

SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C

Avhandlingar och uppsatser

N:o 549

ÅRSBOK 50 (1956) N:o 5

THE TITANIFEROUS ORE-BEARING  
GABBRO OF HELSINGLAND  
CENTRAL SWEDEN

BY

PER H. LUNDEGÅRDH

*Pris 2 kronor*

STOCKHOLM 1957

KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER

573333

SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C

Avhandlingar och uppsatser

N:o 549

ÅRSBOK 50 (1956) N:o 5

THE TITANIFEROUS ORE-BEARING  
GABBRO OF HELSINGLAND,  
CENTRAL SWEDEN

BY

PER H. LUNDEGÅRDH

STOCKHOLM 1957

KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER

573333

## CONTENTS

Preface .....	3
General petrological survey of Central and Northern Helsingland .....	5
The titaniferous ore-bearing gabbro .....	15
Introduction .....	15
Structures, textures, and mineral composition .....	15
General .....	15
Davainitic gabbro (early gabbro) .....	19
Rich-ore gabbro (middle gabbro) .....	20
Late gabbro .....	24
Geochemical evidences .....	25
Petrographic parallels .....	32
Literature cited .....	33

### Preface

The present investigation of the titaniferous ore-bearing gabbro of Helsingland was entered upon in 1952. At that time, several magnetometric and chemico-analytical data were available, owing to investigations by, at first, Mine-inspector B. Kjellberg and, later on, the Kramsta Ltd (*AB*). Further, the ore-bearing gabbro of the Kramsta field had been penetrated by a number of diamond drill holes.

The results of Kjellberg's investigations have been published in *Teknisk Tidskrift*, Stockholm 1930, whereas the data collected by the Kramsta Ltd, under the leadership of the former Director of the company, A. L:son Alarik, are only available as a report produced by stencil in 1943 for private circulation. Thanks to the courtesy of the Kramsta Ltd and the Chief director of the Geological Survey of Sweden, Prof. N. H. Magnusson, formerly consulting geologist to the company, all data collected by the company have been placed at my disposal.

The maps published in this paper are new except for those showing the Kramsta field (Figs. 3<sup>1</sup> and 8), which have in part been taken from the Kramsta report of 1943. The orientations of the ore-bearing gabbro massifs are, however, different in Kjellberg's paper of 1930 and the Kramsta report of 1943.

The greatest concentration of titaniferous ore occurs in the Kramsta massif (Figs. 8—9). The horizontal long axis of this massif is in Kjellberg's map N. N. E., whereas it is E. N. E. in the map compiled by Alarik in the Kramsta report of 1943. Reconsiderations of the positions of certain topographical features, as well as a partial re-mapping made by one of my assistants, Mr G. Stålhös, have shown that the map compiled by Alarik is correct regarding its orientation.

<sup>1</sup> The Kramsta massif has here been marked with nos 1—2.

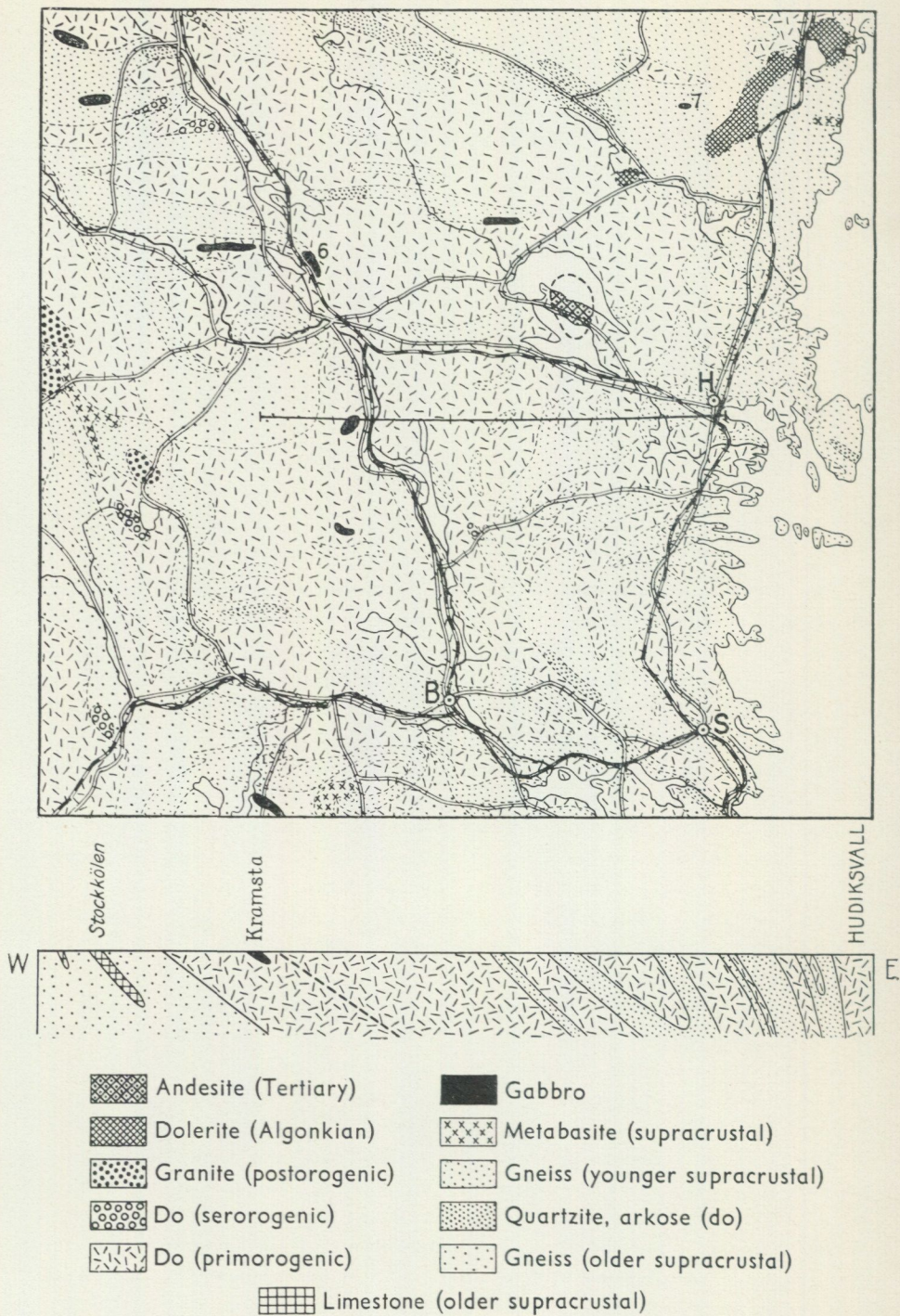


Fig. 1. Petrological map of Central and Northern Helsingland, scale 1 : 1,000,000, and a cross section along the line marked in the centre of the map. B = Bollnäs, H = Hudiksvall, S = Söderhamn. Map drawn by M. Ekman, cross section by G. Rimfors.

The new analytical data presented in this paper are in part chemical (analysts: Mr A. Aaremäe and Mrs A. Balder of the Chemical institution of the Geological Survey, head: Dr G. Assarsson) and in part spectrographic (analysts: the writer when visiting the Institute of plant physiology at the Royal Agricultural College of Sweden and, further, assistants of the Geochemical institute of the Geological Survey under the supervision of its chief, Dr S. Landergren). The analyses of gabbro from the Kramsta and Gartsbo massifs have been executed on local or total general samples (Swedish *knackprov* and *generalprov*), whereas the remaining analyses have been carried out on matter derived from a restricted number of hand specimens (3—5).

In the following text it would have seemed convenient to re-introduce the old term *hyperite* for the plagioclase-hypersthene-clinopyroxene gabbro of Helsingland as once proposed by L. J. Igelström (1883, p. 319 ff.), especially in view of the mode of occurrence of the rock mentioned. (See the following text.) Moreover the terminology would have then been put in conformity with the wide-spread petrographic nomenclature interpreting hyperite as a rock intermediate between common gabbro and norite. (Compare, *inter alia*, E. Wm. Heinrich 1956, p. 74.) In view of the old definition as originally given by A. E. Törnebohm (1877, p. 35), viz. a gabbroic rock composed chiefly of plagioclase, augite, hypersthene, olivine, and titaniferous oxidic ore, as well as of the later Swedish and exclusively national application to a number of mostly olivine-bearing, effusive and hypabyssal, doleritic rocks in Southern Sweden, I have, however, hesitated about the advisability of doing so. (For further information regarding the variable use of the term hyperite, see S. Hjelmqvist, 1950.)

In part of the Helsingland norite, *inter alia* that of the Kramsta massif, the anorthite percentage of the plagioclase is as low (38—42 %) as to actualize the use of the term meladiorite. Because the contents of  $\text{Na}_2\text{O}$  in the meladioritic varieties analysed with respect to their major elements (Table 1) have proved to be fairly moderate in comparison with the contents of  $\text{CaO}$ , I have decided to retain none the less the term norite.

For valuable discussions of data concerning the investigation thus presented, I am indebted to Prof. N. H. Magnusson, Dr J. Eklund, and Dr S. Landergren. In the field, I have been assisted by the following extra geologists: H. W. Lindholm, Th. Lundqvist, J. Sjöström, and G. Stålhös.

