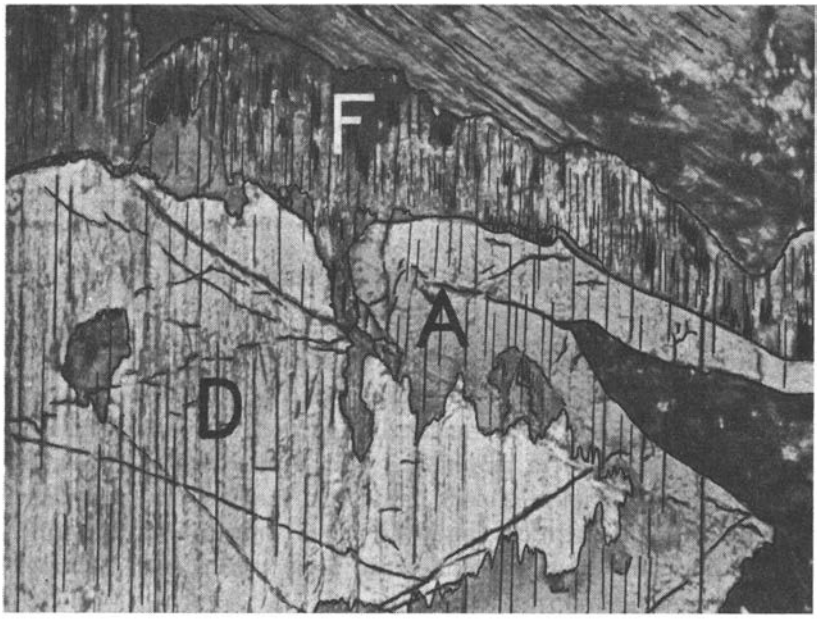

Fig. 13. Pigeonitic diallage (D), surrounded by: 1. compact amphibole (A), 2. fibrous amphibole (F), and 3. chlorite (upwards). To the right a wedge-shaped plagioclase individual (= black). Sp. 99, + nic., magnified about 150 ×. P. H. L. 1942.

When growing large, the areas occupied by secondary amphibole in these cases always consist of the compact variety. In Fig. 13 (sp. 99=hornbl.-eucrite) the order proposed by KROKSTRÖM is better answered to. Here compact amphibole penetrates pigeonitic diallage intimitely, and first outside a distinct border line the fibrous variety is met with.

The second mafic one of the main minerals, the *common green hornblende*, most often occurs solitary as large and small individuals of an irregular shape. In many cases, however, it is connected with and secondary, or at least deuteric, after clinopyroxene, as was pointed out above. The pleochroism displays no peculiarities: α = pale yellow green — yellowish green, β = green brown — green of various shades, most frequently olive — grass green, γ = brownish green — blue green. The optical properties are as follows: $c:\gamma = 18^\circ\, ^2/_3$ (sp. 16), 16° (sp. 98), $13—14^\circ$ (sp. 155); $2\,V_\gamma =$ $= 99^\circ$ (sp. 98).

The fibrous amphibole already mentioned has gained a strong position in sp. 98 not only as a restricted outer zone around part of the clinopyroxene, but also as large individuals composed by strictly parallel fibres, individuals, often containing grains of clinopyroxene with rims of compact hornblende, or grains of solitary compact hornblende, all non-orientated, or sometimes grains of plagioclase, too. Seldom the fibrous amphibole inwards grades into an extensive *chlorite* mass (secondary after *olivine*?), and may surround this in part. The penetrating, fibrous amphibole is evidently later than the compact variety.

The following accessories were observed: *hypersthene* and *enstatite* (only in sp. 16, where they are rather important; $2\,V_\gamma$ of the enstatite $= 83^\circ$), *calcite*, not only in connection with plagioclase (sp. 98), *pyrite* (sp. 155), and *ore* (magnetite, accompanied by some ilmenite).

6. Hypersthene-eucrites (=ultra-basic norites) with local olivine-bearing varieties.

The Grovstanäs hypersthene-eucrites (marked out as *norites* in Pl. XII) occur almost everywhere in the massif, except for the SE part. They always display a fresh appearance, disregarded from the wide-spread alteration of the pyroxene to amphibole. As a rule the hypersthene-eucrites are (black —)gray black — black gray, fine medium- to fine-grained and most often xenomorphic rocks, showing no or only a faint banding. The plagioclase now and then, sometimes the hypersthene, too, becomes hypidiomorphic (= subhedral).

A typical hypersthene-eucrite (sp. 103 from the vicinity of the little peninsula near the N coast of the isle of Bergsö) was analysed chemically and geometrically (Table 9).

The predominant main constituent, the *plagioclase* (An = 86—87 %), in most cases was found to be fresh, and when altered only containing small, irregular-shaped grains or flakes, especially of *sericite* ($2\,V_\alpha = 15^\circ\, ^1/_2$ in sp. 157), but several times of *clinozoisite*, too. More seldom *calcite*, and in single specimens, *chlorite*, or a mass of a *saussuritic* habit, occur. Rarely *epidote* was observed (as a rule in connection with ore). Remarkable is the impregnation with minute brown black *ore* grains exhibited by sp. 141.

As is already known, the plagioclase here and there assumes a hypidiomorphic physiognomy, i. e. it forms table-shaped crystals. Rarely these »tables» are arranged as to give a very slight ophitic texture, however. Only in sp. 103 *diabasic* features could be traced. On the contrary rounded, probably crushed and recrystallized grains of a distinctly granoblastic

Table 9. Hypersthene-eucrite from the little peninsula of »Lönsudden» near the N coast of the isle of Bergsö. Specimen 103 (no. 4 in Fig. 2). Analyst = N. SAHLBOM.

	Weight-%	Mol. Prop.
SiO_2	41.94	698
TiO_2	1.54	19
Al_2O_3	16.29	160
Fe_2O_3	6.92	43
FeO	10.30	143
MnO	0.25	4
MgO	7.90	196
CaO	11.56	206
Na_2O	1.66	27
K_2O	0.31	3
P_2O_5[1]	0.45	3
Cl_2	0.22	3
S	0.30	9
H_2O+	0.46	26
H_2O-	0.22	
	100.32	

Norm (%)				
Or		1.67		
Ab		12.58		
An		37.27		Σ sal 51.52
Di	$CaSiO_3$	8.01	15.57	
	$MgSiO_3$	4.92		
	$FeSiO_3$	2.64		
Hy	$MgSiO_3$	3.61	5.72	
	$FeSiO_3$	2.11		
Ol	Mg_2SiO_4	7.88	12.36	
	Fe_2SiO_4	4.48		
Mt		9.96		
Il		2.88		
Ap		1.01		
Py		0.60		Σ fem 48.10
NaCl (from sea water)				0.35
H_2O+				0.46
				100.43

III : 5 : 4 : 4—5 = *Auvergnose*
Or : Ab : An = 3.3 : 24.4 : 72.3

Geometric analysis:

	Vol.-%	Weight-%
Plagioclase	53.5	46.1
Hypersthene	17.1	18.6
Diallage (with pigeonite)	10.9	11.65
Ore	8.3	13.1
Amphibole	7.0	7.15
Clinozoisite with epidote	2.8	3.0
Sericite + chlorite	0.3	0.3
Apatite	0.1	0.1
Calcite	0.0	0.0
	100.0	100.0

NIGGLI values	
qz	−31.1
al	18.6
fm	48.9
c	29.3
alk	3.1
si	81.3
ti	2.2
mg	0.46
k	0.11
p	0.37
s	1.1

[1] This value is no doubt too high (compare the geometric analysis!). But, as was pointed out earlier, a little P_2O_5 may be contained within the lattice of some constituent mineral of the rock.

Table 10. The n_α coordinate of $\perp$(010) as found from hypersthene-eucrite plagioclase twins.

$M = 58°.3 \pm 0°.32. \quad \sigma = 2°.58 \pm 0°.228. \quad N = 64$

Values	$<2.0 \times \sigma$	$1.5 \times \sigma$	$1.0 \times \sigma$	$0.67 \times \sigma$	$>0.67 \times \sigma$	$1.0 \times \sigma$	$1.5 \times \sigma$	$2.0 \times \sigma$
Real error distribution	2	2	12	18	17	10	4	2
Error distribution according to GAUSS	1 1/2	4	10	16	16	10	4	1 1/2
Difference	+ 1/2	−2	+2	+2	+1	0	0	+ 1/2
Deviation from M>	5°.16	3°.87	2°.58	1°.72	1°.72	2°.58	3°.87	5°.16
Values	<53°.15	54°.4	55°.7	56°.6	>60°.0	60°.9	62°.2	63°.45

Table 11. The n_β coordinate of $\perp$(010) of the same plagioclase twins.

$M = 60°.2 \pm 0°.32. \quad \sigma = 2°.55 \pm 0°.225. \quad N = 64$

Values	$<2.0 \times \sigma$	$1.5 \times \sigma$	$1.0 \times \sigma$	$0.67 \times \sigma$	$>0.67 \times \sigma$	$1.0 \times \sigma$	$1.5 \times \sigma$	$2.0 \times \sigma$
Real error distribution	2	4	12	18	16	10	4	1
Error distribution according to GAUSS	1 1/2	4	10	16	16	10	4	1 1/2
Difference	+ 1/2	0	+2	+2	0	0	0	− 1/2
Deviation from M>	5°.10	3°.83	2°.55	1°.70	1°.70	2°.55	3°.83	5°.10
Values	<55°.1	56°.4	57°.65	58°.5	>61°.9	62°.75	64°.0	65°.3

Table 12. The n_γ coordinate of $\perp$(010) of the same plagioclase twins.

$M = -46°.1 \pm 0°.32. \quad \sigma = 2°.52 \pm 0°.223. \quad N = 64$

Values	$<2.0 \times \sigma$	$1.5 \times \sigma$	$1.0 \times \sigma$	$0.67 \times \sigma$	$>0.67 \times \sigma$	$1.0 \times \sigma$	$1.5 \times \sigma$	$2.0 \times \sigma$
Real error distribution	3	5	9	17	18	12	3	0
Error distribution according to GAUSS	1 1/2	4	10	16	16	10	4	1 1/2
Difference	+1 1/2	+1	−1	+1	+2	+2	−1	−1 1/2
Deviation from M>	5°.04	3°.78	2°.52	1°.68	1°.68	2°.52	3°.78	5°.04
Values	<41°.05	42°.3	43°.6	44°.4	>47°.8	48°.6	49°.9	51°.15

appearance now and then emerge (in sp. 130 most of the plagioclase is sugar-grained!). The plagioclase of sp. 135, from the narrow gabbro protuberance N of Lake Hammarbysjön, in a few cases displays a zonal growth. But, in fact, this is the single slide from the Grovstanäs massif showing such a texture.

Table 13. Physical, especially optical, properties of the most important minerals contained in the hypersthene-eucrites (olivine-hypersthene-eucrites=o).

Sp. no.	Hyper-sthene	Diallage				Amphibole		Plagioclase	
		Diopside		Augite					
	$2V_\gamma$	$2V_\gamma$	$c:\gamma$	$2V_\gamma$	$c:\gamma$	$2V_\gamma$	$c:\gamma$	$2V_\gamma$	G(20°C)
6							12°	102°	2.729
24	102° 2/3	59° 1/3	39° 1/2				19°	101° 1/4	2.736
48	101° 1/2	59° 2/3	39°						
58	111° 1/3							101°.0	2.740
61	110°		38° 2/3	61°	40° 1/2				
63	104°				40°.2		18°	99° 1/2	2.740
91	108° 2/3	60°	39°		40—45°		17°	96°	2.730
94	100°								
103	109°			61°	40° 2/3				
126	114°			61°	41° 1/2				
129				60° 1/3	44° 3/4		(10°)		
130	108° 4/5		(40°)		40°				
135 NE	115° 1/5			61°	44° 1/3		16°		
141	118°								
145	107°		38° 2/3		40° 1/2				
157	101° 1/3		38° 2/3		(40°)				
159			38° 1/4			93°	24°		
174(o)[1]	107° 1/4								
187	101°					93°	14°		

[1] from an olivine-eucrite area.

The frequency of different plagioclace twins will be evident from Table 27, at the beginning of chapter VII. The poles ⊥ (010) are recorded in Fig. 26 (ch. VII: 1). The error distribution of the n_α-, n_β-, and n_γ-coordinates of these poles displays a close agreement with the normal curve (Tables 10—12). The position of a point representing the mean coordinates of ⊥ (010) shows a distinctly lower percentage of An (= 88 %) and a more eccentric position, when compared with NIKITIN's curve, than the corresponding point of the medium-grained ultra-basic gabbros (Fig. 26, ch. VII: 1).

A few physical properties of hypersthene-eucrite plagioclases are reported in Table 13.

The main mafic minerals of the hypersthene-eucrites are the pyroxenes, among which the *hypersthene* predominates, or sometimes dominates. But *diallage* as a rule has gained a strong position, too.

The hypersthene individuals tend to stretch out parallel to the elongation. This tendency, however, is not very obvious, and therefore hypidiomorphic development will only sometimes be found. The hypersthene displays a faint pleochroism: α = brown red—clear red, β = red—red brownish, γ = green, most often clear green. $2\,V_\gamma$ varies between 100 and 118°, as is shown by Table 13. These values correspond to a molecular percentage of $FeSiO_3$ = 22—41.5 %, according to WINCHELL (1933, p. 218).

In most cases the hypersthene has undergone a more or less extensive, marginal alteration to *green compact amphibole* (to the largest extent = common hornblende). Small spots of this mineral are also rather common within the individuals. Sometimes the compact amphibole becomes colourless when it borders upon the hypersthene, suggesting a decrease, perhaps a disappearing of the Al_2O_3-component necessary for the formation of common green hornblende. The compact amphibole needs exhibit no orientation coincident with that of the hypersthene, although parallelism exists in most cases. The inclined orientation seems to be due to an alteration along part of the fissures, the parallel and more common one obviously depends on a change especially along the cleavages.

Internal change along the numerous fissures and cleavages forms a phenomenon repeatedly met with in nearly every slide examined. Its result, however, is a rather intricate one. In general we find a colourless *fibrous amphibole* of a cummingtonitic or perhaps sometimes anthophyllitic (no evidently orthorhombic development has been traced, indeed) habit. This amphibole can hardly be closely examined. It is always strongly birefringent, most frequently monoclinic, and optically positive. ASKLUND (1925), in the Stavsjö norite, found a pale amphibole presenting a high birefringence and an optically positive character. According to him, this amphibole, which occurs as a zone around hypersthene remnants, must evidently be a cummingtonite originating from the hypersthene (1925, p. 21). This amphibole does not seem to be fibrous, however.

Now and then the fibrous amphibole is accompanied by a dense, brownish mass, consisting of the most minute *hematite* grains and other, indefinable particles, here and there it is exchanged for a great many diminutive *diabantite* grains, or occurs together with this mineral.

The internal alteration to fibrous amphibole has sometimes grown very extensive (Fig. 14).

Serpentine was observed within the fissures and cleavages of some hypersthene crystals in sp. 58. *Biotite* may locally appear instead of the compact, secondary amphibole.

A few hypersthene crystals contain orientated, elongated microlites of *magnetite* and *ilmenite*, another, minute part small, rounded inclusions of plagioclase.

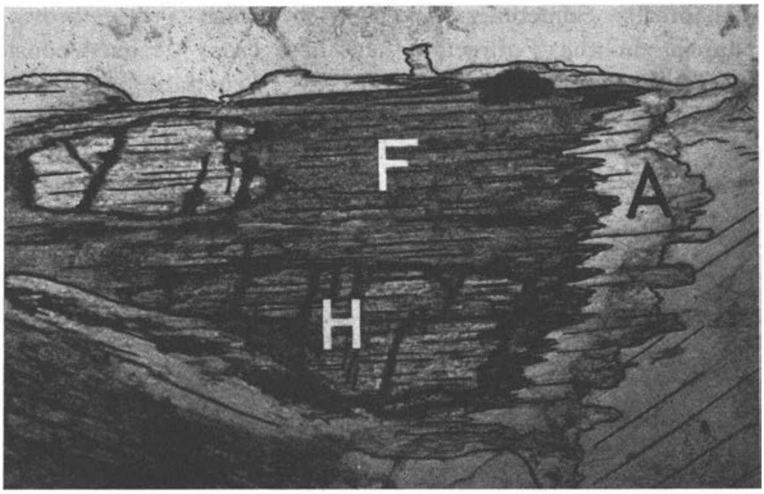

Fig. 14. Hypersthene (H), to the largest extent changed into fibrous amphibole (F), surrounded by a rim of compact amphibole (A), upwards and to the right bordering upon plagioclase. Sp. 141, 1 nic., magnified about 150 ×. P. H. L. 1942.

As an inferior main mafic mineral *clinopyroxene* occurs. The commonest varieties are colourless *augite* and green *diopside*, always developed as *diallage* (optical properties recorded in Table 13!). Twinning on (100) may sometimes appear. Marginal alteration to *green*, *compact amphibole*, almost always = common hornblende, seems to be the rule. In general the change is a trifle stronger than that of the hypersthene. Spot-wise internal alteration is met with nearly everywhere, though it may lack now and then. Some of the diallage crystals of sp. 135 NE contain orientated, needle-shaped *ore* microlites.

Once (sp. 63, Fig. 15), hypersthene was seen to penetrate diallage with coincident cleavage directions. SVEDMARK (1885, p. 57) reports similar intergrowths to be rather common within the »olivine gabbro» of Vreta, Rådmansö.

Only two specimens (24 and 61) contain as much colourless-green *pigeonite* as to form a subordinate chief mafic mineral. But, in general, no pigeonite will be found within the hypersthene-eucrites. The optical properties are as follows: $2\,V_\gamma = 45^\circ$ (sp. 24); $c:\gamma = 30^\circ\,{}^1/_2$ (sp. 24), $29^\circ\,{}^2/_3$ (sp. 61), 30° (from occasional crystals in sp. 91), and 32° (from occasional crystals in sp. 103). The alteration is similar to that of the diallage.