### General Petrological Survey of Central and Northern Helsingland

The Archean (Archaean) of Central and Northern Helsingland, Central Sweden (Fig. 1), consists mainly of sedimentary gneisses and porphyritic primorogenic granite. The former derive their origin from clay slates, arkoses, and quartzites. In the northernmost part of the province, the arkoses and quartzites are frequently well-preserved.

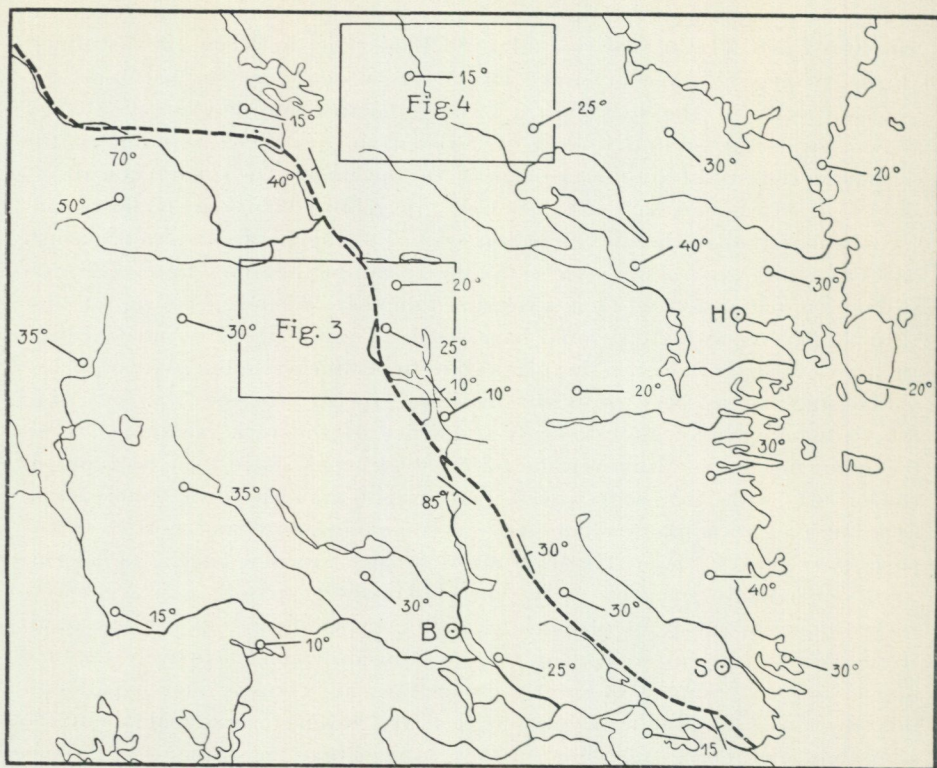


Fig. 2. Structural sketch map of Central and Northern Helsingland, also showing the positions of the areas mapped in Figs. 3—4. The thick broken line shows the position of the great fault zone. Plane and linear schistositities have been marked with conventional symbols. B = Bollnäs, H = Hudiksvall, S = Söderhamn. Scale 1 : 1,000,000. Drawn by G. Rimfors.

The sedimentary gneiss belongs to a supracrustal series also comprising basic effusives, *inter alia* meta-splites. (Compare P. H. Lundegårdh, 1956.) This series is underlain by rocks belonging to the iron ore—limestone-bearing leptite-hälleflint series, which has been interpreted as the oldest Archean supracrustal series known in Sweden, viz. oldest Svecofennian RAMSAY—WAHL—BACKLUND, or oldest Svionian SEDERHOLM—MAGNUSSON. (Compare W. Ramsay, 1909, W. Wahl, 1936, and H. G. Backlund, 1937; further J. J. Sederholm, 1920, and N. H. Magnusson, 1936.) It has therefore been classed as the younger supracrustal series of the region investigated. Still younger supracrustal rocks have been discovered in the Los-Hamra region, immediately outside the western border of Fig. 1 (H. von Eckermann, 1936).

In a previous paper (P. H. Lundegårdh, 1956) I have compared the younger supracrustal series with the Finnish Bothnian as redefined by A. Simonen (1953):

3. Synkinematic (primorogenic) Svecofennidic (Svecofennian) granites.

2. Bothnian (sedimentary rocks, intermediate and basic volcanics).
1. Svionian (sediments including limestone, and volcanics corresponding to the leptite-hällflint series in Sweden).

The Bothnian in South-Western Finland represents an eo-geosynclinal facies, however, whereas the younger supracrustal series of Helsingland (exclusive of the Los-Hamra region) is built up chiefly of differentiated sediments, viz. argillites and arenites. The former have undergone strong alteration and now mostly appear as a garnetiferous *schlieren*-gneiss, or veined gneiss, containing disseminated sulphide ore<sup>1</sup> and sometimes intimately associated with a serotogenic-palingenic *kakolite* granite<sup>2</sup> (cp. Anna Hietanen, 1947), whereas the arenites have now and then been preserved in a rather low-metamorphic condition. The central part of the boundary between Helsingland and the adjacent province in the north — Medelpad, is thus marked with a horizon of a tourmaline-bearing felspar quartzite accompanied by an arkose still retaining its original quartz gravel (though, of course, in a recrystallized state). Part of these rocks may be defined as grits. They frequently show graded bedding. The width of the horizon increases towards E. — E. S. E. The arenites have, however, there mostly altered to coarse, acid, granitic garnetiferous gneisses, primorogenic *kakolite* granites, and, locally, rocks with large microcline and cordierite porphyroblasts. (Compare the following text.)

The older supracrustal series does seldom contain garnetiferous rocks. It is dominated by leptites and leptite gneisses grading into veined gneisses, viz. metamorphic derivatives of intermediate and acid volcanics. The series further contains sparse tiny layers and boudins of limestone and sedimentary iron ore.

The primorogenic, or synkinematic, granite is for the most part porphyritic, viz. filled with coarse reddish microcline eyes which have sometimes been enclosed in thin shells of sodic plagioclase. A basic grey variety is also common. In Fig. 1 we observe a large central mass of granite with a lot of branches into the surrounding supracrustal rocks, the oldest of which are found in the west. A major boudin of limestone- and iron-ore-bearing rocks belonging to the older supracrustal series has there been observed. The primorogenic granite contains several minor massifs of the titaniferous gabbro described in this paper. (See also Figs. 3—4.) The massifs seem to have been once attached to each others so as to form a few extensive layered intrusions into those supracrustal rocks later to be exchanged for the primorogenic granite.

The *S*-plane structure of Central and Northern Helsingland as displayed by the map and cross section given in Fig. 1 has been developed by strong pre-granitic folding resulting in conformable differential movements within

<sup>1</sup> Simultaneously with the development of the primorogenic granite, the sulphide ore has locally assembled to strong impregnations, such as Flomyran in North-Westernmost Helsingland and part of the Bergsjö area in North-Eastern Helsingland.

<sup>2</sup> After Kakola, South-Western Finland. A secondary granite with regularly distributed patches of (biotite +) garnet and/or cordierite. The rock mentioned in the text always contains biotite.

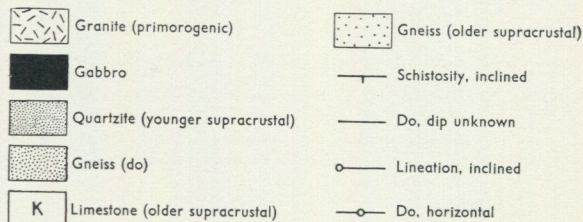
the rock complex. During this phase of the orogenesis the titaniferous gabbro seems to have been divided into several minor massifs. In the cross section given in Fig. 1 we observe the striking parallelism of the dips of the various folds cut by the profile. Although, as is evident from Fig. 2, other dips are to be found along other profiles, the isoclinal character of the folding in Central and Northern Helsingland is mostly pronounced.

In the cross section Fig. 1 and in Fig. 2 the centre of a great fault zone has been marked with short dashes. In this zone the primorogenic granite has been crushed. As is shown by Fig. 5, certain plagioclase individuals have escaped cataclasm and now appear as porphyritic remnants in a matrix of small recrystallized grains of quartz, felspar, and biotite. The titaniferous gabbro situated near the fault zone has in part been subjected to cataclasm, too, as will be evident from the following text.

In the gabbro no signs of post-cataclastic mineralizations have been observed, whereas in part of the primorogenic granite coarse post-tectonic microcline porphyroblasts are common. In the southern vicinity of Söderhamn especially, these have proved to be younger than the *S*-planes of the great fault zone. The porphyroblasts are either final primorogenic or serogenic. In the first case they ought to have crystallized from the rest solutions of the primary granite magmas, in the second case they should be counted among the alteration products of the regional migmatitization discussed below.

It would seem probable that the block to the north-east of the great fault zone has slipped down as compared with the south-western block. The north-eastern block is, indeed, free from older supracrustal rocks, whereas the south-western block is rich in such rocks. This may, however, equally well be due to the development of a syncline in the north-east, near the Medelpad border, and an anticline in the western part of the province. The great boudin of older supracrustal rocks in the western part of Fig. 1 ought to represent then a remnant of the anticlinal rocks, most part of which should have been converted into migma.

During the final phase of the primorogenic folding it seems probable that a flowage of the migmatitic older supracrustal rocks has occurred towards the centre of the syncline in the Medelpad border region, originating the shallow isoclinal folding of the younger supracrustal rocks in North-Eastern Helsingland as exemplified by the profile in Fig. 1. Homogenized



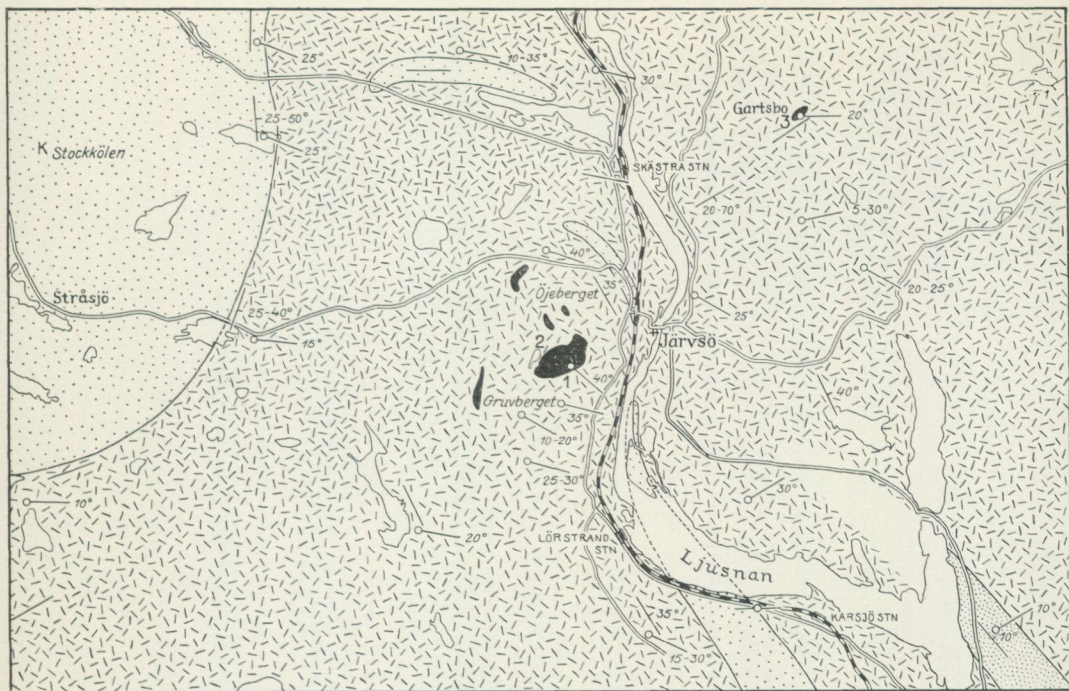


Fig. 3. Petrological map of the Kramsta region. Kramsta massif marked with nos 1 and 2. Scale 1 : 200,000. Compare Fig. 2. White land area in S. E. granite with inclusions of gneiss. Drawn by G. Rimfors. (Godkänd för spridning den 4 juni 1957 i Rikets allmänna kartverk.)

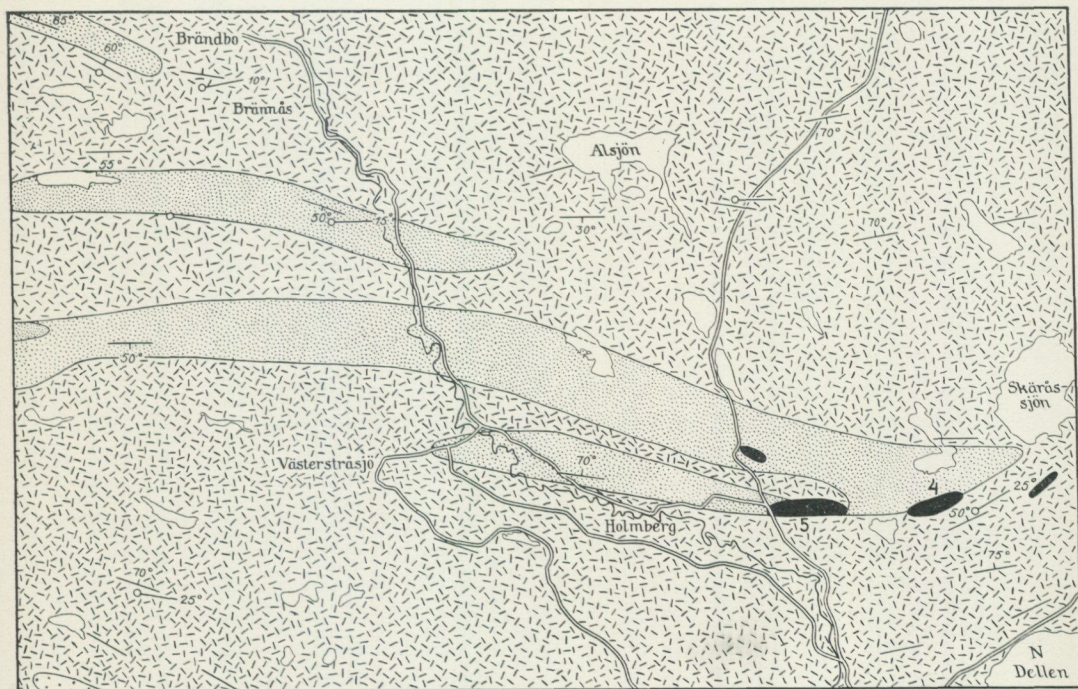


Fig. 4. Petrological map of the region N. W. of Lake Dellen. Scale 1 : 200,000. Compare Fig. 2. Drawn by G. Rimfors. (Godkänd för spridning den 4 juni 1957 i Rikets allmänna kartverk.)

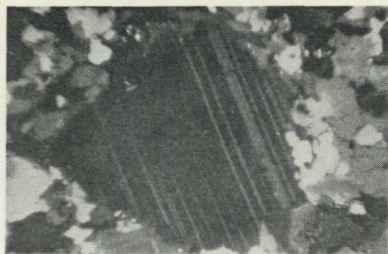


Fig. 5. Plagioclase remnant in cataclastic granite. Southern vicinity of Kramsta gabbro. + nic., magnification 7 ×. Photo by P. H. Lundegårdh.

magma portions derived from the migma composed of the older supracrustal rocks, as well as of their substratum, have apparently intruded along the S-planes of the isoclinal-folded complex during a late-primorogenic period of relaxation and have crystallized as the primorogenic granites shown in the cross section Fig. 1, whereas epigenetic final-migmatitic solutions rich in mineralizers have caused the various granitizations *in situ* frequently met with.

The two principal primorogenic intrusive granites are porphyritic intermediate (most common) and grey basic (tonalitic). These types of granite are also met with in other parts of the bed-rock of Sweden, such as the Gothian of South-Western Sweden (grey basic Åmål granite and porphyritic Filipstad—Askim granite).

In North-Eastern Helsingland the leading primorogenic *in situ*-granite is a red, as a rule garnetiferous and often cordierite-bearing, kakolitic (p. 7) microcline-granite stratigraphically and genetically associated with the quartzite and arkose above mentioned. In the neighbourhood of Göteborg (Gothenburg) we meet with a similar though not kakolitic granite derived from the same kind of sediment. (Investigations by the writer, in part unpublished, in part described in P. H. Lundegårdh, 1953.)

The primorogenic isoclinal folding of North-Eastern Helsingland has met with rather strongly differentiated sediments, viz. on the one side arkoses and quartzites (arenites) and on the other side argillaceous rocks sometimes admixed with basic volcanics (pure argillites and tuffitic argillites). These sediments have been highly apt to react with, and under the influence of, solutions arising from the migmatitic substratum. The two principal metasomatic actions are 1) a basic front implying an addition of, in the first hand, magnesium, and 2) an acid, granitizing front dominated by potassium aluminate. These two actions have frequently been intermixed, especially in the quartzites, the granitized derivatives of which are rich in both secondary microcline and garnet.

Under the high-pressure conditions caused by the isoclinal folding, the advance of the basic front has caused essentially an intense formation of garnet. As a matter of fact, North-Eastern Helsingland is richer in metasomatic garnetiferous rocks than any other part of the Swedish Archean, inclusive of Södermanland. Both the argillites and the arenites of the younger supracrustal series have mostly been sprinkled with aggregates or single



Fig. 6. Anorthositic inclusion rich in titaniferous iron ore. Metagabbro in the northern vicinity of Lake Dellen (no 4 in Fig. 4). Photo by P. H. Lundegårdh.

grains of garnet, and often the primorogenic intrusive granite of the coast region, too, contains garnet. The primorogenic acid and serorogenic granites of North-Eastern Helsingland have as a rule developed as garnet-kakolites (cp. p. 7). Only locally the pressure has been as low as to permit the formation of high quantities of cordierite. As could be expected in this region, high frequency of cordierite often excludes the occurrence of garnet.

In South-Western Helsingland garnet is by far less common though streaks of garnetiferous meta-argillites are found even there. Neither the primorogenic granite nor the serorogenic granite are, however, garnet-bearing. (Compare H. von Eckermann, 1922 and 1936.)