Amphibole has already been mentioned as an alteration product of the pyroxenes. A few of the optical properties given in Table 13 are determined on marginal, compact amphibole = *common hornblende*. Green, solitary, irregular-shaped, big and small grains of the latter mineral occur in considerable amounts in almost every thin section examined. It most frequently displays ordinary pleochroism and birefringence (see part 7 of this chapter!). Sometimes, however, brownish green—brown green colours appear in the γ direction. In these cases we must consider the possibility of the hornblende being primary. Penetrating amphibole, containing various non-orientated mineral grains, especially of pyroxene, are very rare. When becoming the predominant mafic constituent, the hornblende causes the hypersthene-eucrites to grade into hornblende- or uralite-

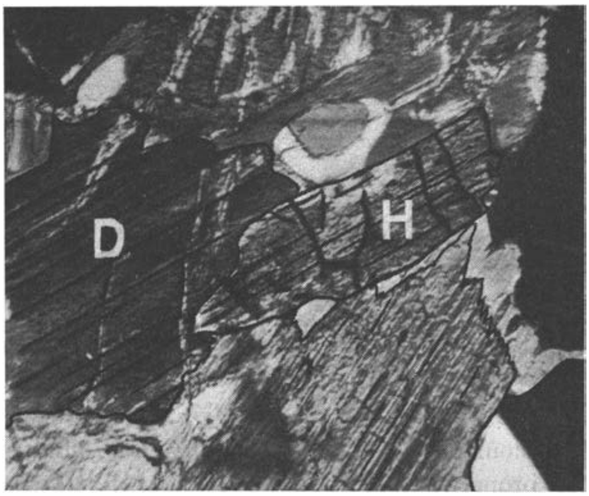

Fig. 15. Hypersthene (H) penetrating diallage (D), showing an orientation coincident with that of the former mineral. Sp. 63, 1 nic., magnified about 150 ×. P. H. L. 1942.

hypersthene-eucrites; and when the hypersthene vanishes, we get fine medium- to fine-grained hornblende- or uralite-eucrites (described in part 7 of this chapter!).

Subordinate and accessoric minerals could be traced in every thin section examined. *Ore* (magnetite with some ilmenite) is the most important of these.[1] It frequently sprinkles the amphibole or the biotite. In a few specimens (91 and 103) it occurs in large quantities, and, consequently, forms an inferior main constituent. In sps. 126, 129, and 135 NE, now and then in sp. 141, *biotite* has gained a position to be accounted for (there making a subordinate main to subordinate mineral). The biotite always exhibits a strong pleochroism: α = pale yellowish—colourless, $\beta = \gamma$ = red brown—dark red brown.

Olivine may sometimes appear, and then we get olivine-bearing hypersthene-eucrites (the *olivine-novites* of Pl. XII), here and there grading into olivine-eucrites (see Pl. XII!). This mineral needs no further description, owing to the fact that it displays a physiognomy and an alteration similar to those of the olivine individuals of the allivalites and olivine-eucrites.

[1] In fact, the hypersthene-eucrites of the Grovstanäs massif are richer in magnetite than any other ultra-basic gabbro variety there present (compare ch. VII: 1!).

In sp. 135 NE, from the S border line of the narrow gabbro protuberance N of Lake Hammarbysjön, *quartz* occurs as an inferior constituent, there forming a great many small grains.

Varying minor accessories were observed in most of the specimens examined. Disregarded from the alteration products above mentioned, they are as follows: *Serpentine*, secondary after olivine totally vanished, in sp. 94 S of the W part of Lake Båtdragsträsket (the genuine olivine-bearing hypersthene-eucrites of course contain serpentine, too), *calcite* as minute flakes in the amphibole of sp. 94, minute grains of *apatite* within the plagioclase of sp. 103, diminutive grains of *rutile*, pale greenish lists of *apatite* (within the plagioclase), and grains of *epidote*, all very rare, in sp. 126, *quartz* grains, most frequently obviously corrosive and secondary (or deuteric?), in sps. 129 and 141, *epidote*, *penninite*, and *apatite*, all rare, in sp. 129, *calcite* and *penninite*, both very rare, in sp. 130, one single, large *apatite* crystal within the plagioclase of sp. 141, and *penninite* in sp. 157. All penninite, epidote and calcite now reported are secondary. The apatite and quartz form totally occasional constituents, and in general they are wanting in the ultra-basic Grovstanäs gabbros.

Within the hypersthene-eucrite of point 103 the sole *pyrrhotite* »deposit» of the Grovstanäs massif was found, a single grain, consisting of two drop-shaped inclusions, intimately connected to each other. No clear evidences of the presence of nickel-bearing pyrrhotite have been traced within the massif, not even spectroscopically.

7. **Hornblende-eucrites, uralite-eucrites.**

A. Fine medium- to medium-grained varieties.

The coarser hornblende- and uralite-eucrites of the Grovstanäs massif are greenish black gray—gray green black, fine medium- to medium-grained, as a rule xenomorphic rocks, which rarely become hypidiomorphic. The banding very frequently is well-developed, sometimes excellent (alternating anorthosite and extremely amphibole-rich bands).

The predominant constituent, the *plagioclase*, (An = 89—90 %), has in general undergone a pronounced alteration, which now and then has grown strong. The change has sometimes followed cleavages and fracture lines. Its chief product is *sericite* ($2\,V_\alpha = 17^\circ$ in sp. 37), most often accompanied by *clinozoisite* ($2\,V_\gamma = 83^\circ$ in sp. 97) in almost equal, or equal, quantities. Here and there irregular-shaped flakes and grains of *calcite* occur. Very seldom *chlorite* (in part penninite), or a *saussuritic* mass, was found. *Epidote* is extremely rare. It always seems to be due to chemical reactions between plagioclase and amphibole.

The plagioclase of the hornblende- and uralite-eucrites as a rule displays

Table 14. Physical, especially optical, properties of the most important minerals contained in the fine medium- to medium-grained hornblende- and uralite-eucrites.

Sp. no.	Diallage			Amphibole		Plagioclase	
	Diopside	Augite					
	c : γ	2 Vγ	c : γ	2 Vγ	c : γ	2 Vγ	G (20° C)
9				94°	18° 1/2		
12		59° 2/3	42°	96° 1/3	16° 1/2	99° 1/2	2.742
15					(16° 1/2)		
20				99° 1/3	16° 1/2	103° 1/3	2.732
29				97° 1/2	18° 2/3		
37				96° 1/2	18°	101° 3/4	2.737
39	38°			96°	17° 1/4		
42				94° 1/2	18° 2/3	103° 1/5	2.734
43				95° 1/2	19° 3/4	102°	2.735
50				102°	14° 2/3		
59				92° 2/3	19° 2/3		
62				98° 1/3	15° 2/3		
65				98°	16° 1/4		
71				99°	16° 3/4	102°	
77				101° 2/3	17° 2/3		
95				95° 1/2	17° 1/3		
99					20°		
100	38° 1/2			95° 1/4	17° 1/3		
107				99° 3/4	19°	103°	
134				91° 1/2	18°		
154				97° 1/2	17°		
170				97° 1/2	17° 1/2		
181	38°			92° 2/3	19°		

an alteration more extensive than that of the remaining plagioclase-bearing gabbro varieties of the Grovstanäs massif, i. e. the allivalites and olivine-eucrites, the eucrites and hypersthene-eucrites. This fact obviously depends on the in part evidently secondary character of the amphibole eucrite varieties, as will be recorded later on.

Some physical properties of the plagioclase are reported in Table 14. The frequency of twinning laws will be found in Table 27, at the beginning of chapter VII.

The poles ⊥ (010) are plotted in Fig. 26 (ch. VII: 1), their n_α-, n_β-, and n_γ-coordinates in Tables 15—17. The poles ⊥ (010) scatter quite well around

Table 15. The n_α coordinate of $\perp$(010) as found from hornblende- and uralite-eucrite plagioclase twins (fine medium- to medium-grained rock types).

$M = 56°.9 \pm 0°.26$. $\sigma = 2°.25 \pm 0°.184$. $N = 75$

Values	$<2.0\times\sigma$	$1.5\times\sigma$	$1.0\times\sigma$	$0.67\times\sigma$	$>0.67\times\sigma$	$1.0\times\sigma$	$1.5\times\sigma$	$2.0\times\sigma$
Real error distribution	0	5	13	19	20	14	5	2
Error distribution according to GAUSS	2	4 1/2	12	19	19	12	4 1/2	2
Difference	−2	+ 1/2	+1	0	+1	+2	+ 1/2	0
Deviation from M>	4°.50	3°.38	2°.25	1°.50	1°.50	2°.25	3°.38	4°.50
Values	<52°.4	53°.5	54°.65	55°.4	>58°.4	59°.15	60°.3	61°.4

Table 16. The n_β coordinate of $\perp$(010) of the same plagioclase twins.

$M = 60°.4 \pm 0°.31$. $\sigma = 2°.66 \pm 0°.217$. $N = 75$

Values	$<2.0\times\sigma$	$1.5\times\sigma$	$1.0\times\sigma$	$0.67\times\sigma$	$>0.67\times\sigma$	$1.0\times\sigma$	$1.5\times\sigma$	$2.0\times\sigma$
Real error distribution	2	6	10	15	20	14	5	2
Error distribution according to GAUSS	2	4 1/2	12	19	19	12	4 1/2	2
Difference	0	+1 1/2	−2	−4	+1	+2	+ 1/2	0
Deviation from M>	5°.32	3°.99	2°.66	1°.77	1°.77	2°.66	3°.99	5°.32
Values	<55°.1	56°.4	57°.75	58°.6	>62°.2	63°.05	64°.4	65°.7

Table 17. The n_γ coordinate of $\perp$(010) of the same plagioclase twins.

$M = -47°.1 \pm 0°.22$. $\sigma = 1°.94 \pm 0°.158$. $N = 75$

Values	$<2.0\times\sigma$	$1.5\times\sigma$	$1.0\times\sigma$	$0.67\times\sigma$	$>0.67\times\sigma$	$1.0\times\sigma$	$1.5\times\sigma$	$2.0\times\sigma$
Real error distribution	2	8	15	17	23	14	4	0
Error distribution according to GAUSS	2	4 1/2	12	19	19	12	4 1/2	2
Difference	0	+3 1/2	+3	−2	+4	+2	−1 1/2	−2
Deviation from M>	3°.90	2°.90	1°.94	1°.29	1°.29	1°.94	2°.90	3°.90
Values	<43°.2	44°.2	45°.15	45°.8	>48°.4	49°.05	50°.0	51°.0

a point (shown by Fig. 26, ch. VII: 1) near to the NIKITIN (1933) curve. This point, representing the mean coordinates of $\perp$(010), is situated in the most immediate vicinity of the corresponding dot as found from the allivalite and olivine-eucrite plagioclase, a matter of fact, supporting the assumption of the fine medium- to medium-grained hornblende- and uralite-eucrites being altered olivine-bearing gabbros. In fact, some of the rocks in question are connected with and bear a close external resemblance to the olivine-eucrites.

Within the peculiar amphibolitic hornblende-eucrite from the S cape of the peninsula of Djupstensholmen (sp. 107) the plagioclase is totally granoblastic, strikingly fresh, and fine-grained. Usually several individuals have assembled to make layers, alternating with nemato- to granoblastic amphibole (elongated prisms and grains). The distinctly gneissose texture of the rock winds extremely in the little outcrop forming the cape. Obviously the rock concerned has undergone a complete recrystallization.

Granoblastic plagioclase, due to crush and (or) recrystallization, may occur at many other localities, too, but never does it gain such a dominant position within the fine medium- to medium-grained gabbro varieties as in the rock now described.

Among the mafic constituents *amphibole* forms the single main mineral. Its physiognomy varies. Small, often granoblastic grains, large, more or less irregular-shaped individuals, aggregations of grains, and penetrating crystals, containing small amphibole individuals showing different orientations, are all typical exponents, suggesting a wide variation amplitude as to the appearance. Minute amphibole crystals now and then occur as non-orientated, idiomorphic microlites, seldom xenoblasts, within the plagioclase. Similar microlites were reported from Rådmansö by SVEDMARK (1885). Very large amphibole individuals were found in the islet of Kråkholmen and in the SE part of the isle of Bergsö. They will be described in connection with the hornblendites and davainites.

The amphibole as a rule consists of *common green hornblende*, the optical properties of which are shown by Table 14. The birefringence is the normal one. The pleochroism is almost always well-developed (reported in Table 18). Twinning on (100) is rare. Varieties displaying a fibrousness parallel to the elongation may sometimes appear (often in sp. 100).

To a large extent, the genesis of the amphibole is unclear. But several remnants of *pyroxenes*, rarely of *serpentine* secondary after *olivine*, indicate an origin due to an alteration of earlier minerals, including chemical reactions between such ones and the plagioclase. The large individuals, containing small amphibole grains showing different orientations, bear also close resemblance to part of the penetrating amphibole already mentioned. Interstitial expansion and granoblastic grains between the plagioclase individuals form another, obviously secondary development of the amphibole within the rocks now concerned.

Secondary hornblende is to be classed as *uralite*. As much, probably most amphibole here dealt with c a n n o t be proved to be evidently sec-

Table 18. The pleochroic colours of the amphibole of several fine medium- to medium-grained hornblende- and uralite-eucrites.

Sp. no.	α	β	γ
9	colourless	green	grayish green—blue green
12	yellow green—colourless	green	blue green
20	yellow green, frequently a trifle red brownish	green	blue green
29	pale green yellow—greenish yellow	olive green, quite strongly	deep bluish green—blue green
37	very slightly green yellow	green—pale olive green	pale blue green—greenish blue
39	pale yellow green—greenish—colourless	olive green—grass green	blue green—green blue
42	very slightly green yellow	green, rarely bluish green	greenish blue—green blue
43	pale green yellow	green, quite slightly; sometimes yellowish green	greenish blue, quite slightly, —pale green blue
50	light yellowish green	olive green	blue green, sometimes a trifle brownish red
59	colourless—pale yellow; sometimes greenish	grass green, or sometimes olive green	green blue
62	yellow green–green yellow–colourless	grass green, or sometimes olive green	blue green—light green blue, sometimes very slightly
65	colourless—very slightly yellow green	grass green—olive green	green blue, sometimes very slightly
71	colourless—very slightly yellow green	grass green—yellow brownish green	blue green, or often grayish green blue
77	colourless, or sometimes a trifle green yellowish	grass green, or sometimes olive green	green blue, or often blue green
95	colourless, or often pale yellowish green	grass green, or more frequently olive green	blue green
99	colourless—pale yellow green	pale grass green	pale brownish green—pale green blue
100	very slightly yellow green—very slightly green	pale grass green or brownish green	pale gray green—pale blue green
107	colourless	grass green	blue green
134	colourless	olive or grass green	blue green

ondary, we are forced to call the gabbro variety now described »hornblende- and uralite-eucrites», however.

Primary hornblende may occur, but, in fact, no difference as to the appearance between the amphibole of the homogenous individuals and that of the crystals containing remnants of pyroxene could be traced. DU RIETZ (1929, p. 502) reports from Rådmansö: »The difference between the certainly uralitic and the primary hornblende is not great». Afterwards he states that »the primary hornblende is usually zonary with a pale or colourless center and strongly pleochroic margins» (p. 502). In a slide from the Grovstanäs massif, however, a beautiful, distinctly zonal, analogous amphibole individual, containing a big remnant of hypersthene, was observed (Fig. 16, sp. 154). And, indeed, this discovery forms no single exception, for, as has become evident from sp. 154, the few zonal amphiboles reported from there all have emanated from orthopyroxene and are consequently obviously deuteric or secondary. The origin of the zones seems to

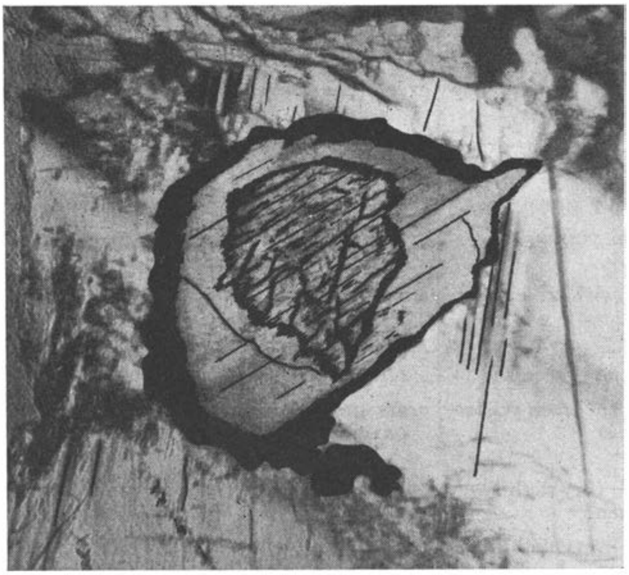

Fig. 16. Hypersthene remnant, surrounded by zonal amphibole (inner zone = gray, outer zone = black). Sp. 154, + nic., magnified about 150 ×. P. H. L. 1942.

be due to a decrease in CaO, Na_2O, Al_2O_3, and an increase in FeO, MgO, towards the hypersthene remnants.

No other zonal amphiboles were found within the hornblende- and uralite-eucrites, except for those in sp. 154. Needle-shaped, orientated *ore* microlites, in two directions, appear within a few amphibole crystals (Fig. 17). According to SVEDMARK (1885, p. 89), similar microlites are present within the »hornblende gabbro» of Gillberga, Rådmansö.

Now and then the amphibole has undergone some alteration to *chlorite*, or, to a less extent, to *epidote* ($2\,V_\gamma = 105°$ in sp. 59) with *clinozoisite*. Small, irregular-shaped flakes of *calcite* may occur, too (in sp. 99 they grow numerous). Seldom green chlorite-»fingers» were found (frequently in sps. 43 and 154), indicating an origin of the rocks in question from *olivine*-bearing eucrites.