When moving northwards from the boundary between Eastern Helsingland and Medelpad, we observe a change of the metasomatism as displayed by a marked decrease in the frequency of garnet. A similar change will be

found when we follow the streak of quartzite, arkose, and primorogenic-granitic derivatives of these rocks from the coast to the east of Hudiksvall and to the western part or Southern Medelpad (Fig. 1). In the eastern part of this streak the rocks have been throughout sprinkled with garnet, or locally cordierite, and the granitization, or better felsparization (felspathization), is strong, whereas, in the western part, the degree of alteration is low and garnet lacking.

Simultaneously with the decrease in primorogenic metasomatism, several minor intrusions of a grey, mostly non-porphyrific, serorogenic granite called Hernö granite appears as a new element of the bed-rock. The sediments of Medelpad, classed by Magnusson (1949, p. 60) as members of the Hernö series, are less differentiated than those of North-Eastern Helsingland, and this may to some extent be responsible to the great change in frequency of garnet.

Summarizing the data given above: North-Eastern Helsingland is rich in primorogenic granite, and its differentiated supracrustal rocks have been subjected to strong high-pressure metasomatism characterized by the formation of garnet especially. (Remember the isoclinal folding.) On the other hand, serorogenic rocks are not so very common (with local exceptions, of course) and consist mostly of kakolitic granite.

Medelpad, and the adjacent province to the north — Ångermanland, contain very moderate quantities of primorogenic granite and have suffered from a less prominent metasomatism. On the other hand, the serorogenic migmatites and palingenic granites form very important members of the rock assemblage. The content of garnetiferous rocks is rather low (including meta-argillites only), and kakolitic granites are rare. The sediments are on the whole less differentiated than those of North-Eastern Helsingland. They might be interpreted as derivatives of geosynclinal graywackes (terminology in accordance with old Swedish and modern American petrographic nomenclature; cp. Heinrich 1956, p. 123). These are not so very high in aluminum and have thus been less apt to the formation of secondary minerals rich in this elements, such as garnet.

The difference in alteration between North-Eastern Helsingland and the provinces to the north thereof do not, however, seem to be due only to the data now recorded and discussed. Magnusson has studied this problem repeatedly and has suggested a thrust fault implying an elevation of the Helsingland block in relation to the Medelpad—Ångermanland block (Magnusson 1957, pp. 72—73). Recent investigation have, indeed, revealed a mylonite zone stretching towards S. E. from the southern end of Lake Storsjön in Jemtland. This zone is more difficult to follow when we approach the Medelpad—Helsingland boundary and the Gulf of Bothnia, however, though it has been traced in the immediate vicinity of the streak of quartzite mentioned in the above text. As a matter of fact, this streak has in part been divided into boudins owing to strong differential movements. (Compare Fig. 1.)

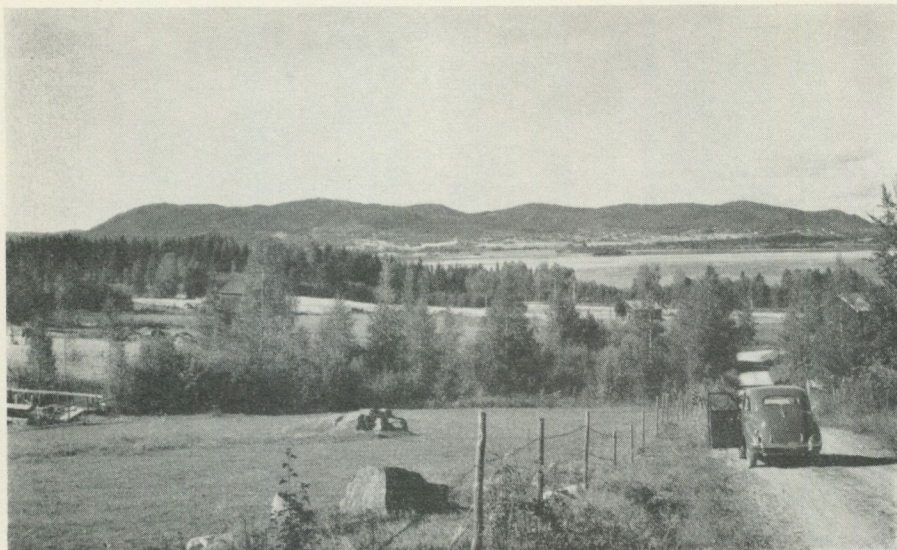


Fig. 7. The Kramsta gabbro-bearing area from S. Photo by P. H. Lundegårdh.

Magnusson's finding has simplified the petrological problems of Helsingland—Medelpad very much. North-Eastern Helsingland should represent an elevated block displaying nowadays a deep section through rocks which have been subjected to a far-reaching migmatitization and granitization (including reomorphism) in primorogenic time, whereas Medelpad—Ångermanland should expose to view a rather superficial section through geosynclinal graywackes. Owing to their stratigraphic position these ought to have escaped primorogenic alteration to a large extent, whereas, after the negative change of their position as caused by Magnusson's thrust fault, they have been penetrated by the serorogenic migmatitization front. Contrary to the rocks of North-Eastern Helsingland they had until this phase of the orogenesis remained in a low-metamorphic condition and were thus highly apt to change their petrographic characters when soaked with the migmatizing agents.

The significance of Magnusson's thrust fault is also stressed by another petrological difference between Helsingland and Medelpad; viz. the marked increase in frequency of intrusions of Algonkian (Jotnian) dolerite (Åsby dolerite) in the latter province. Moreover, in Helsingland Algonkian dolerite is only met with near the northern boundary — that is: near the thrust fault. (See Fig. 1.)

The serorogenic granite of Medelpad and Southern Ångermanland has for the most part developed as a grey, medium-grained rock called Hernö granite. It contains muscovite and on the whole shows several characteristics remembering of its mother rocks — the graywackes of the Hernö series. It is intimately associated with a reddish, or grey, coarse-porphyrific granite

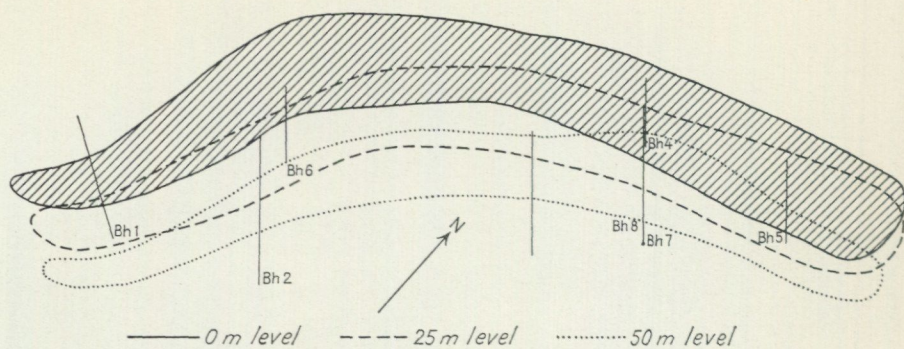


Fig. 8. Rich-ore gabbro, Kramsta massif. Scale 1 : 4,250. Drawn by M. Ekman.

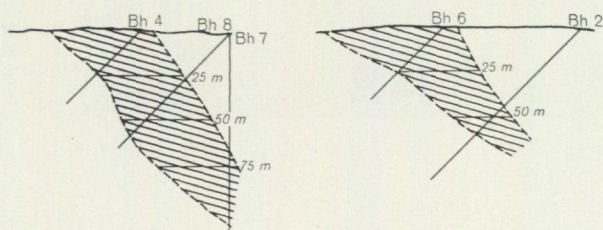


Fig. 9. Cross sections through rich-ore gabbro, Kramsta massif. Compare Fig. 8. Drawn by M. Ekman.

— Revsund granite, which is the leading rock of Eastern Jemtland and Northernmost Ångermanland. Magnusson (1936) has from a regional point of view compared the Revsund (and Härnö) granites with the southerly Stockholm and Fellingsbro granites. The age of the latter is between 1,700 and 1,800 millions of years, according to determinations on radio-active matter by A. Parwel and F. E. Wickman (1954). They have been classed as final Svecofennian RAMSAY—WAHL—BACKLUND, or final Svionian SÆDERHOLM—MAGNUSSON. (Compare p. 6.)

In the northern and western parts of Helsingland eruptive rocks younger than the serorogenic granites just described have been met with. A post-orogenic granite, Råtan granite, forms a prominent member of the westerly bed-rock, outside the left margin of Fig. 1 especially. Near the boundary between Helsingland and Medelpad the Jotnian Åsby dolerite is quite common, as already touched upon. In and N. W. of Lake Dellen, W. N. W. of Hudiksvall, andesitic tuff and lava (the latter in part glassy) has intruded along opening fissures constituting a regular system. The andesite probably intruded during the Tertiary. It contains fragments of primorogenic granite and quartzite. The latter may have been derived from the strata of Algonkian (Proterozoic) sandstone once covering at least part of the Archean of Helsingland. (Compare A. Blomberg 1895, pp. 39 and 54 ff., and L. Redaelli, 1957.)