In most cases the change into chlorite does not grow very strong, but it may give rise to the appearance of a pale green *penninite* (sps. 107 and 181), or some other chlorite mineral a trifle more birefringent (in sps. 12 and 71), as an inferior mafic constituent. The penninite is opt. + in sp. 107, and usually opt. — in sp. 181, with 2 V very small, or $= 0°$ ($2 V_\gamma$ in sp. $59 = 0°$). In sp. 107 the pleochroism shows the following colours: α = pale yellow green or, more frequently, green, β = pale green, and γ = colourless. In sp. 107 some epidote has originated from the penninite.

In a few of the hornblende- and uralite-eucrites here described *clino-pyroxene* occurs as a subordinate mafic constituent. It is always more or

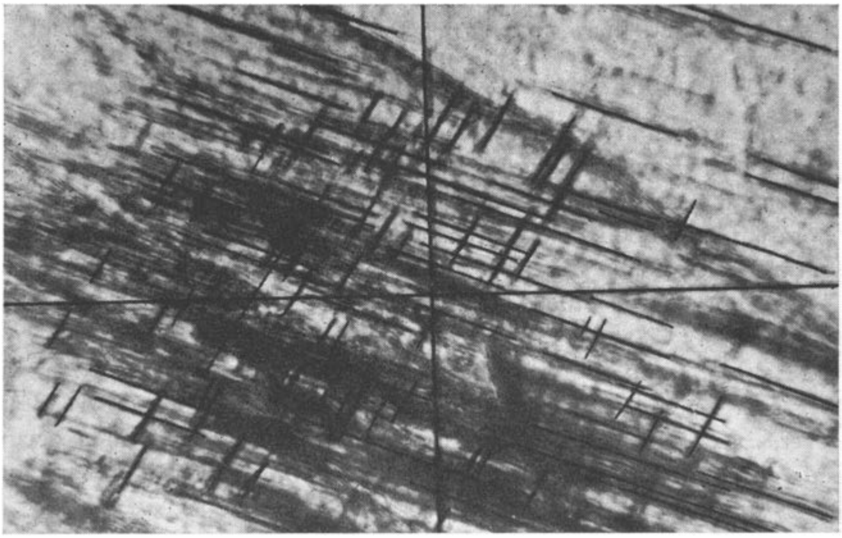

Fig. 17. Ore microlites within amphibole. Sp. 149, magnified about 675 ×. P.H.L. 1942.

less altered to amphibole. The optical properties of the commonest clino-pyroxene, the *diallage* (diopside and augite), will be found in Table 14. *Pigeonite* does only appear in sp. 99, where it forms an inferior main mineral ($c:\gamma = 34° \, ^1/_3$).

Biotite now and then emerges as a subordinate mineral, too (in sps. 29, 37, 71, and 95). It displays a strong pleochroism: α = yellowish—reddish yellowish, β = brown, sometimes reddish brown, γ = red brown—brown. In sp. 71 flakes of biotite and penninite frequently alternate.

In sps. 29 and 134 *quartz* occurs as an inferior constituent. Most often it forms small, corrosive grains, sometimes rather large individuals, however. Evidently it is secondary.

The commonest accessory is *magnetite*, sometimes accompanied by *ilmenite*, and occurring in almost every thin section examined, especially within many amphibole crystals, suggesting their secondary character. Most of the magnetite grains are small.

The following accessories are rarer: One single, strongly altered, dark brown *titanite*(?) grain in sp. 9, dark brown red *rutile* as small particles and corrosive quartz as single grains within the amphibole of sp. 20, *rutile* within the amphibole of sp. 37, single *titanite* and *apatite* grains, accompanying ore, in sp. 107, *biotite* in sp. 107, *hypersthene* in sps. 154 and 181. In the former slide (154) the hypersthene is most often surrounded by amphibole, trimmed with chlorite-spinel-»fingers», in most cases mingled with much magnetite, and sometimes more or less altered to a *diabantitic* mineral ($2\,V_\alpha$ near to $0°$) along the fissures and cleavages. The presence of the chlorite-spinel-»fingers» indicates an earlier existence of *olivine*.

Pyrite here and there appears as a totally occasional constituent.

B. Fine medium- to fine-grained varieties.

The fine medium- to fine-grained hornblende- and uralite-eucrites display greenish black gray—gray green black, sometimes green black, rocks, which are in general xenomorphic, frequently granoblastic, seldom hypidiomorphic. The present amphibole eucrites seem to be a trifle less common than the coarser varieties above described. The banding is not as prominent as in the latter, but on the other side it is better developed than in the hypersthene-eucrites.

The alteration of the prevailing constituent, the *plagioclase* (An = 86—87 %), is in general similar to the change described in section A. Calcite, however, has gained a stronger position than there, and often occurs in considerable amounts. Chlorite (in part *penninite*) is a little more common, too. *Zoisite* may appear in rare cases.

The frequency of twinning laws will be reported in Table 27, at the beginning of chapter VII. The poles ⊥ (010) scatter well around a point close to NIKITIN's (1933) curve, as is displayed by Fig. 26 (ch. VII: 1) and Tables 19—21. This dot (Fig. 26, ch. VII: 1) represents the mean n_α-, n_β-, and n_γ-coordinates of ⊥ (010) and is situated in the most immediate vicinity of the corresponding dot of the hypersthene-eucrites, suggesting an intimate relationship between the fine medium- to fine-grained amphibole eucrites and these rocks.

The small, more or less granoblastic plagioclase grains now and then occurrent (for inst. in sp. 101), in general fail to show any percentage values of An differing from those of the large individuals. An exception is offered by the circumstances in sp. 171. Here the small grains present a percentage of An = 81—82, and the large ones a corresponding value of about 90 %. The small grains seem to have originated by a crush of large plagioclase individuals, an act, which was most frequently followed by recrystallization. A. F. BUDDINGTON (1939, for inst. p. 57) reports a similar change within many metagabbros of the Adirondacks, and obviously crush displays a phenomenon met with in most metagabbros.

Table 19. The n_α coordinate of $\perp$ (010) as found from hornblende- and uralite-eucrite plagioclase twins (fine medium- to fine-grained rock types).

$M = 58^\circ.5 \pm 0^\circ.46. \quad \sigma = 3^\circ.53 \pm 0^\circ.322. \quad N = 60$

Values	$< 2.0 \times \sigma$	$1.5 \times \sigma$	$1.0 \times \sigma$	$0.67 \times \sigma$	$> 0.67 \times \sigma$	$1.0 \times \sigma$	$1.5 \times \sigma$	$2.0 \times \sigma$
Real error distribution .	1	5	9	20	13	7	5	2
Error distribution according to GAUSS	1	3 1/2	9 1/2	15	15	9 1/2	3 1/2	1
Difference	0	+1 1/2	− 1/2	+5	−2	−2 1/2	+1 1/2	+1
Deviation from M> . .	$7^\circ.06$	$5^\circ.30$	$3^\circ.53$	$2^\circ.35$	$2^\circ.35$	$3^\circ.53$	$5^\circ.30$	$7^\circ.06$
Values	$< 51^\circ.45$	$53^\circ.2$	$55^\circ.0$	$56^\circ.15$	$> 60^\circ.85$	$62^\circ.0$	$63^\circ.8$	$65^\circ.55$

Two values $n_\alpha : \perp (010) = 68^\circ$ cause a pronounced positive skewness.

Table 20. The n_β coordinate of $\perp$ (010) of the same plagioclase twins.

$M = 60^\circ.8 \pm 0^\circ.38. \quad \sigma = 2^\circ.93 \pm 0^\circ.267. \quad N = 60$

Values	$< 2.0 \times \sigma$	$1.5 \times \sigma$	$1.0 \times \sigma$	$0.67 \times \sigma$	$> 0.67 \times \sigma$	$1.0 \times \sigma$	$1.5 \times \sigma$	$2.0 \times \sigma$
Real error distribution .	2	5	11	16	16	11	3	0
Error distribution according to GAUSS	1	3 1/2	9 1/2	15	15	9 1/2	3 1/2	1
Difference	+1	+1 1/2	+1 1/2	+1	+1	+1 1/2	− 1/2	−1
Deviation from M> . .	$5^\circ.86$	$4^\circ.40$	$2^\circ.93$	$1^\circ.96$	$1^\circ.96$	$2^\circ.93$	$4^\circ.40$	$5^\circ.86$
Values	$< 54^\circ.95$	$56^\circ.4$	$57^\circ.9$	$58^\circ.85$	$> 62^\circ.75$	$63^\circ.7$	$65^\circ.2$	$66^\circ.65$

Table 21. The n_γ coordinate of $\perp$ (010) of the same plagioclase twins.

$M = -45^\circ.8 \pm 0^\circ.41. \quad \sigma = 3^\circ.21 \pm 0^\circ.293. \quad N = 60.$

Values	$< 2.0 \times \sigma$	$1.5 \times \sigma$	$1.0 \times \sigma$	$0.67 \times \sigma$	$> 0.67 \times \sigma$	$1.0 \times \sigma$	$1.5 \times \sigma$	$2.0 \times \sigma$
Real error distribution .	1	3	10	15	14	9	2	1
Error distribution according to GAUSS	1	3 1/2	9 1/2	15	15	9 1/2	3 1/2	1
Difference	0	− 1/2	+ 1/2	0	−1	− 1/2	−1 1/2	0
Deviation from M> . .	$6^\circ.42$	$4^\circ.82$	$3^\circ.21$	$2^\circ.14$	$2^\circ.14$	$3^\circ.21$	$4^\circ.82$	$6^\circ.42$
Values	$< 39^\circ.4$	$41^\circ.0$	$42^\circ.6$	$43^\circ.65$	$> 47^\circ.95$	$49^\circ.0$	$50^\circ.6$	$52^\circ.2$

Here and there the plagioclase grains are crossed by a strikingly large number of fracture lines, single of which are filled with small, granoblastic grains of plagioclase (sp. 101, for inst.), or of amphibole (in sps. 101 and 110), apparently effected by means of the actions of pressure, crush, and recrystallization, probably migration, too (evidently, when it is a question of the amphibole grains).

The main mafic constituent, the amphibole, always consists of *common green hornblende.* In fact, *fibrous* amphibole was found as an accessory only in one single slide (sp. 101). In general the hornblende occurs as granoblasts, usually assembling to aggregations, or of large, irregular-shaped individuals, containing many small grains, which are non-orientated and most often granoblastic. Remnants of *clinopyroxene* are sometimes preserved. They bear clear evidence of being of a deuteric or secondary origin. *Hypersthene* pseudomorphs were observed in sp. 143. Else there is a total lack of them, however, a matter of fact concealing the genesis of most of the amphibole of the rocks now dealt with.

Minute hornblende crystals appear as non-orientated microlites within part of the plagioclase.

The optical properties of the common hornblende are shown by Table 22. The pleochroism displays normal colours: $\alpha =$ pale yellow green—colourless, $\beta =$ grass green—olive green, and $\gamma =$ green blue—blue green. The birefringence is the usual one. Twinning on (100) may be found in rare cases.

Sometimes the amphibole shows a slight alteration to *penninite* (most frequently optically +, but now and then also —), more seldom to *epidote*, and *clinozoisite*. Green *chlorite*-»fingers» occur in sp. 101, suggesting an earlier presence of *olivine.*

The following subordinate minerals were observed: *ore* (as a rule magnetite), *diopsidic diallage* as remnants within the amphibole, and, not very frequently, *biotite* in sp. 92, clinopyroxene = *pigeonite* — *diopsidic diallage* ($c:\gamma = 35^\circ\ ^1/_2$—$39^\circ$), marginally and spot-wise internally alterated to amphibole, in sp. 101, *quartz* in sps. 102 (large individuals) and 121 (usually as small granoblastic grains, to the largest extent as diablasts filling amphibole individuals, but sometimes also as big, solitary individuals), remnants of clinopyroxene = *diopside* — *augite* in sp. 144, and small lumps of *diallage* in sp. 171.

Varying accessories occur in almost every thin section examined, most frequently *iron ore* (magnetite accompanied by some ilmenite), but sometimes also the minerals now recorded: *titanite* as single crystals within the amphibole of sps. 74, 101, 116, and 144, *pyrite* in sps. 109, 110, 111, 143, 144, and 171, *titanite* as rare particles in sp. 121, as a few rather large, dark brown grains in sp. 143, *muscovite* (sericite) as numerous minute grains and flakes within the amphibole of sp. 171. In sp. 111 and 144

Table 22. Optical properties of the most important minerals contained in the fine medium- to fine-grained hornblende- and uralite-eucrites.

Sp. no.	Diopsidic diallage	Amphibole	
	c : γ	2 V_γ	c : γ
1		99° 1/2	16° 1/3
55		95° 1/2	16° 1/3
74		101° 1/2	15° 1/2
85		101°	16° 1/2
92	38° 1/2	102° 1/2	16° 3/4
101	39°	102°	17° 1/3
102		98° 3/4	20° 1/2
109		95°	18°
110		97° 3/4	20° 1/2
111		102° 1/6	18°
116		94°	17°
119		97° 1/2	17°
121		97°	17° 1/2
143		93° 5/6	15°
144	(40°)[1]	92° 2/3	17° 1/3

[1] diopside—augite, showing no diallage parting.

part of the pyrite individuals has grown rather large, and idiomorphic (cubic). Rarely a little *epidote* borders upon the iron ore grains.

Brown-pleochroic *biotite* occasionally appears in sp. 109 (aggregations of crystals), more frequently in sps. 111 and 119, where it is sometimes accompanied by *penninite.*

Problematic *quartz* inclusions, minute and corrosive, could be traced in sp. 111.

8. **Hornblendites, and davainites.**

The hornblendites never occur as large masses. In fact, they are restricted to form the most subordinate ultra-basic gabbro variety of all within the Grovstanäs massif. In general they confine to run as narrow, in part evidently davainitic bands, through many hornblende- and uralite-eucrites. Only at point 170, on the N shore of the isle of Hornsholmen, they grow more extensive, together with mafic amphibole eucrite there forming a little mass within a quartz-diorite, which they brecciate. The angular remnants thus produced are of the greatest importance, and will be described later on (p. 356).

Table 23. Microlite-rich, slightly titaniferous hornblende (large crystal) from the SE part of the isle of Bergsö (no. 6 in Fig. 2). Analyst = N. SAHLBOM.

	Weight-%	Mol. prop. × 1000	Atomic prop. × 1000	Atomic prop.:s when checked against CaO 1 ×	8 ×	Assumed comp.
SiO_2	42.80	712.6	712.6	3.52	28.16	28
TiO_2	3.80	47.6	47.6	0.235	1.88	2
Al_2O_3	12.71	124.7	249.4	1.23	9.84	10
Fe_2O_3	1.85	11.6	23.2	0.115	0.92	1
FeO	10.70	148.9	148.9	0.735	5.88	6
MnO	0.15	2.1	2.1	0.010	0.08	
MgO	14.24	353.2	353.2	1.74	13.92	14
CaO	11.36	202.6	202.6	1.000	8.00	8
Na_2O	1.34	21.6	43.2	0.213	1.70	2
K_2O	0.54	5.7	11.4	0.056	0.45	
H_2O+	0.22	12.2	24.4	0.120	0.96	1
H_2O-	0.06					
F	0.00					
P_2O_5	0.00					
	99.77					

$OH(Na, K)_2 Ca_8 (Mg, Fe^{\cdot\cdot}, Mn)_{20-n} (Al, Fe^{\cdot\cdot\cdot})_{11-2m} Si_{28} \cdot Ti_{2-n} O_{105-(3n+3m)} + n FeTiO_3 \cdot m FeFeO_3$, where $n < 2$ and $m < 1/2$.

The amphibole of the hornblendites is almost always *common green hornblende* of the same kind as was recorded above. A few exceptions were found, however, the most important of which will be mentioned here.

Among these we shall consider at first the pegmatitic, microlite-rich, idiomorphic (= euhedral), and slightly *titaniferous hornblende* occurring within the amphibole eucrite of the islet of Kråkholmen and the utmost E part of the isle of Bergsö (situated N of the former islet). This hornblende constitutes well-developed, macroscopically black crystals, the length of which sometimes exceeds 3 inches = 76 mm. Part of a very large crystal (3 1/3 inches = 85 mm in length) from a point near to the E shore of the SE part of Bergsö was analysed chemically (Table 23). The formula there shown points out the presence of free *ilmenite*, actually forming numerous needle- and dot-shaped microlites, most of which run parallel to the elongation. The pleochroic colours of this hornblende are the normal ones. $2V_\gamma = 96°$, $n_{\alpha Na} = 1.6455 \pm 0.003$, and $n_{\gamma Na} = 1.6635 \pm 0.003$ ($n_{\gamma Na} - n_{\alpha Na} = = 0.018 \pm 0.006$). No alteration products were traced.

Another important and exceptional amphibole is displayed by the *pargasitic*, macroscopically black green *hornblende* from point 40 in the immediate vicinity of the E end of Lake Båtdragsträsket. This amphibole occurs as medium-grained hornblendite (or possibly davainite) bands within a hornblende- or uralite-eucrite. A chemical analysis was carried out, pro-

Table 24. Pargasitic hornblende from the immediate vicinity of the E end of Lake Båtdragsträsket (sp. 40, no. 7 in Fig. 2). Analyst = N. SAHLBOM.

	Weight-%	Mol. prop. × 1000	Atomic prop. × 1000	Atomic prop.:s when checked against CaO 1 ×	8 ×	Assumed comp.
SiO_2	41.12	684.7	684.7	3.045	24.36	24
TiO_2	0.00					
Al_2O_3	14.94	146.6	293.2	1.305	10.44 }	12
Fe_2O_3	3.94	24.7	49.4	0.22	1.76 }	
FeO	5.80	80.7	80.7	0.36	2.88 }	3
MnO	0.24	3.4	3.4	0.015	0.12 }	
MgO	18.18	450.9	450.9	2.005	16.04	16
CaO	12.60	224.7	224.7	1.000	8.00	8
Na_2O	1.72	27.8	55.6	0.245	1.96 }	2
K_2O	0.29	3.1	6.2	0.03	0.24 }	
F	0.10	5.3	5.3	0.025	0.20 }	2
H_2O+	0.48	26.6	53.2	0.235	1.88 }	
H_2O-	0.20					
P_2O_5[1]	0.10					
	99.71					

$(OH, F)_2(Na, K)_2Ca_8(Mg, Fe^{\cdot\cdot}, Mn)_{19}(Al, Fe^{\cdot\cdot\cdot})_{12}Si_{24}O_{93}$.

posing a probable formula (Table 24). The presence of *fluorine*, in connection with an optically positive character, most fully gives the reasons for the prefix »pargasitic». The pleochroism is a follows: α = very pale yellowish — colourless, β = very pale greenish yellowish, and γ = blue green — pale bluish. $2V_\gamma = 82°\,{}^1/_2$, $c:\gamma = 18°\,{}^1/_5$, $n_{\alpha Na} = 1.6465 \pm 0.003$, and $n_{\gamma Na} = 1.6655 \pm 0.003$ ($n_{\gamma Na} - n_{\alpha Na} = 0.019 \pm 0.006$). Sometimes the pargasitic hornblende has altered to *chlorite* (in part green positive pennite with $2V = 0°$). Small sparkles of *pyrite* were found as an accessory.

At the little cape WNW of the isle of Dåderholmen, fine medium-grained *hornblendite* (sp. 13) sometimes appears instead of hornblende- and uralite-eucrite. This hornblendite, composed of *common green hornblende*, is quite a peculiar rock as regards its subordinate constituents. *Calcite* forms large, irregular-shaped individuals containing small rounded dark red brown — brown particles and aggregations of *rutile* and (or) *ilmenite*. More important, however, is the *fluorite* filling narrow fissures and tending to brecciate the rock. In thin sections the fluorite displays fresh, colourless and transparent masses. In a great many cases the mineral carries minute, rounded, dark brown — dark red particles of rutile, or sometimes perhaps ilmenite, which have frequently assembled to aggregations.

[1] Most probably contained within the amphibole lattice, as no apatite was traced.

IV. The Border and Oldest Dike Rocks Around the Grovstanäs Massif.

0. Nomenclature and principles of division.

The border rocks around the Grovstanäs massif are simply dealt with, as regards their nomenclature. An inner zone, most often not present, consists of *quartz-gabbro* of the same type as was reported from Rådmansö by SVEDMARK (1885, p. 96 ff.), and has got no. 133 in TRÖGER's compendium of nomenclature (1935).

The remaining rocks need no explanation here.

As to the division of the rocks described in this chapter, the following sequence has been established:

A. Border rocks.

1. An inner zone = quartz-gabbro (An $\geq$ 50 %), grading into an
2. Outer zone = *quartz-diorite* (An < 50 %). Nowhere distinct boundaries between these two basite varieties were traced.

B. Dike rocks.

3. *Older amphibolites*, connected with the gabbro massif, but showing a rather low percentage of An within their plagioclase.

1. Quartz-gabbros and 2. Quartz-diorites.[1]

The quartz-gabbros and quartz-diorites bear close resemblance to each other, and therefore they are described in the same part of this chapter. The single distinction traced is the former being a trifle darker, and more mafic, than the latter.

The rocks now concerned are black gray to gray, seldom greenish, xenomorphic, and medium-grained. They occur along part of the outer boundaries of the Grovstanäs massif (Pl. XII) as more or less narrow zones, which seem to form transitions between the ultra-basic gabbros and the gneiss-granites (and granodiorites). A close investigation, however, has never failed to show the existence of a distinct border line parting the ultra-basic gabbros from the transitional basites. And, what is very important, on the N shore of the isle of Hornsholmen a mafic amphibole eucrite, together with a hornblendite, was seen to brecciate the quartz-diorite there occurrent (as was mentioned on p. 353). Fig. 18 exhibits several remnants of the quartz-diorite. Consequently, the quartz-bearing, more salic basites are at least in part shown to be evidently older than the ultra-basic gabbros. Further proofs in this direction were given by the microscopical investigations.

[1] Methodological remarks, see ch. III: 0!

Plagioclase, greenish or grayish white to white, forms the prevalent constituent of the quartz-gabbros and quartz-diorites. It occurs as large and small crystals, which are in general more or less altered, but now and then fresh. The change has given rise to the appearance of *sericite*, most frequently accompanied by inferior quantities of *clinozoisite* and *calcite*, sometimes of *chlorite*, *epidote*, and a *saussuritic* mass. *Talc* was once observed (sp. 136). A few of the subordinate secondary constituents, the clinozoisite and the saussuritic mass, may dominate over the sericite in single specimens. Here and there (in sps. 127, 133, and 135) the plagioclase individuals are filled with aggregations of numerous minute

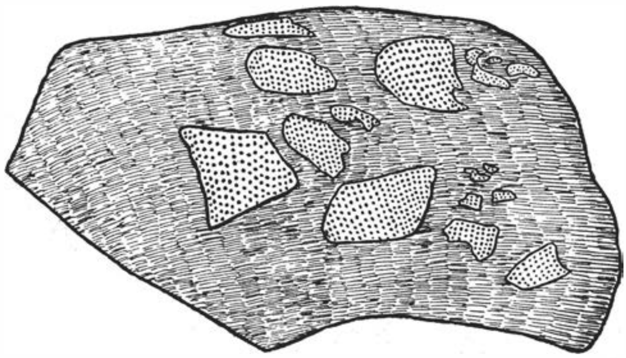

Fig. 18. Remnants of quartz-diorite within the ultra-basic gabbro at point 170 of the isle of Hornsholmen. Scale 1 : 13—1 : 14. Drawn by W. PLAN after photo P. H. L. 1942

hematite grains (producing a red colour), and of green chlorite (in sp. 133 occurring together with some crystals being a trifle larger and determined as *penninite*). In a few cases needle-shaped *ore* microlites emerge in two directions, at an angle of almost 90°.

The plagioclase of the border rocks varies very much, as regards its chemical composition. Values from 37 to 73 % were found, as shown by Fig. 27, where all poles ⊥ (010) are represented (open circles). But only very seldom the differences in one and the same specimen are as large as to cause acid plagioclase individuals penetrating basic ones. The frequency of twins will be evident from Table 25.

Table 25. Frequency of plagioclase twins as found from the border and oldest dike rocks (incl. remnants).

Twinning laws	Quartz-gabbros	Quartz-diorites	Older amphibolites	Σ
Albite	7	16	7	30
Carlsbad	2			2
Σ	9	16	7	32

Interstitial *quartz* here and there will be met with, frequently as large individuals, by far more usually as small grains of a granoblastic appearance, however. Corrosive quartz makes a common development. This quartz penetrates the plagioclase beautifully, producing the most wonderful pictures, now and then for inst. myrmecitic intergrowths (Fig. 19). F. K. DRESCHER-Kaden (1940), in his investigations on the Bergell granite, concludes that myrmecitic intergrowths similar to those within the Grovstanäs border rock plagioclase »metasomatischen Lösungsvor-

Fig. 19. Myrmecitic intergrowth: quartz penetrating plagioclase. Sp. 168, + nic., magnified about 150 ×. P. H. L. 1942.

gängen ihr Dasein verdanken, welche im wesentlichen vom Zustand der Intergranulare bedingt sind» (p. 401).

The corrosive quartz has sometimes effected a division of the amphibole and biotite individuals into minute parts (Fig. 20), most frequently without having changed the orientation of these small pieces to any larger extent, however. In general the quartz corrosion of the minerals now mentioned has not been able to produce any stronger disintegration, but has confined to originate a sprinkling with small, rounded grains all over part of them.

As a whole the quartz forms an inferior main to subordinate constituent of the border basites. The large individuals are now and then seen to contain minute liquid inclusions (»libellæ»), which may run all over them like winding necklaces. In general they show an undulatory extinction more or less pronounced.

The main mafic constituent is *common green hornblende*, forming the most different types of individuals from quite idiomorphic to xenomorphic ones, from large to small ones, from single grains to aggregations of grains. Interstitial granoblastic grains, or interstitial penetration, now and then occur between the plagioclase crystals. The birefringence is a trifle less than that of the ultrabasic gabbro hornblende, the pleochroism strong and: α = pale green yellow—colourless, β = grass green—olive green, γ = blue—blue green. $2\,V_\gamma$ and $c:\gamma$ are reported in Table 26. The values $2\,V_\gamma$ are always higher than those of the ultra-basic gabbro hornblende.

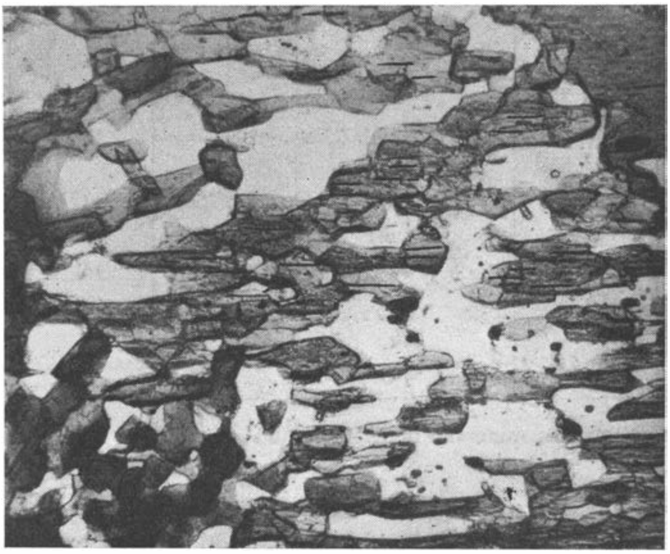

Fig. 20. Amphibole individual, strongly penetrated by quartz. Sp. 151, 1 nic., magnified about 150 ×. P. H. L. 1942.

As was mentioned above, a great many amphibole individuals are sprinkled with quartz grains, several with *magnetite* (seldom *ilmenite*), too. Impregnation with aggregations of minute *hematite* grains (sp. 127) forms an exception.

Close to the boundary on an amphibole eucrite, a quartz-gabbro (sp. 127, An = 68 %) was seen to contain a single amphibole pseudomorph after a *clinopyroxene* crystal. In sp. 133 (An = 44 %), from the vicinity of Lake Hammarbysjön, a few large hornblende individuals, within their kernels, contain a *light-coloured* amphibole obviously secondary after *hypersthene*, the fissures, cleavages, and ilmenite microlites of which are wonderfully well-preserved. Another specimen, no. 168 (An = 46 %), exhibits hypersthene ($2\,V_\gamma = 114^\circ\,{}^1/_2$) as the predominant mafic constituent. The development of this mineral is similar to that of the hypersthene-eucrite hypersthene. The alteration has been directed towards amphibole and *biotite*. SVEDMARK, in his study of the Rådmansö gabbro, reports

Table 26. Some chemical and optical properties as found from the main minerals of the Grovstanäs border basites (remnants not included here).

Sp. no.	% An within the plag., acc. to NIKITIN's curve ⊥ (010), M	Amphibole	
		$2V_\gamma$	$c:\gamma$
93	56	113°	16—18°
118	50—66	105°	17°
122	55		
124	40	113° 1/2	16°
125	38		
127	68		19° 1/2
133	44	103° 1/2	15° 1/2
135 SW	46		
138	45	107° 1/6	11° 1/3
139	52		
151	49	106°	16° 1/2
167	39		
168 [1]	46		
169	40		

[1] Predominant mafic mineral = hypersthene ($2V_\gamma = 114°\ 1/2$).

pyroxene-bearing to pyroxene-rich border rocks (1885, p. 96 ff.). His pyroxene is always a diallage, however. DU RIETZ, too, observed this mode of occurrence of clinopyroxene (1929, p. 515 ff.).

The presence of a slightly pleochroic, optically positive amphibole ($2V_\gamma = 80—85°$) in sp. 118 (An = 50—66 %) suggests the pre-existence of a pyroxene. The positive amphibole grades into common hornblende towards the boundaries upon the plagioclase, and exhibits a birefringence stronger than that of the latter variety. It tends to display a faint fibrousness and is evidently to be classed as a *cummingtonitic* amphibole, according to ASKLUND (1925, p. 21). A similar amphibole was reported from sp. 136. All these pale kernels seem to form analogues to the interior of the zonary amphiboles containing hypersthene remnants, which were recorded in an earlier chapter (III: 7).

As a rule, however, the amphibole of the Grovstanäs border basites seems to be primary. Now and then it penetrates the plagioclase (for inst. in sps. 93 and 136), thus showing its being evidently later than this mineral.

The amphibole is very frequently in part altered to *penninite*, more seldom to a little *epidote*. In sp. 125 most of the hornblende has vanished, and green negative penninite ($2V_\alpha$ very small) now occurs as a main mafic

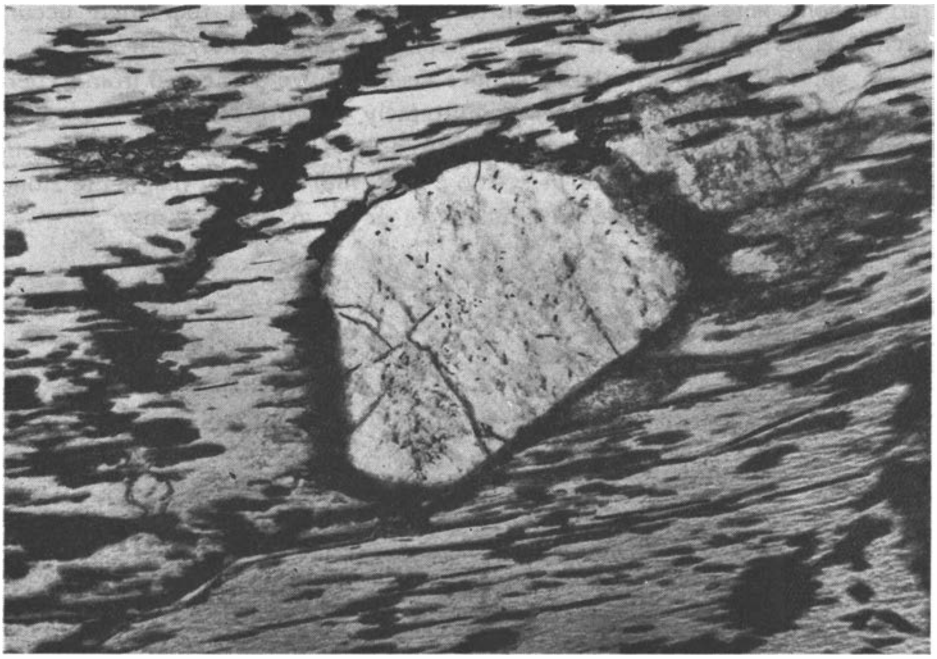

Fig. 21. Ore-impregnated penninite (section ⊥ basis), containing an apatite grain. Sp. 127, 1 nic., magnified about 160 ×. P. H. L. 1942.

mineral. Along its basis this penninite frequently alternates with epidote. The pleochroic colours are the normal ones: α = pale yellow green—colourless, $\beta = \gamma$ = green. In sp. 135 SW the penninite most often forms »pseudomorphs» after hypersthene, the characteristic appearance of which is well-preserved. Here the penninite individuals are elongated in a certain direction ⊥ basis. Parallel to the latter plane the mineral alternates with a dense brownish mass, as well as the similar one of the ultra-basic gabbro hypersthene (p. 340) composed of the most minute grains of *hematite* and other, unidentifiable ores. Analogous masses were observed within the penninite of sp. 127, where rare apatite grains also emerge (Fig. 21).

In general we meet *biotite* ($2\,V_\alpha$ nearly 0°), too, now as a main mineral, then almost or totally lacking. The biotite displays ordinary, strong pleochroism: α = very pale greenish yellowish—colourless, $\beta = \gamma$ = green brown—red brown. It most often penetrates the plagioclase beautifully (Fig. 22), here and there the amphibole, too, thus showing its being later than these minerals. As a rule the biotite individuals are better developed than the hornblende ones and fail to display such a strong sprinkling with corrosive quartz as those frequently do. But they are rather irregular-shaped, too; and several small individuals may cling together, forming large, composite grains. A faint alteration here and there may occur, giving as its results *chlorite* (usually penninite) and *epidote*.

In sp. 168 the biotite is sometimes seen to have originated from hypersthene (the appearance of which is extremely well-preserved).

In several slides *ore*, and most often *pyrite*, too, form inferior constituents (pyrite + magnetite in sps. 93, 118, and 135 SW, magnetite alone in sps. 127 and 151). Else it confines to occur as an accessory.

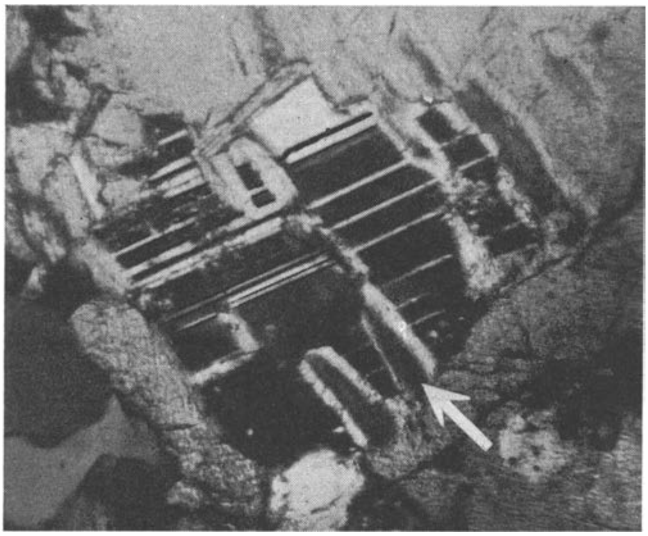

Fig. 22. Biotite penetrating plagioclase (one of the penetrating individuals marked out by an arrow). Sp. 118, + nic., magnified about 150 ×. P. H. L. 1942.