## The Titaniferous Ore-Bearing Gabbro

### Introduction

Titaniferous ore-bearing gabbroic and doleritic rocks with considerable contents of vanadium are known from various parts of Sweden, viz. Ingla-måla and Taberg in Småland (hyperite), Rackeby in Västergötland (norite and metamorphic derivatives), Kramsta, Gartsbo and allied deposits in Helsingland (norite and metamorphic derivatives), Ulvön in Ångermanland (dolerite), Routevare (Routivare) and Akkavare in Norrbotten (anorthosite and norite). Taberg has been mined since long ago, and restricted mining operations have also been started on Ulvön.

Among basic eruptive rocks, and ultra-basites especially, we have to distinguish between orogenic, epi-orogenic, and non-orogenic rocks (P. H. Lundegårdh, 1950). The former should have intruded under prim-, or syn-orogenic conditions, as ophiolites etc., and should have moved rather rapidly from the simatic substratum to their final positions. They ought to have thus retained their original characters even regarding the distribution of various minor elements fairly well, as has also been elucidated by a number of examples in the paper cited. The epi- and non-orogenic basites, on the other hand, should have had a long life in the magmatic state and should have therefore been able to change considerably before their eventual solidification.

During normal differentiations of basic magmas chromium and nickel separate early (V. M. Goldschmidt, *inter alia* 1945), whereas vanadium is enriched in the middle stages of differentiation. Cobalt is more undecided regarding its distribution (P. H. Lundegårdh, 1946 and 1949) though it frequently vanishes in the later stages of suites of differentiation. (Compare L. R. Wager and R. L. Mitchell, 1943, and R. A. Howie, 1955.) As will be seen in the geochemical chapter (p. 25 ff.), the gabbroic rocks of Central and Northern Helsingland have differentiated in accordance with the rules thus outlined.

### Structures, Textures, and Mineral Composition

#### GENERAL

The two principal types of titaniferous gabbro in Central and Northern Helsingland are common gabbro grading into norite and hornblende-gabbro interpreted as metagabbro. (Compare Magnusson 1953, p. 393.) The former is composed mainly of andesine or labradoandesine, hypersthene, augitic diallage, hornblende, and oxidic ore, the latter chiefly of andesine or labradorite, hornblende, and oxidic ore. The metagabbro frequently grades into pyroxene-gabbro, and its uralitic character seems to be beyond doubt.

The titaniferous gabbro is macroscopically as a rule medium- to fine-grained and grey black. The pyroxene-gabbro is hypidiomorphic to xenomor-

Table 1. Major constituents in noritic gabbro, Gartsbo and Kramsta, Helsingland.

Compound	Fig. 3, no 3			Fig. 3, no 2			Fig. 3, no 2			Fig. 3, no 1		
	Noritic gabbro, Gartsbo. Analyst: A. AAREMÅE			General sample, top level of ore zone, Kramsta. Analyst: A. AAREMÅE			Ore-gabbro, noritic, Dax, ore zone, Kramsta. Analyst: A. AAREMÅE			Norite poor in ore, S. E. part of Kramsta massif. Analyst: A. BALDER		
	% by weight	Mol.-prop. × 1,000	Cations %	% by weight	Mol.-prop. × 1,000	Cationprop. × 1,000	% by weight	Mol.-prop. × 1,000	Cations, %	% by weight	Mol.-prop. × 1,000	Cations, %
SiO <sub>2</sub> . . . . .	41.06	683.7	40.89	5.98	74.8	74.8	32.28	537.5	33.57	45.07	750.4	45.04
TiO <sub>2</sub> . . . . .	3.85	48.2	2.88				5.56	69.6	4.35	3.32	41.6	2.50
Al <sub>2</sub> O <sub>3</sub> . . . . .	13.43	131.7	15.75				6.87	67.4	8.43	12.92	126.7	15.21
Fe <sub>2</sub> O <sub>3</sub> . . . . .	4.96	31.0	3.71	13.28	83.2	166.4	13.95	87.4	10.93	1.55	9.7	1.16
FeO . . . . .	17.42	242.5	14.50	19.40	270.1	270.1	21.43	298.3	18.63	19.88	276.7	16.61
MnO . . . . .	0.24	3.4	0.20				0.34	4.8	0.30	0.32	4.5	0.27
ZnO <sup>1</sup> . . . . .	—	—	—				0.04	0.5	0.03	0.03	0.4	0.02
V <sub>2</sub> O <sub>5</sub> . . . . .	0.26	1.8	0.22	0.32	2.1	4.2	0.39	2.6	0.33	< 0.01	0	0
MgO . . . . .	4.96	123.0	7.36				7.61	188.7	11.79	3.49	86.6	5.20
CaO . . . . .	8.93	159.2	9.52				8.63	153.9	9.62	7.58	135.2	8.12
BaO . . . . .	0.01	0.1	< 0.01				0.02	0.1	< 0.01	0.03	0.2	0.01
Na <sub>2</sub> O . . . . .	1.94	31.3	3.74				0.66	10.7	1.34	2.51	40.5	4.86
K <sub>2</sub> O . . . . .	0.97	10.3	1.23				0.52	5.5	0.69	0.79	8.4	1.01
H <sub>2</sub> O <sup>2</sup> . . . . .	1.38						1.46			0.99		
P <sub>2</sub> O <sub>5</sub> . . . . .	0.14						0.17			1.46		
S . . . . .	0.94						0.36			0.21		
F . . . . .	—						—			0.20		
O replaced by S & F	100.49		100.00	Cr <sub>2</sub> O <sub>3</sub> < 0.005			100.29		100.01	100.35		100.01
Total	— 0.37						— 0.14			— 0.15		
Ratios . . . . .	100.12			og = 79.3			100.15			100.20		
	qv <sup>2</sup> = 56.6	og <sup>3</sup> = 73.4					qv = 46.0	og = 78.7		qv = 59.0	og = 68.8	
	Mg : Fe <sup>4</sup> = 0.175						Mg : Fe = 0.175			Mg : Fe = 0.125		

<sup>1</sup> Spectrum analysis by P. H. LUNDEGÅRDH. — <sup>2</sup> The molecular proportion of SiO<sub>2</sub> and CaO + MgO + FeO + MnO (in %). —

<sup>3</sup> Degree of oxidation =  $\frac{100(0.300 + 0.222) 0.7}{(0.700 + 0.778 p) 0.3}$ ; p = FeO : Fe<sub>2</sub>O<sub>3</sub> (I. SAHLIN, 1931). — <sup>4</sup> Calculated from % by weight.



Fig. 10. Cataclastic texture in noritic gabbro: Granulated and uralitized pyroxene with titaniferous iron ore, surrounded by non-affected plagioclase. Gartsbo (Fig. 3). 1 nic., magnification 14 ×.



Fig. 11. Penetrating hypersthene in norite. Kramsta massif. 1 nic., magnification 14 ×. Photos by P. H. Lundegårdh.

phic (anhedral), the metagabbro granoblastic, frequently with *S-Regelung* parallel to the schistosity of the surrounding rocks. (For the most part primorogenic granite; compare Figs. 1, 3 and 4.) Metamorphic banding has never been observed. Locally, however, there appear in the metagabbro irregular spots consisting chiefly of plagioclase with central enrichment of titaniferous iron ore (Fig. 6). These spots may be interpreted either as remnants of differentiation products older than the surrounding gabbro or as products of metamorphic diffusion. In the noritic gabbro on Brattön, in the skerries to the north of Göteborg (Gothenburg) in South-Western Sweden, the writer has observed similar inclusions of ore-bearing anorthosite which are evidently primary. The Brattön gabbro is, however, on the whole non- or low-metamorphic.

The titaniferous gabbro is older than the primorogenic granite. Penetrative apophyses from this granite have been observed both in the Kramsta and the Gartsbo massifs. In the latter the apophyses are distinctly gneissic and conformable with the *S*-planes of the gabbro boudin. (Compare Blomberg 1895, p. 61.)

The gabbro seems to have intruded along the *S*-planes of the supracrustal formations during an early phase of the primorogenic folding and to have crystallized as laccoliths similar to that filled with metapyroxenitic gabbro in the Hamrånge syncline in North-Easternmost Gestrikland (P. H. Lundegårdh 1956, Fig. 1). Besides, the titaniferous gabbro of Central and Northern Helsingland is associated with a davainitic rock (metapyroxenite) which resembles the Hamrånge gabbro very much. This rock will be found in the map Fig. 1 (no 7) to the north-east of the great lake with an andesitic kernel (Lake Dellen) and to the north of Hudiksvall.

During the isoclinal folding and the differential movements preceding the intrusion of the primorogenic basic and porphyritic granites, the laccoliths of titaniferous gabbro seem to have been divided into boudins. As is shown in Figs. 3—4 and 8—9, these boudins have later become oriented parallel to the structural direction conserved until nowadays as a linear

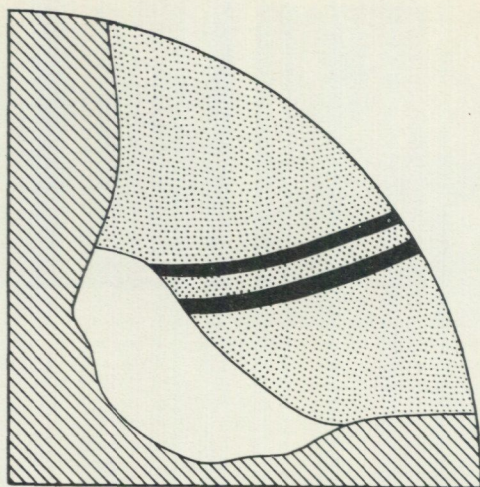


Fig. 12. Ilmenite lamellae in titaniferous magnetite. White = ilmenite grain. + nic., magnification 200  $\times$ . Rich-ore gabbro, Kramsta massif. P. H. Lundegårdh del., M. Ekman cop.

schistosity which is often strong. (Compare also Fig. 2.) The gabbro rock itself has been subjected to strong alterations, too, the nature of which will be soon discussed. These alterations ought to have proceeded during the intrusion of the primorogenic granites, especially as most part of the supracrustal rocks surrounding the gabbro became then either wholly assimilated or mobilized so as to originate separate intrusions at higher levels of the crust.