Other accessories appearing are as follows: *ilmenite* (associated with magnetite), *titanite* in sp. 127 (always accompanied by magnetite), and *apatite*, frequently as considerable grains (Fig. 21), in sps. 127, 136, 138, 139, and 168. The large, xenomorphic apatite crystals are perhaps association and recrystallization products of small ones.

A very yielding study was made on a slide of sp. 169 (quartz-diorite from the NE cape of the isle of Hornsholmen). This specimen contains almost every type of mineral development occurrent within the border rocks, and, consequently, it will be described more closely here.

The prevailing mineral is the plagioclase (An = 40 %), which to a large extent forms big individuals, but, moreover, frequently in connection with the mafic constituents, groups of, or sometimes single, small grains, in most cases pronouncedly granoblastic. These grains, however, are very often changed for angular, sharp-cut plagioclase, as regards its origin perhaps due to an act of crushing.

The alteration is remarkably slight; only along the cleavages small aggregations and elongated crystals were found, all consisting of sericite.

The quartz, being an inferior felsic constituent, does only to a minor extent occur as granoblastic grains. By far more frequently it makes large fields, or a corrosive mass, often split up into corrosive individuals. The quartz fills the interstices, but may appear within the main minerals as intergrowths, or as a brecciating and corrosive mass, too. It has sometimes penetrated the plagioclase very gently, producing a myrmecitic intergrowth of the same type as was shown by Fig. 19.

The main mafic minerals are biotite (a first-rate constituent) and common green hornblende (a second-rate constituent), the latter of which may sometimes descend to an inferior position. The pleochroic colours are the normal ones. The two minerals occur partly as homogenous individuals, partly as inhomogenous, penetrating ones. Most of the former are very irregular-shaped. Quantitatively, they almost equal the inhomogenous ones. The latter, within their interior, carry several plagioclase grains, most often granoblastic and sometimes assembled to groups, moreover, a small number of quartz grains. Frequently a more pronounced invasion of quartz was observed, having caused a brecciating of large or the largest parts of the hornblende and biotite individuals. The remnants as a rule display more or less smooth edges, due to corrosion.

Now and then the biotite penetrates the hornblende beautifully. The pseudohexagonal character of the biotite is in these cases obviously exhibited by sections // basis. Here and there large, penetrating biotite individuals contain small, rounded, non-orientated grains of amphibole. Thus the biotite being later than the hornblende is proved.

Earlier the presence of plagioclase grains within the penetrating amphiboles has shown the former mineral being the earliest of the main constituents. Hence we get the following succession of minerals (from earliest to latest):

1. Plagioclase.
2. Amphibole.
3. Biotite.
4. Quartz.

This sequence is applicable to all border basites around the Grovstanäs massif.

Finally, we shall touch a little more upon the remnants within the amphibole eucrite and hornblendite on the N shore of the isle of Hornsholmen. As was mentioned above, these remnants consist of quartz-diorite. As a rule An is = about 40 %, but in the immediate vicinity of the surrounding ultra-basic gabbro this value grows much larger. In fact, it was seen to amount to about 74 % in single cases. The main mafic mineral is common green hornblende, the optical properties of which vary from the central parts of the remnants and towards their boundaries. Close to one of the border lines $2V_\gamma$ was determined to 92° and $c:\gamma$ to 17°, values in the most excellent agreement with those found from the ultra-basic gabbros. As usual corrosive quartz occurs. Accessoric apatite was observed.

3. Older amphibolites.[1]

The older amphibolites of the Grovstanäs region are rare. One occurrence was found at the NE corner of the ultra-basic gabbro massif, where, as a narrow dike, the rock runs W- and ESE-wards from the utmost tip of the amphibole eucrite, following the strike-and-dip direction of the gneiss-granite. The width of this dike does never exceed 1.1 yards (= 1 m). The amphibolite building it up (sp. 26) displays a grayish black—black, porphyritic, fine medium- to fine-grained rock, to the largest extent composed of granoblastic mineral grains. The main constituents are *plagioclase* and *common green hornblende.* The plagioclase grains are always small and rounded, and as a rule they have clung together, forming aggregations, by that causing the porphyritic appearance of the rock. Repeatedly strong alteration to *sericite* is met with, frequently giving as its result a change of the largest part of the plagioclase. Two albite twins[2], examined on the universal stage, contained 46 % An.

The hornblende in general occurs as small xenoblasts, more seldom as large individuals. The pleochroism and birefringence are the normal ones. $2V_\gamma$ was determined to 100° ½, $c:\gamma$ to 16°. Rarely a slight change to *epidote* was observed.

As single first-rate inferior constituent we find *biotite* (normal pleochroic colours), as sole second-rate one *iron ore.* No quartz and apatite are traceable.

Another narrow dike, connected with amphibole eucrite, was discovered NE of Lake Hammarbysjön, at the gabbro protuberance. The amphibolite here occurrent (sp. 123) exhibits a grayish black—black, fine-grained and granoblastic rock. The main felsic mineral, the *plagioclase*, has always altered, but as a rule rather slightly. The product is in general *sericite*, frequently accompanied by a *saussuritic* mass. Rarely grains of *epidote* occur, as to their genesis apparently due to chemical reactions between the plagioclase on one side and hornblende or ore on the other side. *Calcite* may emerge occasionally. Two albite twins have revealed An = 46 %.

The single mafic constituent of importance, the *common green hornblende*, occurs in amounts equal to those of the plagioclase. Its pleo-

[1] Methodological remarks, see ch. III: o!

[2] The poles ⊥ (010) of all plagioclase twins determined on the older amphibolites recorded in this chapter-part are represented in Fig. 27 (open circles).

chroic colours and birefringence do in no respect deviate from the normal ones. $2V_\gamma = 104^\circ\,{}^2/_3$, $c:\gamma = 18^\circ\,{}^2/_3$. Several small, corrosive, frequently xenoblastic quartz grains were met with in the amphibole. Seldom the hornblende has altered to green, negative *penninite* (with a well-developed pleochroism in green), rarely to *epidote*.

As an inferior to accessoric mineral we meet *pyrite*, sometimes with a little *serpentine* or *epidote* attached to it (when it borders upon plagioclase). Finally, the accessoric occurrence of *apatite* must be reported.

The two largest dikes of older amphibolite cross the border basites N—NNE of Lake Hammarbysjön. Here the Quaternary covers most of the rock, however. The field relations shown by Pl. XII are the probable ones, but, as regards the boundaries and the connection with the amphibole eucrite, the exact situation of the dikes may deviate to some extent from their presumed positions. Sp. 132, from the S one of the dikes, shows a gray black—black, fine-grained, xenomorphic rock, which in one outcrop, close to point 132 (Pl. XII), contains a minor, rounded, drop-shaped remnant of black gray, medium-grained amphibole eucrite (or possibly basic border basite), 0.8 feet (= 25 cm) in length, and surrounded by a narrow zone of granitic materials.

The *plagioclase*, forming the main felsic constituent, is sometimes fresh, but more frequently altered, in general slightly, now and then a little stronger, however. The products of the change is *sericite*, here and there accompanied by some *clinozoisite* and »*saussurite*» (minute quantities). Three albite twins were examined. Two of them, both large individuals, contained 57 % An, the remaining twin, a very small grain, only 52 % An. *Apatite* occurs as an accessory within the plagioclase (few and minute grains).

Quartz, frequently corrosive, forms a first-rate inferior mineral.

The main mafic constituent, the *common green hornblende*, makes irregular-shaped, small and large individuals, very frequently containing *titanite* (as a second-rate inferior mineral), sometimes *biotite* and *magnetite*, too. Normal pleochroism and birefringence is significant for this amphibole. $2V_\gamma$ was determined to 105°, $c:\gamma$ to $17^\circ\,{}^1/_3$. A very slight alteration to *epidote* and *penninite* may seldom appear.

The titanite grains are sometimes of an appreciable size. They display a brownish hue.

The amphibolites now described occur as dikes, crossing border basites or gneiss-granites of a character by far more acid than that of the ultrabasic gabbros. Their present texture is not a primary one, nor does it contain any preserved relics showing primary features (perhaps except for part of sp. 132, which, in fact, carries a more basic plagioclase, too).

The narrow amphibolite dikes were obviously able to effect no compensation of the chemical changes produced by the salic rocks surrounding them. On the contrary, an act of counterbalance must have made similar influences upon the utmost parts of the Grovstanäs massif itself almost invisible. The larger an intrusion is, the larger the compensative capacity it displays.

V. The Oldest Salic Rocks of the Grovstanäs Region.

o. Principles of division.

The rocks dealt with in this chapter are divided in two groups: 1. *leptitic rocks*, and 2. *gneiss-granites* with local *granodioritic* characteristics. The nearest of the more important occurrences of gneiss-granite, interrupted by leptite (there once seen to contain a few thin layers of limestone), is the isle of Östra Langnö, in the S of the Grovstanäs region (BLOMBERG 1889, p. 11). There the leptite exhibits a complete structural coincidence with the gneiss-granite. And, in addition to this fact, faint gradations from the first of the two rocks into the second one is a rule (stated by the author).

1. Leptitic rocks.[1]

The leptitic rocks make the rarest ones found within the Grovstanäs region. In fact, they do only appear as two remnants, the largest of which is a little dubious, as it occurs outside the ultra-basic gabbro, on the boundary between border rocks and gneiss-granite.

The reliable one of the leptitic remnants has come to rest in the anorthosite of Bönskär, where some pegmatite accompanies it. In no direction does it exceed 1.1 yard (1 m). It shows distinct borders upon the anorthosite and the pegmatite partly facing it. A very narrow reaction rim (not exceeding $^4/_5$ inches = 2 cm), now and then containing a little pyrite, surrounds it.

The Bönskär leptite displays a brownish or reddish gray to gray, fine-grained, granoblastic rock, which may contain single porphyroblasts of feldspar. In thin section it was seen to be composed of a great many small and large xenoblasts. The main minerals are *quartz* and *microcline*, the latter of which has altered very slightly. As subordinate constituents *oligoclase*, *biotite* (lepidoblastic), and an ore-bearing, olive green *serpentine* (optically —) occur. The oligoclase contains about 13 % An (lower values were observed, too). The biotite exhibits brown green to greenish brown

[1] Methodological remarks, see ch. III: o!

pleochroic colours. Now and then some *muscovite* was found. Accessoric *magnetite* frequently, accessoric *titanite* rarely emerged.

The dubious leptitic remnant is situated on the boundary between the border basites and the porphyritic gneiss-granite WSW of Lake Båtdragsträsket. It is rather large, measuring 11 × 6 1/2 yards (10 × 6 m). The present rock shows a very light colour, gray—reddish—reddish or grayish white, and a fine-grained, granoblastic texture. The composition resembles that of the Bönskär leptite. From the latter it will be easily distinguished by its well-developed parallel structure, making the lepidoblastic biotite form interrupted, thin layers, running all through it and often assembling to zones or bands of a colour pronouncedly darker than that of the rock as a whole, but sometimes lacking, too. No distinct border lines upon the gneiss-granites were seen.

2. Gneiss-granites with local granodioritic characteristics.[1]

The gneiss-granites building up the outer parts of the Grovstanäs region are of a granodioritic composition. They sometimes loose their parallel structure, or schistosity, thus changing into genuine *granodiorites*. In the W and S parts of the Grovstanäs region, rarely else, rather small—small, gray black—black, mafic inclusions now and then appear within the gneiss-granites. These »dark spots», seldom growing large, are perhaps in most cases »fish»-shaped, but very often they assume a more or less irregular character. In general they do almost agree with the strike-and-dip direction of the gneiss-granites, as regards their orientation. But never exact coincidence was found. DU RIETZ (1929, p. 526) reports from the Rådmansö area that the similar »dark spots» there occurrent (Figs. 24—26, pp. 525—526) »do not generally» appear »in salic and more alkaline varieties of the granodioritic rocks» (= gneiss-granites). In the Grovstanäs region do the microcline-bearing gneiss-granites nearly never contain »dark spots».

The gneiss-granites are gray (black-and-white), more seldom red, medium-grained, xenomorphic rocks. The granodiorites, only to be found immediately outside the border basites, bear close resemblance to the gneiss-granites, but are never red and very seldom pale reddish gray. Now and then the gneiss-granites carry »eyes» (porphyroblasts), or (rarely and) sheets[2] of *microcline*. These »eyes» being porphyroblasts is evidently shown by a few gradations (for inst. at photo-point III in Pl. XII) from non-porphyritic over »eyes»-bearing to band-bearing rocks. The bands are narrow, and of a reddish to red colour. Their length uses to amount to several yards (meters). Their width, how-

[1] Methodological remarks, see ch. III: o!

[2] rods may exist, too, though having never been observed.

ever, does not in normal cases exceed 1 inch (a few cm). The bands may sometimes alternate with single dikes of a red, fine-grained granite-aplite (a few of the »ga»:s in Pl. XII), dikes, the width of which varies from 2 inches to 1 or 2 yards (5 cm—1 à 2 m). The »eyes» are most frequently slightly lense-shaped, and as well as the bands and granite-aplite dikes their elongation coincides with the strike-and-dip direction of the gneiss-granites containing them.

The main constituents of the gneiss-granites are *plagioclase* (andesine) and *quartz*. The former mineral is in most cases a trifle more common than the latter. The plagioclase occurs as small or large individuals, most of which are irregular-shaped, and many of which to some extent assume a granoblastic character. The alteration is frequently rather strong and never wanting. As a rule it has given as its result small flakes and particles of *sericite*, seldom an *ore*-impregnated mass of a *saussuritic* appearance (but probably not to be classed as saussurite). The red gneiss-granites contain a great many *hematite* particles within their plagioclase, sometimes minute and rounded, greenish *chlorite* grains, too.

An is as a rule = 36—42 %. Single values, reaching 48 %, were found within the granodiorites. The following distribution of the twins determined was established: 15 albite and 2 albite-Esterel. All poles $\perp$ (010) are plotted against NIKITIN's (1933) curve in Fig. 27 (filled circles).

The quartz displays large, most frequently undulating, irregular-shaped individuals and small, sometimes granoblastic grains. Liquid inclusions are rather common, and as a rule assembled to strings, similar to necklaces.

As inferior minerals *biotite* and *common green hornblende* ($2\,V_\gamma$ and $c:\gamma$ in two slides = 104° and 111° 1/3, resp. 16° 1/2 and about 10°) are met with. These minerals most frequently display a lepidoblastic development, and are elongated in the strike-and-dip direction of the gneiss-granites, thus making the parallel structure, or schistosity, visible. The pleochroic colours are the normal ones [colourless, or very pale yellow green (α)—deep olive green (β)—deep blue green (γ) within the amphibole, colourless or very pale yellowish (α)—dark green brown (β—γ) within the biotite]. Negative, green *penninite* was frequently observed as an alteration product of the biotite.

The following accessories were found: pale brownish—light brown—brown *titanite* ($2\,V_\gamma$ about 30°), sometimes as considerable crystals, *magnetite* (+ a little *ilmenite*), now and then *pyrite*, *epidote*, and *apatite* (small grains, frequently well-developed crystals; usually contained in the feldspar).

Into the porphyritic and banded gneiss-granites, seldom else, reddish—pink, fresh *microcline* enters as a second rate main to subordinate constituent. Its colour is due to the inclusion of minute *hematite* grains. In most cases it is perthitic. It forms single or assembled (= the »eyes» and bands), xenomorphic, frequently evidently interstitial and, consequently, late individuals.

Only two reliable remnants of gneiss-granite were observed within the ultra-basic gabbro massif. The larger of these remnants is situated in the SW corner of the amphibole eucrite E of Lake Hammarbysjön, the smaller one in the amphibole eucrite at the W shore of the peninsula of Djupstensholmen.

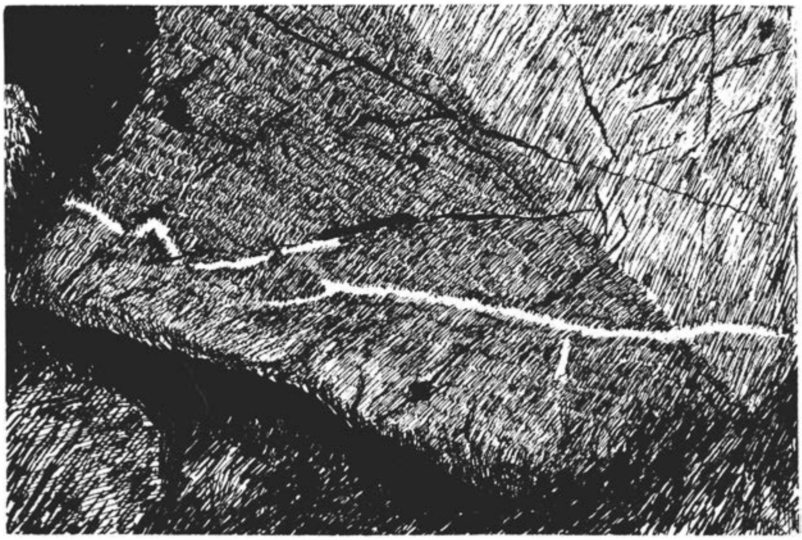

Fig. 23. Granitic materials penetrating hypersthene-eucrite (= dark gray) along a fissure. To the right gneiss-granite (= gray). Point 126, E of the N end of Lake Hammarbysjön. Scale 1 : $5\frac{1}{2}$. Drawn by W. PLAN after photo P. H. L. 1942.

The large remnant (measuring about $3\frac{1}{3} \times 2\frac{1}{5}$ yards = 3×2 m) is well-preserved, and consists of a common, medium-grained gneiss-granite. The small one is accompanied by a little pegmatite. It has become totally recrystallized, and now displays a fine-grained, most often granoblastic texture. The gray, parallel-structured rock resembles some leptite varieties very much. Most of it consists of plagioclase (An = 36 %, the three twins determined represented in the distribution reported above), usually to some extent altered to sericite and chlorite, sometimes talc. The plagioclase as a rule forms small grains, now and then porphyroblasts, too. A great many quartz xenoblasts, within the groundmass frequently gaining the position of a second-rate main mineral, some small flakes of negative, green penninite and of a beautifully brown-pleochroic biotite, together with accessoric epidote, magnetite, and rare amphibole complete the description. This rock coin-

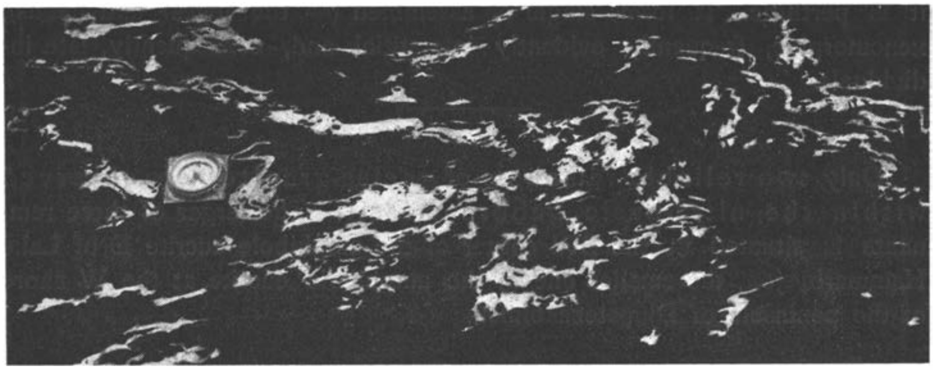

Fig. 24. Granitic segregations within amphibole eucrite. Photo-point IV, NE of Lake Hammarbysjön. P. H. L. 1942.

cides with the amphibole eucrite as regards the strike-and-dip direction of the parallel structure (banding within the gabbro!).

As is shown by Pl. XII, the gneiss-granites very often border directly upon ultra-basic gabbro, in general upon amphibole eucrite. At points 126 and 129 they face a hypersthene-eucrite, however. As an example of distinct boundaries between gneiss-granite and ultrabasic gabbro we will take point 129 (Fig. 23). Here the former rock was mobilized a little, probably after the intrusion of the gabbro, as the chief result of this mobilization giving rise to a small apophysis, penetrating the hypersthene-eucrite along an older fissure and after its consolidation distorded by a system of younger fissures tending towards N. Of course this apophysis does not stop at the boundary, but runs into the gneiss-granite along the fissure, too.

In Fig. 24 from photo-point IV (Pl. XII), the amphibole eucrite there occurrent is mixed up with much granitic materials, which run parallel to its winding and distorted banding as extended segregations.

VI. **The Younger and Youngest Dike Rocks of the Grovstanäs Region.**

Three types of dike rocks[1], evidently younger than the ultra-basic gabbro, occur in the Grovstanäs region. The most important of these are red, or frequently gray to reddish, fine-grained *granite-aplites* (»ga»-dikes in Pl. XII), and red, or sometimes grayish to reddish white *pegmatites* (»p»-dikes in Pl. XII). By far more seldom green black to black, fine-grained, now and then aphanitic, *younger amphibolites* (»a»-dikes in Pl. XII) appear. Most of the dikes now mentioned tend to follow the gneiss-granite strike direction.

[1] Methodological remarks, see ch. III: o!

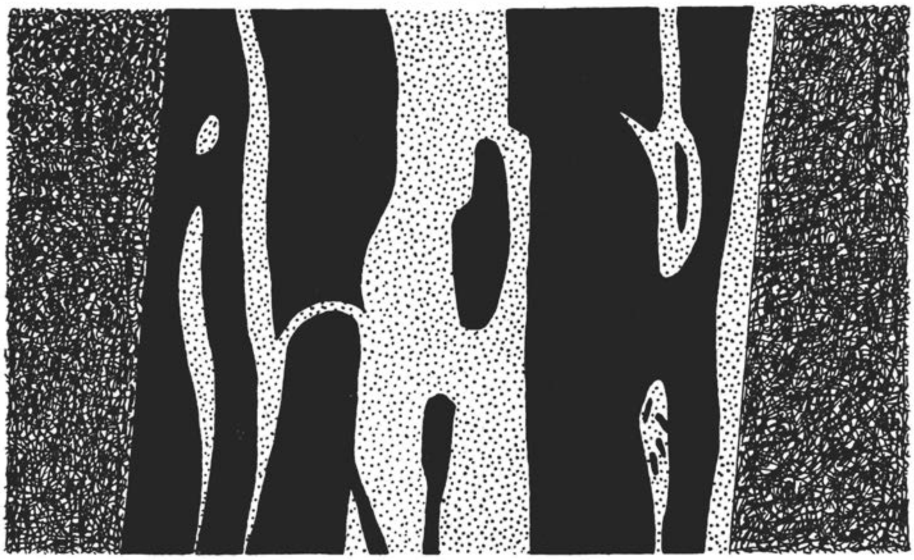

Fig. 25. Composite dike: granite-aplite brecciating younger amphibolite (= black). From the amphibole eucrite of the little peninsula N of NW Bergsö (point 102). Scale 1 : 11. Drawn by P. H. L. 1942.

Rarely, for inst. at point 102 in Pl. XII (Fig. 25), the gray granite-aplite was seen to brecciate the younger amphibolite (»ga. a»-dikes in Pl. XII), thus proving the latter rock to be older than the former. In a few other cases dikes, composed of a central amphibolite and a marginal pegmatite (»p. a»- and »a. p»-dikes in Pl. XII), were observed. The pegmatite is there in part accompanied by granite-aplite (»a. p. ga»-dikes in Pl. XII).

Very seldom pegmatite dikes cut off granite-aplite ones (in the isle of Fjällholmen, for inst.). This fact of course depends on the tendency of most dikes to run parallel to the general strike-and-dip direction within the area (except for the gabbro banding). But there may be still another reason. Within the Grovstanäs region we can distinguish between two types of granite-aplites, one red, or sometimes gray—reddish, aplite-granitic rock, closely related to the gneiss-granites, in which it may frequently occur as bands (see ch. V: 2 !), and one red to gray, granite-aplitic to aplitic rock, intimately connected with pegmatite, with which it may alternate[1], or for which it may exchange in one and the same dike (»p. ga»-dikes with prevalent »ga» and »ga. p»-dikes with predominant »p» in Pl. XII).

In rare cases the salic dike rocks brecciate the ultra-basic gabbro.

[1] Central pegmatite and margins of aplite, central aplite and margins of pegmatite, or, but more seldom, segregations of the one rock within the other.

Du Rietz (1929), in his Rådmansö study, has reproduced a beautiful photo displaying this phenomenon (Fig. 1, p. 479). According to Du Rietz, »the granodiorite is seen to brecciate the gabbro». Of course this observation may be right, but then we have to deal with a mobilized granodiorite of the same type as was touched upon in chapter V: 2.

The oldest of the young dike rocks, the *amphibolite*, exhibits a completely granoblastic rock with a fresh *plagioclase* (An = 60—65 % in sp. 17 from the isle of Bergsö, according to Nikitin's (1933) curves ⊥ RhS and [010]) and a *common green hornblende* with normal pleochroism, $2\,V_{\gamma}$ = about 100°, and $c:\gamma = 16°$ (sp. 17). *Quartz* frequently occurs as an inferior mineral. Accessoric *ore*, *calcite*, and, only sometimes, *apatite*, complete the picture.

The *granite-aplites*, the fine-grained, salic dike-rocks by far most common, show xenomorphous, in part sugar-grained rocks, frequently parallel-structured. They consist of three main minerals, all salic, i. e. *quartz*, *microcline*, and *plagioclase* (andesine). The microcline as a rule exhibits a fresh appearance, the andesine, on the contrary, is always more or less altered to minute *sericite* grains or flakes (seldom accompanied by *pennite*, *clinozoisite*, and *epidote*). More striking than the change, however, is the impregnation with rounded *hematite* particles, never lacking in the reddish—red varieties, and there being not only intra-granular, but interstitial, too. Of the most important mafic minerals present, negative green *penninite* is to be regarded as an inferior constituent, and *biotite*, *sericite* (muscovite), and *amphibole* as accessories. Other accessories met with are *pyrite*, *magnetite* (accompanied by some *ilmenite*), *calcite*, and *apatite*.

The andesine contains 33—41 % An, according to the plottings of poles ⊥ (010) against Nikitin's (1933) curve (Fig. 26 A, filled circles). These values and the positions of the poles ⊥ (010) bear close resemblance to the corresponding properties of the andesine of the gneiss-granites (disregarded from the former andesine being a trifle more acid than the latter). The distribution of twins is quite a different one, however, displaying 6 albite-Esterels. The relation between the gneiss-granites and the aplite-granites must be a rather intimite one, as the latter rocks do not only occur as bands within the former, but sometimes also as winding, elongated inclusions, small »lenses», and brecciating intrusions. Gradations also exist, though they are rare (in the SE islet of Måsskären, for inst.).

The *pegmatites* of the Grovstanäs region should be divided into three groups: 1. *Pink microcline-quartz*-(biotite) *pegmatite*, 2. *White* to *pink microcline-oligoclase-quartz-biotite pegmatite*, and 3. *White* to *grayish white oligoclase-quartz-biotite pegmatite*. The biotite does never form more than an inferior constituent. The first group is by far most common, the second one will only seldom be met with, and the third one confines to a few localities, the most important of which is situated in the largest pegmatite dike of the area, there forming an outcrop straightly S of the E end of Lake Båtdragsträsket (point 45). Within the pegmatite of this outcrop grains of a macroscopically black *allanite* occur as an accessory (to be described in another paper).

VII. The Grovstanäs Region: A General Survey.

1. Mineralogy.

At first, the pronouncedly xenomorphic character of most of the mineral grains contained within the Grovstanäs rocks must be pointed out. In fact, only the hypersthene-eucrites (= ultra-basic norites) do exhibit any considerable degree of hypidiomorphism.

A. The *plagioclase* of the ultra-basic gabbros is most often xenomorphic, but now and then it may become hypidiomorphic. A marked poorness in K_2O characterizes it (see LUNDEGÅRDH 1941, Table I, p. 416!). As a rule the alteration is slight, having given as its chief result sericite and clinozoisite (minute grains, flakes e. d.). $2V_\gamma$ varies between $99° \frac{1}{2}$—$104° \frac{1}{4}$ in chemically practically equivalent plagioclase (An = 87—90 %, N = 20).

As to the frequency of twinning laws (Table 27), there is at first

Table 27. Frequency of plagioclase twins as found from the ultra-basic gabbros of the Grovstanäs massif.

Twinning laws	Anorthosites (except Bönskär). An = 88—89 %	Allivalites, ol-eucrites. An = 88—89 %	Amphibole eucrites, fine medium- to medium-grained. An = 89—90 %	Eucrites. An = 88—89 %	Hypersthene-eucrites. An = 86—87 %	Amphibole eucrites, fine medium- to fine-grained. An = 86—87 %	Σ
Albite	12	35	34[1]	6	28	21	136
Pericline . .		10	13[2]		3	6	32
Carlsbad . .		4	2		3	3	12
Albite-Carlsbad		2	2	1	1	6	12
Manebach-pericline . . .						2	2
Manebach . .					1		1
Σ	12	51	51	7	36	38	195

[1—2] Including one single twin from the Mellingeholm amphibole eucrite (point 2 in Fig. 2), the properties of which are represented in Tables 15—17 (1), Figs. 26—27 (1), and 28—29 (2).

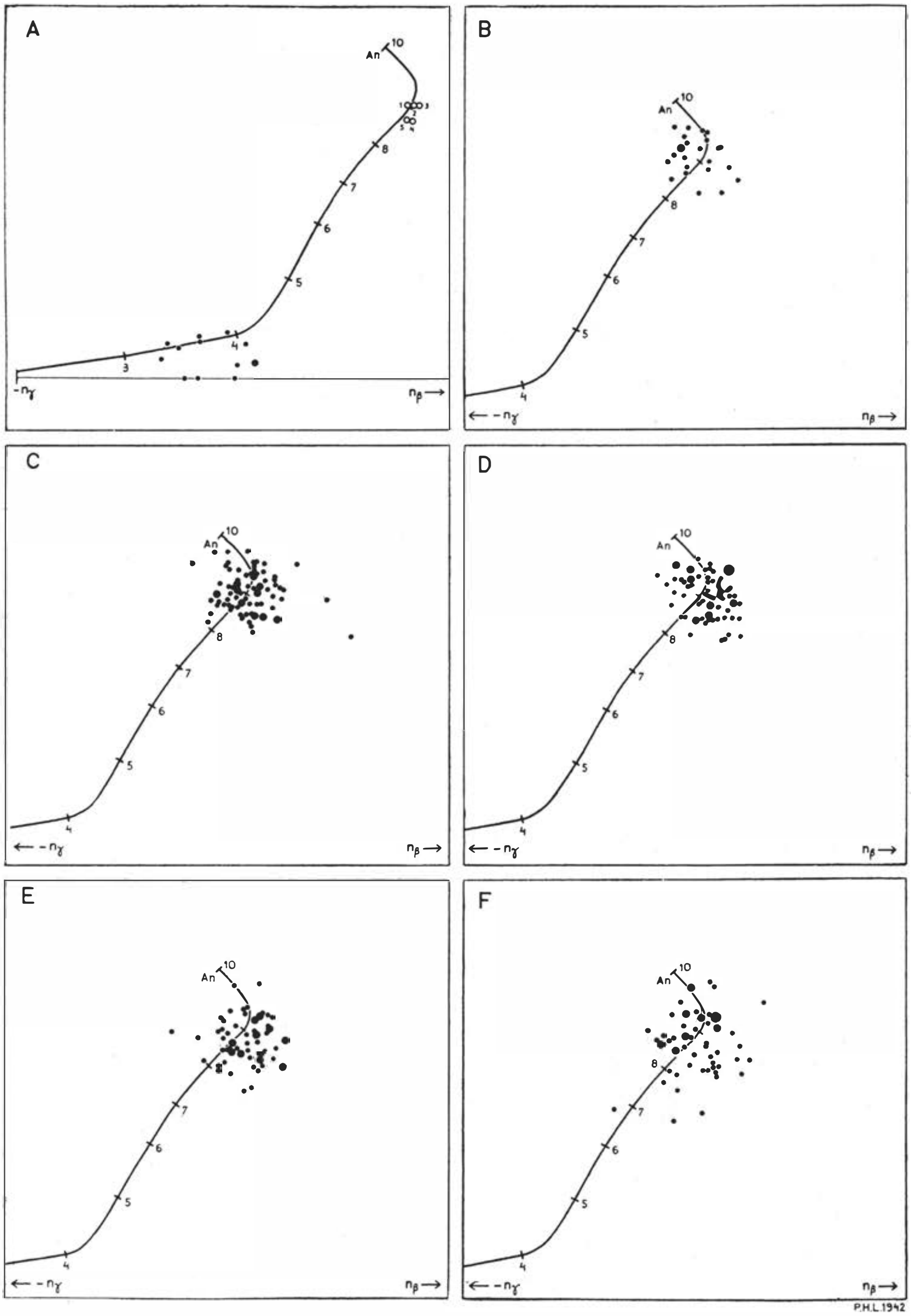

Fig. 26. A. The poles representing the mean coordinates of $\perp$ (010) of several plagioclase twins of 1. the anorthosites (excl. that of Bönskär), 2. the allivalites and olivine-eucrites, 3. the fine medium- to medium-grained amphibole eucrites, 4. the hypersthene

to notice the huge relative number of albite twins, and then the close resemblance between the distributions of the allivalite- + olivine-eucrite plagioclase twins on one side and the fine medium- to medium-grained amphibole eucrite plagioclase twins on the other side. The relationship suggested by this fact gains further support, when we look at Fig. 26 A. Here the open circle 2 = the mean pole ⊥ (010) of the allivalite- + olivine-eucrite plagioclase twins, and the open circle 3 = the corresponding pole of the fine medium- to medium-grained amphibole eucrite plagioclase twins, touch upon each other.

A comparison between the analogous characteristics of the hypersthene-eucrites (the open circle 4 in Fig. 26 A) and the fine medium- to fine-grained amphibole eucrites (the open circle 5 in Fig. 26 A) gives reason for the assumption of a relationship there, too. The indications are not so pronouncedly marked out, however, because of the obvious differences displayed by Table 27. But Fig. 26 A supports our conception very well, in fact.

All measured plagioclase poles ⊥ (010) of the ultra-basic gabbros are represented in Fig. 27 (filled circles), together with the ⊥ (010) poles of the eucrites being a combination of the distributions shown by Figs. 26. Here we meet the measured ⊥ (010) poles of the quartz-gabbros, quartz-diorites, older amphibolites (open circles), and gneiss-granites (filled circles), too. The positions of all these poles agree very well with the situation of the NIKITIN (1933) curve. As has been suggested earlier (LUNDEGÅRDH 1941, p. 429), NIKITIN has founded his curve upon determinations on high-temperature and high-pressure plagioclase (most often from deep-seated rocks).

W. LARSSON (1940, Fig. 46, p. 364) has plotted a great many ⊥ (010) poles of plagioclase twins of a) volcanics from the Andes, b) rocks of the Nygård plutone, and c) hyperites from W Sweden, against the NIKITIN curve. Beautiful agreement is displayed by b) and c), while the more acid part of the plagioclase of a) shows a pronounced eccentricity towards n_β.