In the neighbourhood of Kramsta fine-grained amphibolitic metabasites remember of basic volcanic strata in more acid supracrustal rocks which have disappeared, and in the area exposed to view in Fig. 4 the primorogenic acid granite frequently grades smoothly into acid supracrustal rocks which are apt to be interpreted as the source of the granite. The conformable *S*-planes of the two kinds of rocks may, however, just as well be due to post-granitic *S*-tectonization and must not thus be regarded as indicative of a granitization *in situ*.

As already mentioned, the chief result of the final tectonic first-range event in Helsingland — the great fault zone cutting the province into two halves (Fig. 2), has been a textural disintegration. In the titaniferous gabbro the fault has often produced cataclasm (Fig. 10). Sometimes the whole rock has been crushed though it has afterwards recrystallized to a granoblastic matrix. No post-cataclastic mineralizations have been observed, however. In the primorogenic granite, on the other hand, coarse post-tectonic microcline porphyroblasts are common in certain areas. (Compare p. 8.) We have seen that these are not only younger than the general schistosity but also younger than the *S*-planes of the great fault zone.

From a petrological point of view the gabbro of Central and Northern Helsingland has to be divided into three groups, viz. early, middle, and late gabbro. The early gabbro is the sparse davainitic (metapyroxenitic) rock, which contains no primary oxidic ore and little apatite. It should be counted among the ultrabasites, which form the first rocks produced by normally differentiating basic magmas.

The middle gabbro is the common titaniferous gabbro composed essentially of plagioclase (early middle gabbro with 50 % An, late middle gabbro with 40 % An), clinopyroxene, and/or hornblende. It is rich in oxidic ore. The late gabbro is a norite much richer in apatite than the preceding rocks and poorer in oxidic ore than the middle gabbro.

Although no clear penetrative contacts between the three types of gabbro have been observed, we are none the less forced to present them in the order thus marked with their different mineralogical compositions. This order is also in harmony with their chemistry regarding both major and minor elements.

#### DAVAINITIC GABBRO (EARLY GABBRO)

The davainitic gabbro is a green black, fine- to medium-grained metapyroxenitic rock, which according to finds of local boulders seems to form a small lenticular massif in a primorogenic-granitic garnetiferous meta-arkose near the Medelpad border, N. N. E. of Lake Dellen and to the north of Hudiksvall (Fig. 1, no 7). Mr P. W. Palm in Njurunda, who was the first to discover this gabbro, has been kind enough to provide me with a chromium analysis of the rock (Table 2). Similar gabbro occurs locally in greenstone massifs in the north-westernmost part of Helsingland (the upper left corner of Fig. 1).

The davainitic gabbro consists essentially of hornblende and plagioclase pseudomorphs. Considerable amounts of biotite are also often met with. Minor constituents are secondary oxidic and sulphidic ores, quartz, and apatite. Calcite appears now and then as single individuals. Microscopically it displays a hypidiomorphic to xenomorphic texture.

The hornblende is secondary after pyroxene and shows pale pleochroism in bluish green to pure or olive green.  $C:\gamma$  amounts to about  $20^\circ$ ,  $2V\gamma$  to  $95^\circ$ . As a rule no pyroxene remnants are found. Now and then a calcic actinolite with higher birefringence and weaker pleochroism than the common hornblende appears. This amphibole shows  $c:\gamma = 15-17^\circ$ . The actinolite and the common hornblende most frequently form different parts of one and the same individual.

The plagioclase has as a rule altered completely to saussurite and sericite. Simultaneously intragranular quartz has developed. The occasional appearance of secondary calcite indicates a rather basic composition of the plagioclase.

The apatite forms small laths which are generally not very common.

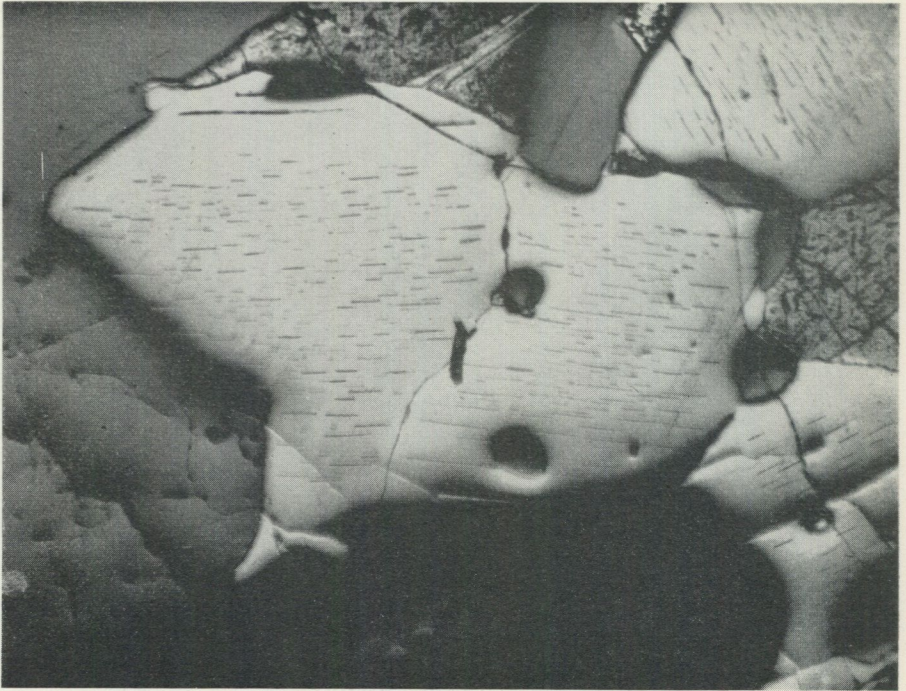


Fig. 13. Ilmenite with rutile needles in regular distribution. Rich-ore gabbro, Kråmsta massif, 1 nic., magnification 110  $\times$ . Photo by C. Larsson and P. H. Lundegårdh.

#### RICH-ORE GABBRO (MIDDLE GABBRO)

The normal titaniferous gabbro is a common gabbro grading into norite. In the rich-ore varieties low in amphibole, clinopyroxene is always more common than orthopyroxene. We there observe the following superior minerals: Plagioclase (An either about 40 % or about 50 %), oxidic ore, and clinopyroxene. Orthopyroxene forms an inferior constituent, whereas apatite is the leading minor mineral. Further some of the hornblende contained in the rock is probably of early formation. (Compare p. 22.)

Owing to late alterations the following minerals have been introduced: Uralitic hornblende, sulphidic ore, biotite, quartz, and microcline. The two last-mentioned minerals only appear occasionally and in small quantities.

As mentioned, some varieties of norite contain andesine (about 40 % An) and others labradoandesine (about 50 % An). The latter seem to be older than the former. Most plagioclase individuals have originally been thick and tabular. Primorogenic tectonization has, however, frequently crushed and sometimes bent the *tabulae* though the individuals of the plagioclase are on the whole rather well-preserved as compared with those of the pyroxene (Fig. 10). Strong sericitization is, however, now and then met with. Polysynthetic twinning according to the albite law is common. Akline twins have

also been observed, whereas pericline twins seem to be more common in the metagabbro later described.  $2V\gamma$  amounts to  $87^\circ$  in the andesine and to  $79-81^\circ$  in the labradoandesine (universal stage determinations). Microlites of early oxidic ore have got a wide distribution, as already pointed out by Blomberg (1895, p. 61).

The clinopyroxene is for the most part an augitic diallage ( $c:\gamma = 39-44^\circ$ ,  $2V\gamma c. 60^\circ$ ) though pigeonite, with lower  $c:\gamma$  values ( $30-39^\circ$ ), has also been seen in the thin sections examined. The orthopyroxene is a hypersthene showing weak pleochroism. Both kinds of pyroxene have been subjected to marginal and irregular internal alteration to weak-pleochroic uralitic hornblende. Fibrous cummingtonite sometimes occurs in the alteration aureoles around the hypersthene.

As mentioned, the pyroxene has frequently been crushed (Fig. 10). In varieties which have escaped the youngest phase of the primorogenic tectonization, the hypersthene especially, as a mineral of late formation, has grown into extensive individuals (Fig. 11), certainly in part at the expense of pre-existent grains of other minerals.