The ⊥ (010) poles of the granite-aplites (Fig. 26 A) seem to suggest a slight tendency of assembling below the acid part of the NIKITIN curve, i. e. they exhibit higher values of the n_α-coordinate than the corresponding

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eucrites, 5. the fine medium- to fine-grained amphibole eucrites (all = open circles), and the ⊥ (010) poles of a few plag. twins of the granite-aplites (filled circles, N = 12). B. The ⊥ (010) poles of several plag. twins of the anorthosites (excl. that of Bönskär; N = 24). C. The corresponding poles of the allivalites and olivine-eucrites (N = 82). D. The corresp. poles of the fine medium- to medium-grained amphibole eucrites (N = 75). E. The corresp. poles of the hypersthene-eucrites (with ol-hyp.-eucrites; N = 64). F. The corresp. poles of the fine medium- to fine-grained amphibole eucrites (N = 60). Expls. necessary, see Fig. 27!

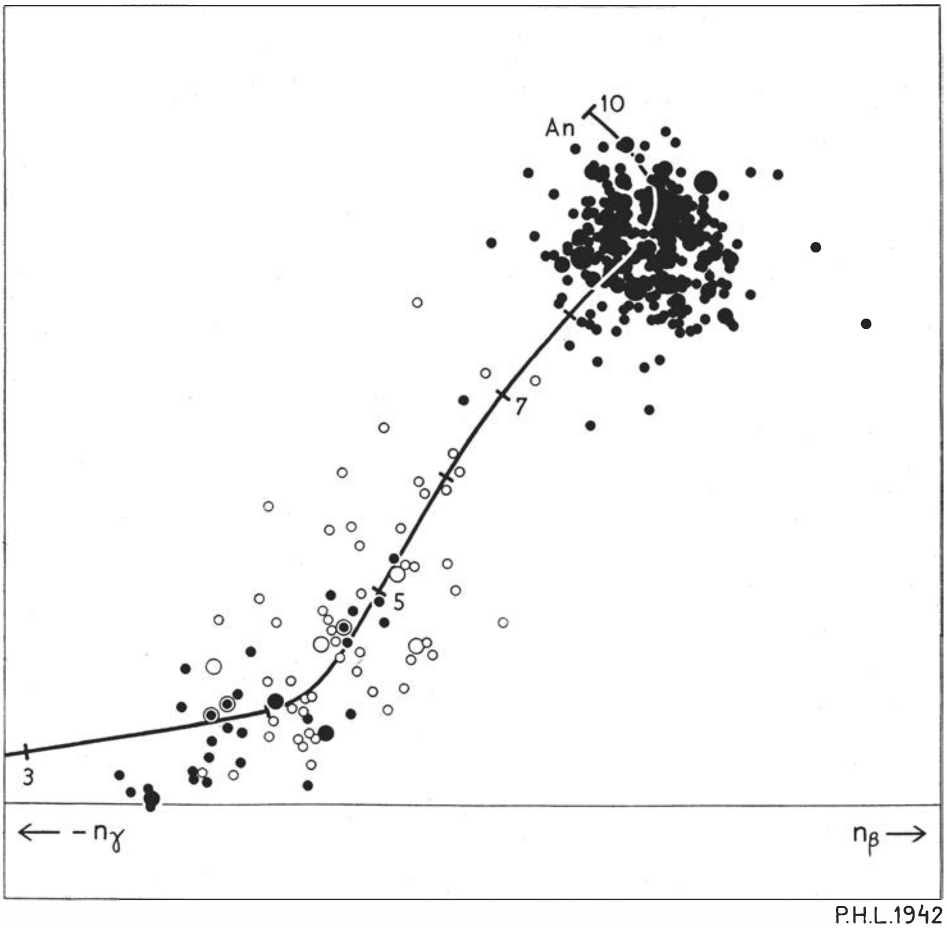


Fig. 27. All poles ⊥ (010) measured on the plagioclase twins of the gneiss-granites (filled circles; N = 34), border rocks (incl. older amphibolites; open circles; N = 64), and ultra-basic gabbros (filled circles; N = 319). Small circles = 1 pole, medium circles = 2 poles, large circles ≧ 3 poles. ◉ = 1 gneiss-granite pole + 1 border rock pole. The poles are plotted against NIKITIN's curve of 1933, in this Fig. magnified 2 ×.

points of the NIKITIN curve. As a whole, they almost coincide with the situations of ⊥ (010) poles of the gneiss-granites, as was mentioned in ch. VI.

The poles ⊥ RhS and the twinning axes [010], as found from the ultra-basic pericline twins, are plotted against NIKITIN's (1933) curves in Figs. 28—29. The positions of the latter scatter well around NIKITIN's curve [010], the situations of the former, however, assemble around a center at a larger distance from n_β than NIKITIN's curve ⊥ RhS. In that they agree with the corresponding poles of the Bönskär bytownite (LUNDEGÅRDH 1941, Fig. 2, p. 426).

As regards the plagioclase individuals within the anorthosites and

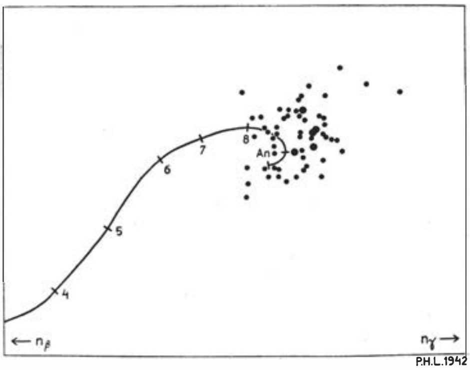


Fig. 28. The ⊥ RhS poles of several plagioclase twins of the ultra-basic gabbros (N = 63). Expls. necessary, see Fig. 27!

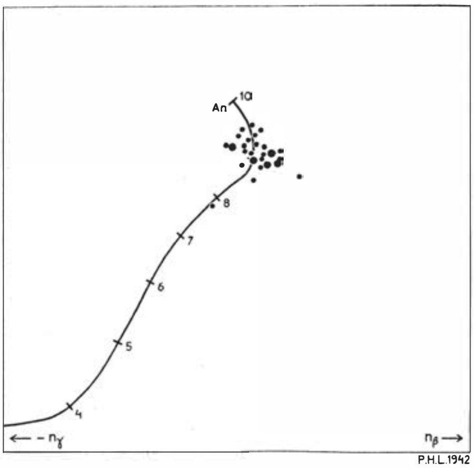


Fig. 29. The [010] twinning axes of several plagioclase twins of the ultra-basic gabbros (N = 32). Expls. necessary, see Fig. 27!

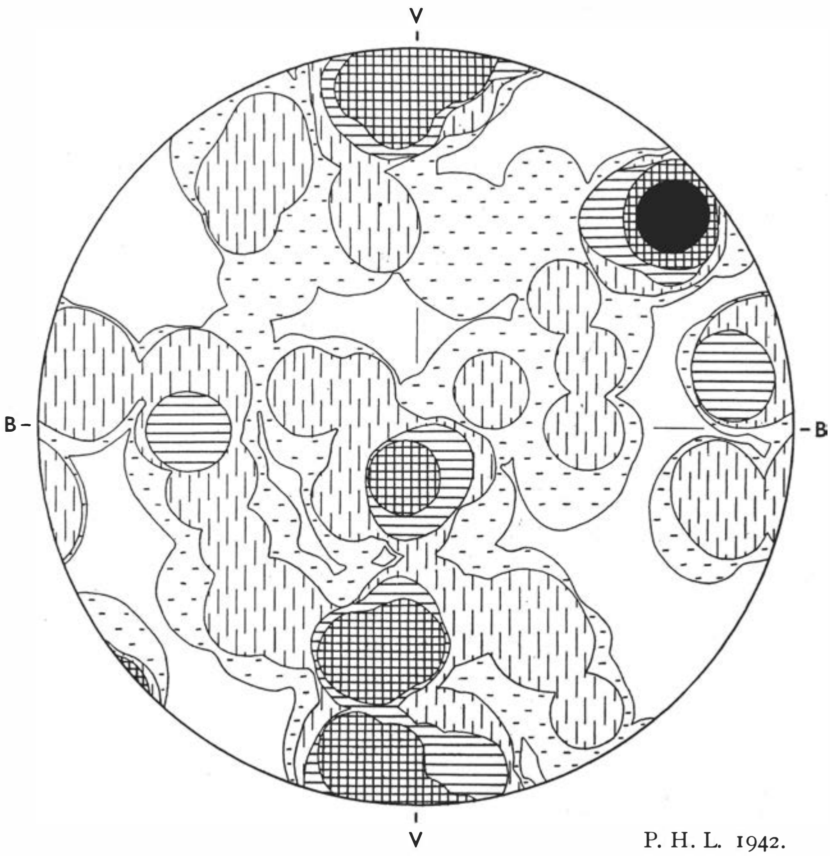
anorthositic bands, their lack of distinct orientation (non-orientation) has already been mentioned in connection with the description of the anorthosites (ch. III: 1). An investigation as to the orientation of 100 poles ⊥ (010) evidently exhibits this fact (Fig. 30 = »Regelung»[1] within an anorthosite band of the olivine-eucrite at point 10, from the shore WSW of the isle of Dåderholmen).

In a few cases needle-shaped ore microlites were observed. They appear in two directions, at an angle of almost 90°. SVEDMARK (1885), too, reports the existence of similar microlites within the plagioclase of the Rådmansö gabbros.

In the Grovstanäs region a red-pigmenting of the plagioclase may sometimes occur. This pigmenting very frequently intensifies close to fissures, thus indicating a migration of mobile Fe along these.

B. The *olivine* of the olivine-bearing ultra-basic gabbros is always surrounded by beautiful coronas, or reaction rims, and is always more or less altered inside these border zones. Coronas and interior alteration are similar to those reported from other gabbro occurrences. $2\,V_\gamma = 88$—$99^\circ\ ^1/_2$, giving 7—31.5 % Fe_2SiO_4, according to BACKLUND (1909). No distinction between the peridotite olivine and the allivalite + olivine-eucrite olivine can be traced, nor does the olivine-bearing hypersthene-eucrite (= ultra-basic olivine-norite) olivine deviate from the one just mentioned as to its character.

[1] Terminology and methods according to B. SANDER (1930).



P. H. L. 1942.

Fig. 30. Frequency of poles $\perp$ (010) of several plagioclase twins of an anorthosite band within olivine-eucrite no. 10, SW of the isle of Dåderholmen. B = the plane of banding, strike = N 5° W, dip = 52° W, V = the vertical plane, strike = N 85° E. 6—5—4—3—2 % (N = 100; stereographic projection).

C. The *diallage* of the ultra-basic gabbros is as a rule *diopsidic* or *augitic* ($2 V_\gamma = 59—61° \frac{1}{2}$, $c:\gamma = 38—45°$). Alteration to amphibole was always observed. The amphibole is in general = common green hornblende. In a few cases needle-shaped, orientated ore microlites are contained within the diallage. BRÖGGER (1931, p. 39) reports the presence of similar microlites within South-Norwegian larvikites and essexite-gabbros.

Now and then *pigeonite* appears, too ($c:\gamma = 28—34° \frac{1}{3}$). It is not only confined to the hypersthene-eucrites, as would be expected from earlier investigations as to the occurrence of this type of clinopyroxene within gabbros (W. WAHL 1906, pp. 64—65, 1908, p. 22; ASKLUND 1925, p. 17, and LARSSON 1935, p. 89, for inst.). On the contrary, it is met with almost as frequently in the olivine-eucrites and eucrites as in the hypersthene-eucrites. But, nowhere within these Grovstanäs rocks does it form more than an inferior constituent, and in most cases it is totally wanting.

D. The *hypersthene* of the ultra-basic gabbros displays an alteration similar to that of the diallage. Amphibole poor in Al_2O_3 was sometimes met with, however. Biotite does not frequently appear as an alteration product. The hypersthene is in part hypidiomorphic, thus differing from the remaining gabbro minerals, except plagioclase and hornblende. $2V_\gamma = 100—118°$ (hypersthene after olivine not included here!), giving 22—41.5 % $FeSiO_3$[1], according to WINCHELL (1933). Thus the hypersthene is as a rule richer in Fe than the olivine, the difference amounting to as much as 10—15 %.

According to recent investigators (N. L. BOWEN and J. F. SCHAIRER 1935), hypersthene is more probably a low-temperature mineral, converting into clinopyroxene on heating over 1100—1150°. In the Grovstanäs massif the hypersthene is always accompanied by a bytownite a trifle more acid (An = 86—87 %) than the common bytownite-anorthite (An = 88—90 %), a bytownite, strikingly fresh, and not seldom hypidiomorphic, too. Tables 4 and 9 show an obvious decrease in CaO and an increase in Na_2O from a typical allivalite to a typical hypersthene-eucrite.

One single occurrence of hypersthene-bearing border rock was observed (in the isle of Hornsholmen). Here the hypersthene forms a main constituent. Moreover, accidental »pseudomorphs» after hypersthene were found (amphibole, biotite, penninite) in a few thin sections.

E. The *common green hornblende* of the amphibole eucrites was in part shown to be evidently secondary, and the amphibole as a whole must not be considered to be primary, in spite of the occurrence of numerous individuals of a primary appearance. Too many remnants of pyroxene, appreciable or diminutive, bear evidence of an extensive alteration, having given as its result a facies in agreement with P. ESKOLA (BARTH 1939, p. 245) to be characterized by a lower formation temperature than the genuine gabbro facies. This »hornblende-gabbro facies» we meet almost everywhere within the Grovstanäs massif, as it is the result of an alteration of part of every gabbro type there present.

Alteration of the hornblende to penninite, rarely epidote, may sometimes be met with. The $2V_\gamma$-values were compared with the corresponding $c:\gamma$-values. No trend could be traced there. The correlation coefficient was calculated (according to G. U. YULE and M. G. KENDALL, 1940, p. 214). It does not deviate very much from O.

Orientated, most often needle-shaped ore microlites may sometimes occur. By far more common are included more or less irregular-shaped grains of ore, however.

[1] A. WEICH (1914, pp. 428—430) reports $FeSiO_3 = 23—44$ % within the hypersthene of various norites (N = 6, incl. one olivine-norite).

The hornblende of the rocks outside the boundaries of the ultra-basic gabbros in general displays a stronger pleochroism and higher $2V_\gamma$-values than the hornblende of the latter rocks. Its alteration is similar to that of the amphibole earlier touched upon.

F. The *biotite* and *quartz* of the ultra-basic gabbros as a rule confine to appear as accessories within or accidental constituents of some of the hypersthene- and amphibole eucrites situated in close proximity to the outside boundaries of the massif. The quartz especially seems to be evidently secondary, as it most often occurs as corrosive, interstitial grains, but the biotite, too, now and then bears evidence of being of a late origin.

The biotite of the remaining rocks of the region needs no explanation here, nor does the quartz. Certain significant data concerning their development and their relative age have already been reported in a few of the earlier chapters.

G. An important fact is connected with the contents of primary *ore* (*magnetite*, most often accompanied by a little *ilmenite*) of the ultra-basic gabbros. There is a striking lack of that component within the allivalites and olivine-eucrites, but, on the contrary, the hypersthene-eucrites are as a rule rich in it. P. GEIJER (1931, p. 89), from the Kiruna—Gällivare—Pajala region, reports similar circumstances within the corresponding, though more acid, gabbros (olivine-gabbros and norites) there occurrent.

H. As to the accessories, the appearance of *apatite* must be touched upon a little here. In general there is a total lack of this mineral within the ultra-basic gabbros, while it emerges in most of the remaining rocks of the region. The hypersthene-eucrites, however, are rather rich in apatite, when compared with the ultra-basic gabbros as a whole. GEIJER (1931, p. 89), too, from the area just mentioned, points out the pyroxene gabbros being pronouncedly richer in apatite than the olivine-gabbros.

2. Structures.

As is shown by Pl. XIII, the banding of the ultra-basic gabbros is as common as to have permitted strike-and-dip measurements all over the massif. Only a few small areas were furnished with a very restricted number of determinations, due to an extensive covering by postglacial sediments, or to their exhibiting no or solely rare banded outcrops.

A single glance upon the Grovstanäs massif (Pl. XIII) shows that it tends to follow the parallel structure of the gneiss-granites rather well. Interruptions and deformations of the latter rocks we find now and then, however, for inst. SSE of the NE corner of the massif, immediately E of the peninsula of Litslö, in the S half of the isle of Fjällholmen, and near to the rock boundary E of Lake Hammarbysjön.

The highest dips of the Grovstanäs massif were found within the N and E parts (especially the N one) of the N massif-half. The pronouncedly low dips within the SW part of the N massif-half (the isle of Bergsö and the area NW—W-wards from there) must also be paid attention to. The narrow protuberance towards W, bordering upon Lake Hammarbysjön, follows the gneiss-granite strike-and-dip direction extremely well. A look at the petrological map (Pl. XII) indicates that most of the amphibole eucrites of the massif have assembled to its NW parts, i. e. to the area just touched upon.

The S massif-half exhibits a tongue-shaped protuberance towards W, following the gneiss-granite strike-and-dip direction well. This protuberance, tending as far as to the N shore of the isle of Fjällholmen, is also suggested very well by the structures. Moreover, the structures indicate the presence of a basin immediately W of the isles of Tjuvholmen and Träffsholmen. This presumed, kidney-shaped structural depression must towards N begin immediately W—WNW of the islet of Bönskär. In S it seems to end at or in the bay S—SSW of the isle of Träffsholmen. Towards W its border perhaps passes the islet of Fjärdgrundet. Around and probably also within it, the widest mafic and salic bands and »lenses» found in the Grovstanäs massif are present. Elsewhere no massive anorthosites and peridotites of any importance were observed.

As a whole, the S part of the Grovstanäs massif looks like a section through a vertical, rather irregular-shaped »fish» or »lens», with its tips towards E and W, and connected with the SE corner or the N massif-half along a short line from a point situated between the islets of Kråkholmen and Bönskär, and to a point ENE of the E cape of Bönskär (Fig. 2). If we assume this connection line to be due to a disintegration of a ancient thin wall of older rocks (a presumption not yet proved, however), and thus divide the Grovstanäs massif into two separate bodies, we get the existence of the following peculiarities explained: 1. The odd amphibolite building up the S cape of the peninsula of Djupstensholmen (described in ch. III: 7), 2. the well-preserved leptite remnant of the islet of Bönskär (ch. V: 1), and 3. the altered gneiss-granite remnant on the W shore of the peninsula of Djupstensholmen (ch. V: 2).

Finally, we will draw attention to two important facts: 1. The chief part of the granite-aplites has assembled NE—E of the massif, and 2. the largest pegmatite dike penetrates the massif from the E boundary. As to the pegmatites we might add, that these rocks seem to be more commonly met with inside the massif than outside it.

Further interpretations as to the origin of, and further conclusions drawn upon the situation of the Grovstanäs massif will not be justified, until the whole of the gneiss-granite area of Central Roslagen has got explored. We have proved the ultra-basic gabbro to be younger than its environments[1] (except for the dike rocks), but we can say nothing about the regional circumstances.

The gabbro banding of the Grovstanäs massif, the general behaviour of which was described now, is as a rule of a small range, produced by a tendency of the plagioclase individuals to assemble to felsic sheets, forming thin shells, approximately conformous with the surface of the gabbro body. Facing these felsic shells we meet mafic ones. The banding is most often only faintly curved or winding, but now and then a more intricate development occurs: 1. Local distortions (part of the outcrop shown by Fig. 3), and 2. mafic »fishes» or »lenses» (Fig. 10), in a few cases surrounded by a local, concentric banding (Fig. 10). In the SE part of the massif we meet the huge anorthosite and peridotite bands and »lenses» already touched upon.

An interesting fact to be repeated here is formed by the gneiss-granite remnant from the W shore of the peninsula of Djupstensholmen. This remnant exhibits an evidently secondary recrystallization, and a parallel structure, as to its orientation coincident with the banding of the surrounding gabbro. No chemical changes were traced within it, however.

In a few outcrops a rare granodiorite banding was discovered. A beautiful example of this banding, which is always a mafic one, was met with at photo-point II (NE of Lake Hammarbysjön in Pl. XII). The two bands there present do not exceed $^4/_5$ yards ($^3/_4$ m) in length. They consist of common green hornblende, accompanied by some biotite, and run approximately parallel to the border line of the gabbro body, and to the strike direction of the gneiss-granites within this part of the Grovstanäs region.

W. LARSSON (1935) was the first investigator to describe a Swedish gabbro intrusion as a plutone. His Nygård plutone in part shows a concentric, semicircular banding of a type similar to that of the Grovstanäs massif. LARSSON assumes his banding to be due to a differentiation, combined with a floating. He founds his presumption i. a. on investigations as to the orientation of the plagioclase of an anorthosite

[1] According to DU RIETZ (1929, pp. 531—532), the ultra-basic gabbros of Rådmansö, and, consequently, those of the Grovstanäs massif, too, were effected by a differentiation of the same magma that later gave rise to the Roslagen gneiss-granites (with local granodiorites). The author is forced to decline this hypothesis, however, as he has not been able to find any supports of it.

band within a norite, an orientation, which must be considered as excellent. As the banded Grovstanäs gabbros have failed to show any orientation of their plagioclase, we can hardly apply LARSSON's explanation to them. Yet no probable explanation of the reason for this plagioclase having clung together to form shells can be given, for, in fact, a gravitative differentiation does not seem to be able to account for it.

3. Petrology.

The ultra-basic gabbro masses of Central Roslagen, and among them the Grovstanäs massif, have gained an extraordinary position among basite occurrences of different ages in various parts of the world. The reason for this is their low percentage of SiO_2 in spite of the fact that they are not extremely mafic. Scarcely no one of the numerous, more or less extensive basalt and gabbro areas, up to date described in the literature, does exhibit as high a percentage of An of their plagioclase as 86—90 %, and a total amount of SiO_2 not exceeding 42 % in their normal types of rocks. Moreover, the Grovstanäs anorthosite does contain only about 45 % SiO_2 (LUNDEGÅRDH 1941, Table I, p. 416).

A look at Table 28 makes the extreme position of the Roslagen ultra-basic gabbros more prominent. Only the Mellingeholm amphibole eucrite, building up a very small mass, does break the homogenity, as regards the contents of SiO_2. Of a certain interest is the pronounced similarity between the former rocks and the Bergen olivine-gabbro. When taking the Caledonian gabbros, shown by Table 28, as a whole, we can trace no resemblance, however. The mean NIGGLI values are as follows:

	The Roslagen ultra-basic gabbros (N=4)	Caledonian gabbros (N=5)	Basaltic lava, Skjaldbreið, Iceland (N=6)
al	27.1	18.0	18.0
fm	39.2	51.1	49.0
c	31.2	24.1	28.7
alk	2.5	6.9	4.1

Finally, we shall throw a glance upon the various ultra-basic gabbros of the Grovstanäs massif as to their division. The data reported in this paper have given rise to the following classification (from oldest to youngest. downwards and to the right):

Table 28. The NIGGLI values of a few of the Roslagen ultra-basic gabbros, compared with the corresponding values of several other basites.

NIGGLI values	Allivalite (sp. 52), the Grovstanäs massif	Hypersthene-eucrite (sp. 103), the Grovstanäs massif	Amphibole eucrite (no. 2 in Fig. 2), Mellingeholm	Allivalite (DU RIETZ 1929, p. 507), the Rådmansö massif	Normal norite S. FOSLIE 1920, p. 21), the Raana norite field	Olivine-gabbro (N=2, C. F. KOLDERUP 1903, p. 99), the Bergen region	Gabbro-norite (KOLDERUP 1903, p. 90), the Bergen region	Normal olivine-gabbro (TH. VOGT 1927, p. 294), Sulitelma	Basaltic lava (N=6, T. TRYGGVASON 1943), Skjaldbreið, Iceland	Allivalite[1] (HARKER 1908, p. 80), major intrusion, Allival, Rum	Eucrite[1] (HARKER 1908, p. 98), major intrusion, Allt Mòr na h-Uamha, Rum	Massive amphibolite (no. 1 in Fig. 2), Gruvudden, Limmaren
qz=	−24.6	−31.1	−2.7	−18.6	−5.0	−31.4	−48.8	−25.3	−15.1	−35.7	−12.4	−35.5
al=	31.0	18.6	27.3	31.5	12.4	22.4	14.1	23.0	18.0	17.7	18.6	25.5
fm=	35.5	48.9	35.4	36.8	71.5	37.2	53.3	42.4	49.0	62.8	54.5	44.7
c=	30.9	29.3	34.2	30.5	13.2	35.2	20.1	27.7	28.7	17.6	24.2	23.4
alk=	2.6	3.1	3.1	1.1	2.9	5.2	12.6	7.0	4.1	2.0	2.7	6.3
si=	85.8	81.3	109.7	85.8	106.6	89.4	101.6	102.7	101.3	72.3	98.4	89.7
ti=	0.18	2.2	1.6	—	1.0	0.3	0.9	0.38	3.2	0.14	0.95	3.9
p=	0.18[2]	0.37[2]	0.18	—	0.05	0.3	1.3	0.0	0.17	0.0	0.0	0.33
k=	0.29	0.11	0.30	0.11	0.25	0.16	0.31	0.05	0.12	0.06	0.09	0.42

[1] Tertiary rocks closely related to plateau basalts.
[2] These values do not seem to be representative (compare Tables 4 and 9!).

A. GABBROS, ASSUMED TO BE PRIMARY:	C. GABBROS, UNCLEAR AS TO THEIR POSITION:	B. METAGABBROS:
1. *Anorthosites*		
2. *Allivalites*		
3. *Olivine-eucrites*	7 a. *Hornblende-eucrites* (fine medium- to medium-grained)	*Uralite-eucrites*
4. *Peridotites*	8. *Hornblendites*	*Davainites* (only as bands)
5. *Eucrites*		
6. *Hypersthene-eucrites* (norites)	7 b. *Hornblende-eucrites* (fine medium- to fine-grained)	*Uralite-eucrites*

4. Orography and joints.

In his orographic studies on Roslagen, SVEDMARK mentions three main directions of joints (1887, p. 189), easily traced as valleys in almost every map of this region. The NE—SW valleys he assumes to be oldest (1887, p. 206), and in that he seems to be quite right, as they most frequently follow the gneiss-granite strike direction. To the E—W valleys he fails to give any fixed position (1887, p. 206). These, however, now and then agree with the actual gneiss-granite strike direction, too. As the youngest system of the area he classes the NNW—SSE and NW—SE valleys (1887, p. 206).

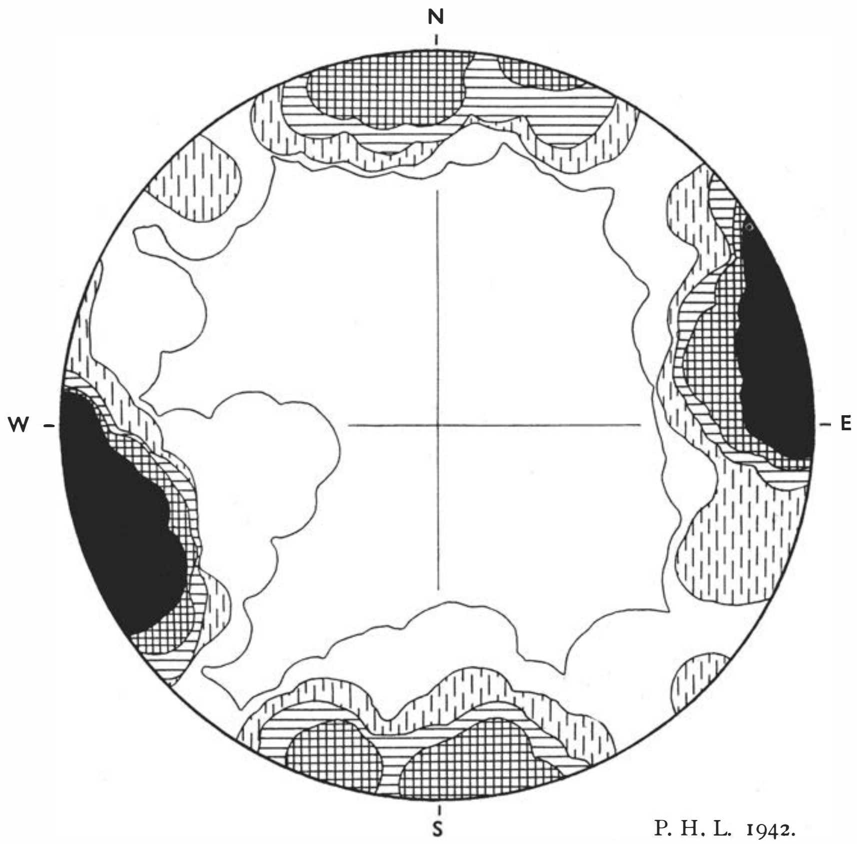
The lineament Lake Väsbysjön—Solö, in Fig. 2, shows an excellent E—W valley, the Mora—Österviken—Västerfjärden—(Räknö—Hemmarö) lineament indicates an ENE—WSW valley.

The directions of joints of the Grovstanäs region have clung together to form two maxima (Fig. 31), the most prominent of which is effected by the fissures (»major joints» according to F. LAHEE 1923, p. 226) running towards N—NNW. The second maximum contains the fissures tending towards E—W.

Most of the gabbro fissures are filled with *amphibole* (narrow zones, never exceeding $^1/_8$ inch = 3 mm), but several unfilled and a few *calcite*-filled joints (displaying a wideness amounting to $^2/_3$ inch = 16 mm in single cases) were observed, too. Rarely joints exhibiting other minerals, or *mylonite* zones, occur. The gneiss-granite fissures are as a rule unfilled. No difference of age was traced between the joints now reported.

NE of Lake Hammarbysjön (at photo-point V), within the amphibole eucrite, a small dike of aplite and pegmatite is cut off, and displaced by a »major joint».

The positions of joints of the Grovstanäs region suggest a MOHR system, produced by a stress having worked from NNE—NE or (and) from SSW—SW, i. e. at right angles to the acute bissectrix of



P. H. L. 1942.

Fig. 31. Frequency of joints within the Grovstanäs region. > 10—(9—8)—(7—6)—(5—4)—(3—2) poles (N = 143) = > 7—6—4.5—3.1—1.7 % (Stereographic projection).

the two mean planes of joints. If this conception is in accord with truth, secondary tensions must have effected the gaps now filled with amphibole and other minerals.

Of course the joints may have originated by means of tensions. This possibility, however, seems a little dubious because of the coincidence in age between the N—NNW and the E—W fissures.

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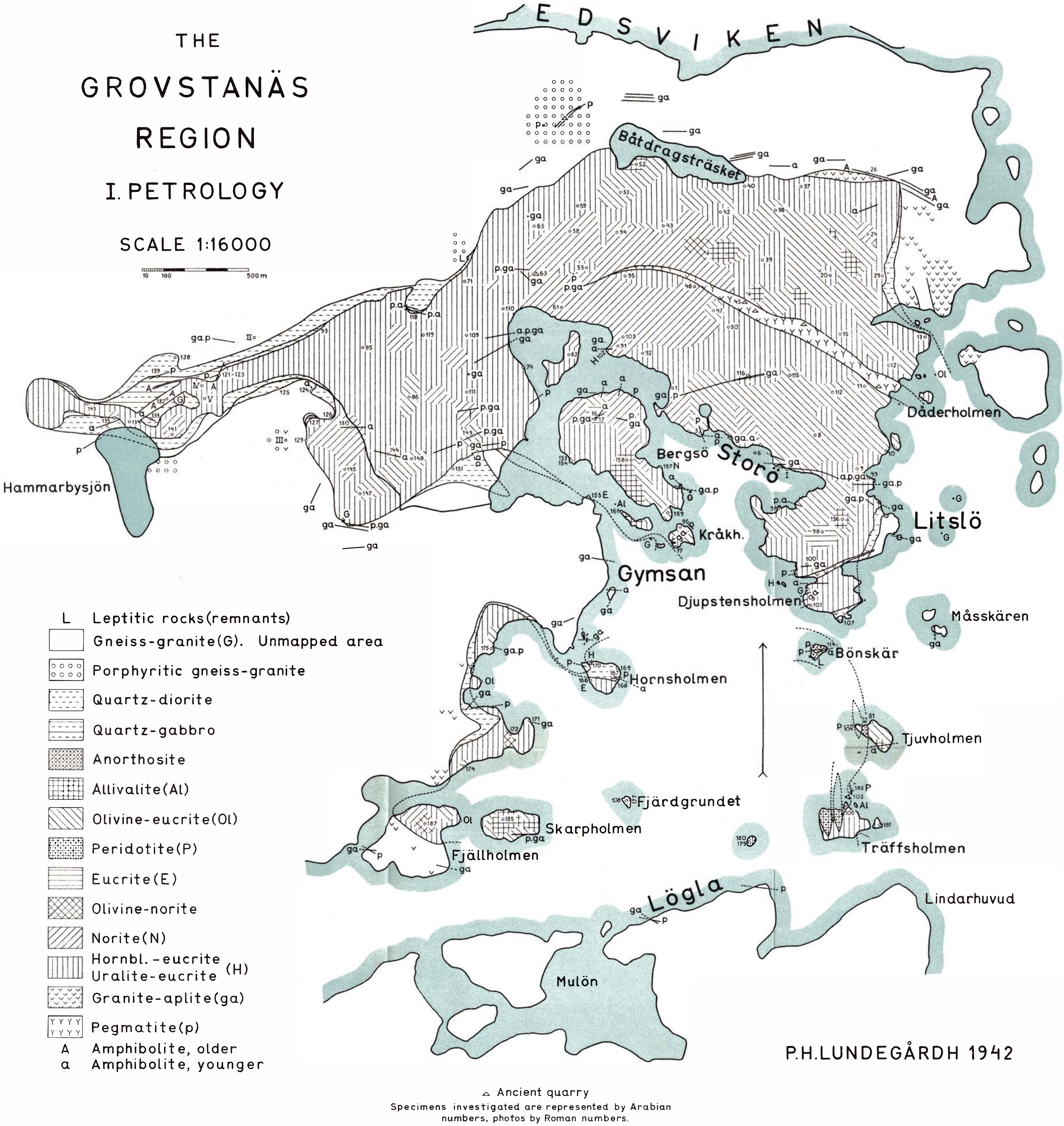
THE
GROVSTANÄS
REGION
I. PETROLOGY
SCALE 1:16000
500 m
EDSVIKEN
Båtdragsträsket
Hammarbysjön
Bergsö
Storö
Kråkh.
Gymsan
Djupstensholmen
Litslö
Däderholmen
Måsskären
Bönskär
Hornsholmen
Tjuvholmen
Fjärdgrundet
Skarpholmen
Fjällholmen
Träffsholmen
Lögla
Lindarhuvud
Mulön
L Leptitic rocks (remnants)
Gneiss-granite (G). Unmapped area
Porphyritic gneiss-granite
Quartz-diorite
Quartz-gabbro
Anorthosite
Allivalite (Al)
Olivine-eucrite (Ol)
Peridotite (P)
Eucrite (E)
Olivine-norite
Norite (N)
Hornbl.-eucrite
Uralite-eucrite (H)
Granite-aplite (ga)
Pegmatite (p)
A Amphibolite, older
a Amphibolite, younger
P. H. LUNDEGÅRDH 1942
Ancient quarry
Specimens investigated are represented by Arabian numbers, photos by Roman numbers.

The gabbro area (incl. quartz-diorite) is surrounded by a dotted line