The oxidic ore consists of magnetite and ilmenite. Figs. 12-15 give us some hints regarding the mode of occurrence of the oxidic ore. The ilmenite appears either as *lamellae* or separate grains (Figs. 12-13). The larger *lamellae* have sometimes been bent during the final tectonization in analogy with the plagioclase of the tectonized gabbro, as well as of the similarly tectonized primorogenic granite (near the great fault zone especially), which now and then displays curved *tabulae*.

The oxidic ore has further been penetrated by the sulphide ore, which has been introduced during the final primorogenic phase of the tectonization of the bed-rock. (See below.) The oxidic ore ought therefore to have developed before this phase.

The magnetite as a rule contains microscopical spindle-like thin laths, or needles, of spinel which have been arranged parallel to the cubic faces of the mineral. The titanomagnetite of the rock is magnetite with exsolved ilmenite in dense regular distribution as scarcely detectable *lamellae* similar to those described by S. Hjelmqvist (1950) from Smålands Taberg. When magnified moderately, this titanomagnetite behaves like a homogeneous mineral showing weak anisotropy. Further some titanium seems to be contained in the magnetite lattice (titaniferous magnetite). Part, or all, of the exsolved ilmenite has frequently assembled secondarily to sparse larger *lamellae*. (Compare Fig. 12.) Grains of pure, certainly primary ilmenite are also common. (See Figs. 12-13.) The latter often contain anisotropic needle-like microlites, most probably consisting of rutile, in regular distribution. In several ilmenite individuals we observe a marginal zone free from such microlites (Fig. 13). This zone seems to be younger than the rest of the mineral and may have grown during the primorogenic phase of the evolution of the bed-rock. (Compare the description of the hornblende as given below.)

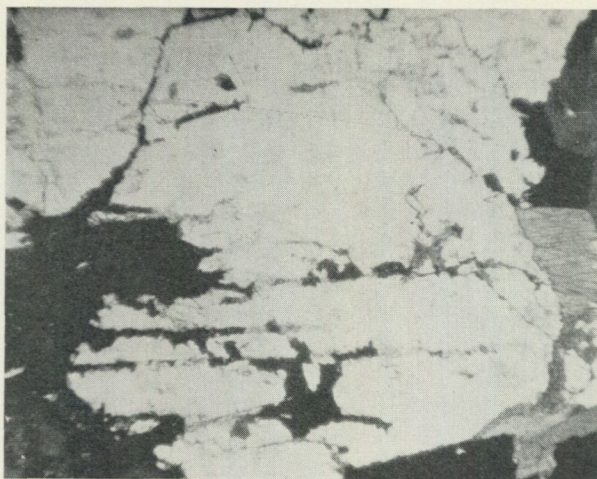


Fig. 14. Oxidic ore penetrating plagioclase. Rich-ore gabbro, Kramsta massif. 1 nic., magnification 23  $\times$ . Photo by P. H. Lundegårdh.

The oxidic ore sometimes penetrates the plagioclase in a rather progressive manner indicating once again the existence of a second generation of this kind of ore (Fig. 14), especially in view of the microlites of early oxidic ore frequently appearing within the plagioclase individuals. (Compare above.)

H. Ramberg (1948) has discussed the problem of secondary development of titaniferous iron ore. He has pointed out that during high-temperature alteration of basites in low-temperature facies such a kind of ore may be formed by dissociation of, *inter alia*, biotite, the lattice of which is known to contain very frequently considerable amounts of various major and minor elements. Although the bulk of the oxidic ore of the Helsingland norites has certainly crystallized early, there are none the less strong reasons to suspect that the metamorphism working during the primorogenic phase of the tectonization has caused migrations of, *inter alia*, iron and titanium resulting in the secondary development of oxidic ore as displayed by the phenomena reproduced in Figs. 14—15. (Compare also p. 28.)

Turning now to the amphibole, we have to distinguish between two varieties, viz. one uralitic hornblende with moderate pleochroism in various shades of pure green (low in iron) and one hornblende with strong pleochroism in green brown to brownish green (high in iron and probably titaniferous, too). The latter is by far more common and shows  $2V\gamma$  values about  $120^\circ$ , whereas the former has  $2V\gamma = 95$  à  $100^\circ$ .

The strong-pleochroic hornblende mostly forms homogeneous individuals the age of which is unclear, though such hornblende now and then borders upon pyroxene grains showing the same orientation as the hornblende. Now we have to mention as a very important matter of fact that both these and other pyroxene grains are sometimes rich in irregular, often fingering precipitations of oxidic iron ore. (Compare Fig. 15.)



Fig. 15. Fingering oxidic ore inclusions in clinopyroxene. Norite from the neighbourhood of Tallåsen, Northern Helsingland (no 6 in Fig. 1). 1 nic., magnification 65  $\times$ . Photo by P. H. Lundegårdh.

Turning back to Ramberg's considerations as given above, an alteration from hornblende (or biotite) to pyroxene should be accompanied by the development of oxidic ore. In the Hamrånge syncline, North-Easternmost Gestríkland, clinopyroxene and olivine have developed secondarily, owing to primorogenic metasomatism (P. H. Lundegårdh 1956, p. 341). Any objections against the assumption of an early hornblende rich in iron and titanium to be present in the titaniferous gabbro cannot thus be raised. Another indication of a late formation of pyroxene is displayed by the orthopyroxene intergrowths as exemplified in Fig. 11.

The apatite mostly displays small laths and more irregular grains though, in certain varieties, individuals measuring as much as 3 à 4 mm in length have been observed. (Compare Fig. 16.) The latter appear in inhomogeneous gabbro varieties bearing evidences of strong alterations such as high frequency of fingering precipitations of oxidic ore in pyroxene. (Compare above.) It seems probable that they have grown considerably owing to secondary migrations in the rock. The ordinary gabbro (An of the plagioclase about 50 %) contains less apatite than the meladioritic gabbro (An about 40 %).

The latest minerals of the rocks now described — exclusive of the pale uralitic hornblende already discussed — are displayed by a number of gifts from the neighbouring primorogenic granite, viz. biotite, quartz, microcline, and sulphidic ore. These are all penetrative with respect to the rest of the gabbro. Sulphide ore — pyrrhotite essentially, has reached a strong position in the Gartsbo massif, as is also indicated by the chemical analysis (Table 1). Sulphur there amounts to 0.94 %. In the ore zone of the Kramsta massif

two determinations of sulphur have given 0.36 and 0.39 % (Tables 1 and 6). Here, too, most sulphur has been captured as pyrrhotite. Consequently, sulphur has been enriched considerably in the magnetic concentrate from the Kramsta ore zone analysed in Table 6.

Microscopic investigations of polished sections from Gartsbo have shown the following sequence of ore mineralization: Magnetite and titaniferous magnetite (oldest) — separate ilmenite grains — pyrrhotite.

The rich-ore metagabbro differs essentially from the rock now described in having granoblastic texture. Weak *S-Regelung* parallel to the schistosity of the surrounding bed-rock is a common feature.

The metagabbro consists chiefly of quite fresh, wholly recrystallized plagioclase (andesine with 40 % An, or labradoandesine with 50 % An) which is free from ore microlites, common hornblende with strong pleochroism in brown to brownish green, and titaniferous oxidic ore similar to that described in the above text. The minor minerals are also the same as in the rich-ore pyroxene-gabbro. Apatite is more common in the metagabbro variety with andesine than in the variety with labradoandesine.

#### LATE GABBRO

The final member of the gabbro suite of Central and Northern Helsingland is a grey black, medium- to fine-grained norite composed essentially of andesine, hypersthene and, as a rule, considerable quantities of hornblende. Oxidic ore is an inferior mineral, whereas augite mostly confines to form a minor constituent, together with apatite. Among accessories sulphidic ore, quartz, and microline have to be mentioned. These are all three of very late formation.

When studied microscopically, the late gabbro reveals a xenomorphic texture. Its andesine contains 37—40 % An.  $2V\gamma$  amounts to  $88^\circ$ . Polysynthetic twinning according to the albite law is common. Except for a weak and local sericitization, the andesine is in most samples rather well-preserved.

The hypersthene shows good pleochroism in red and green.  $2V\gamma$  amounts to  $100$  à  $110^\circ$ .

The hornblende is an iron-rich one displaying strong pleochroism in various shades of brown green.  $2V\gamma$  is  $120^\circ$ . Remnants of pyroxene, both ortho- and clino-, are often found. A purely green-pleochroic variety has also been observed though only in restricted quantities. Sometimes all pyroxene has been exchanged for hornblende (late metagabbro).

The oxidic ore is similar to that of the rich-ore gabbro. Locally it has been penetrated by sulphidic ore, for the most part pyrrhotite.

The augite shows  $c:\gamma = 43$  à  $44^\circ$ . Irregular, often fingering precipitations of oxidic ore are sometimes common (Fig. 15). The significance of these has been discussed on pp. 22—23.



Fig. 16. Apatite in recrystallized norite from the neighbourhood of Tallåsen (no 6 in Fig. 1). 1 nic., magnification 12 ×. Photo by P. H. Lundegårdh.

The apatite has been spread all through the rock as a lot of small grains. Indeed, Table 1 shows to us that the  $P_2O_5$  percentage of the late norite of the Kramsta massif amounts to as much as 1.5. In metamorphic varieties of the late gabbro the apatite individuals have frequently grown very large. In Fig. 16 a prism measuring 4 mm in length can be seen. This occurs in a late gabbro rich in pyroxene in spite of the fact that it has apparently undergone strong alteration. The subordinate augite of the rock is, however, rich in precipitations of oxidic ore indicating that it is not primary. (Compare pp. 22—23.)

In the Kramsta massif (Fig. 3, nos 1—2) the middle rich-ore gabbro (no 2) occupies the north-western part, there forming the vanadium-bearing ore zone, or 'ore body', shown in Figs. 8—9. The south-eastern part of the massif consists of the late gabbro (no 1), which is almost free from vanadium (Tables 1—2). The significance of this phenomenon will be discussed in the following chapter.

#### Geochemical Evidences

As regards the major chemical constituents determined in the titaniferous gabbro of Helsingland (Table 1), we at first observe the low contents of silica as displayed by the quartz ratio,<sup>1</sup>  $qv = 46-59$ . In harmony with the supposed magmatic evolution of the gabbro, the highest quartz ratio is found in a late norite poor in oxidic ore. This is the gabbro of the south-eastern part of the Kramsta massif (Fig. 3, no 1), and it is quite fresh. It is not thus astonishing that it shows a very low degree of oxidation,<sup>1</sup>  $og = 68.8$ . According to Landergren (1948, p. 25),  $M(og)$  of 237 gabbros from various parts of the world amounts to 77.5 (68.0—96.0) and  $M(og)$  of 22 Swedish gabbros to 76.6 (70.0—84.0). The  $og$  value of a general sample from the rich-ore gabbro (ore zone) of the Kramsta massif is higher, 79.3, — a consequence of the high content of magnetite in this rock — whereas the  $og$  value of the Gartsbo gabbro, which contains moderate quantities of oxidic ore, occupies an intermediate position: 73.4.

The low  $og$  values speak strongly in favour of the infracrustal character of the titaniferous gabbro — basalts show higher  $og$  values than gabbros

<sup>1</sup> For explanations of these terms, see Table 1.

Table 2. Titanium, vanadium, chromium, manganese, cobalt, and nickel in the gabbro of Central and Northern Helsingland, in approximate order of differentiation.

Fig: no	Rock and locality	An, %	Mg (%) : Fe %	Parts per million of					
				Ti	V	Cr	Mn	Co	Ni
3: 1	Norite poor in ore, Kramsta (youngest)	39	<sup>1</sup> 0.125	<sup>1</sup> 19,900	<sup>1</sup> < 70	<sup>2</sup> < 0.1	<sup>1</sup> 2,500	<sup>2</sup> 10	<sup>2</sup> < 1
1: 6	Norite, 4 km N. of Tallåsen	39	0.15	10,200	80	10	2,250	80	80
3: 2	Ore-gabbro, noritic, Dax, Kramsta	<sup>3</sup> 40	<sup>1</sup> 0.175	<sup>1</sup> 33,300	<sup>1</sup> 2,700	<sup>2</sup> < 0.1	<sup>1</sup> 2,650	<sup>2</sup> 30	<sup>2</sup> 30
3: 2	Ore-gabbro, general sample, Kramsta	<sup>3</sup> 40	—	35,800	<sup>1</sup> 2,200	<sup>2</sup> < 0.1	—	<sup>2</sup> 60	<sup>2</sup> 35
3: 3	Gabbro, noritic, Gartsbo	42	<sup>1</sup> 0.175	<sup>1</sup> 23,100	<sup>1</sup> 1,800	40	<sup>1</sup> 1,850	< 10	< 10
4: 4	Metagabbro rich in ore, near Ångesholm	50	—	19,200	1,500	40	1,600	150	260
4: 5	Gabbro, noritic, poor in ore, near Blistra	50	0.47	7,200	500	30	1,850	70	100
1: 7	Davainitic metagabbro free from ore, Annsjön	—	—	<sup>2</sup> low	<sup>2</sup> 50	<sup>4</sup> 700	—	<sup>2</sup> 35	<sup>2</sup> 300

<sup>1</sup> Analyst: A. AAREMÅE (chemical analysis).

<sup>2</sup> Analyst: P. H. LUNDEGÅRDH (spectrum analysis).

<sup>3</sup> Very approximate determination.

<sup>4</sup> English commercial analysis obtained from Mr P. W. Palm. An approximate determination by the writer has given 1,000 p. p. m.

Remaining analyses from the Geochemical laboratory of the Geological Survey (spectrum analysis).

and andesites higher og values than diorites (Landergren, *loc. cit.*). The degree of oxidation is, however, not alone decisive in this respect. During primorogenic evolutions, reductions occur at lower levels of the orogenic zones. The early Svecofennian metamorphic acid volcanics known as leptites thus show comparatively low og values: M = 81.2, N = 159. Swedish granites are, indeed, distinguished by higher values: M = 83.1, N = 120. (Data from Landergren, *loc. cit.*)

The successive differentiation of basic magmas is characterized by, *inter alia*, decreasing percentages of calcium in the plagioclase and decreasing numerical values of the ratio Mg : Fe. The magmatic suite from a petrological point of view already suggested (p. 19) to be displayed by the Helsingland gabbro (Tables 1—2) is normal in this respect, as far as quantitative data are available. Moreover, the early davainitic gabbro at Annsjön (Fig. 1, no 7) is as mentioned free from primary oxidic ore and shows a weak-pleochroic magnesium hornblende. Its ratio Mg : Fe can therefore be suspected to be high (> 1).

The distribution of phosphorus is to some extent reflected by the data given in Table 1 and to some extent by the microscopic investigations. Phosphorus has been strongly enriched in the late gabbro as exemplified by the Kramsta norite poor in ore ( $P_2O_5 = 1.46\%$ ) and the Tallåsen norite, which contains several large apatite prisms. (Compare Fig. 16.)

**Table 3. Titanium, vanadium, chromium, cobalt, and nickel in various Swedish noritic and hyperitic rocks, arranged as groups in approximate order of age.**

Rock and locality	Parts per million of				
	Ti	V	Cr	Co	Ni
Norite, mafic, Brattön, Bohuslän (youngest) . . .	c. 35,000	600	< 1	50	20
Titaniferous hyperite, <sup>1</sup> Inglamåla, Småland . . . .	43,900	800	—	100	10
Magnetite-olivinite, <sup>2</sup> Taberg, do . . . . .	30,300	2,900	50	130	160
Hyperite <sup>2</sup> , do, do . . . . .	10,400	700	180	60	90
Hyperite, Baskarp, Vestergötland . . . . .	—	—	2	50	50
Titaniferous gabbro, <sup>3</sup> noritic, Rackeby, do . . . .	c. 15,000	c. 200	3	50	50
Norite, W. of Stavsjö, Östergötland . . . . .	46,700	—	100	50	90
Norite, ultra-basic, Grovstanäs, Uppland . . . . .	59,200	1,000	2	65	20
Do, do, Sundby, do . . . . .	—	200	50	65	115

<sup>1</sup> Analyst: S. LANDERGREN (spectrum analysis). (Landergren 1948, p. 101.)

<sup>2</sup> Analyst: S. LANDERGREN (spectrum analysis). (Hjelmqvist 1950, p. 48.)

<sup>3</sup> General sample. Local concentrations showing as much as 45,000 p. p. m. Ti and 1,100 p. p. m. V are known, according to spectrum analysis by S. LANDERGREN (p. 31).

<sup>1</sup> Analyst: N. SAHLBOM (chemical analysis). (B. Asklund 1925, p. 19.)

<sup>1</sup> Analyst: N. SAHLBOM (chemical analysis). (P. H. Lundegårdh 1943, p. 337.)

Remaining determinations by P. H. LUNDEGÅRDH (spectrum analysis).

Considering titanium, this metal has been concentrated in the middle and late gabbro (Table 2), in harmony with the experience from other differentiated intrusions of basic magma. Although most titanium has been captured together with divalent iron as ilmenite molecules (many of which appear in regular distribution in the magnetite of the gabbro), titanium and iron are not wholly covariable:

	Fe, %	Ti, %	Ti:Fe
1. General sample from ore zone, Kramsta (Table 1) . . . . .	24.4	3.58	0.15
2. Ore-gabbro, Dax, do (do) . . . . .	26.5	3.33	0.13
3. Do, Clax, do (Table 4) . . . . .	23.4	3.10	0.13
4. Do, near Ängesholm (Table 2) . . . . .	25.0	1.92	0.08

1—3 are samples of late middle gabbro (An about 40 %), whereas 4 displays an early middle gabbro (An = 50 %).

Howie (1955) has recently studied the geochemistry of the Madras charnockite series, India. He reports, *inter alia*, the compositions of the constitutional minerals of an intermediate rock of the series (1955, p. 742). The TiO<sub>2</sub> content there amounts to 1.7 %, the bulk of which (1.22 %) has formed ilmenite together with divalent iron. The biotite has received 0.36 % and the magnetite 0.07 % TiO<sub>2</sub>, whereas the pyroxene has captured very little titanium. P. H. Lundegårdh (1946, p. 124) investigated the clinopyroxene of an ultra-basic norite showing Ti = 0.92 % (Table 3) and found there < 100 p.p.m. Ti. S. R. Nockolds and R. L. Mitchell (1948, p. 561), on the other hand, report 0.55 % Ti to be present in an augite separated

Table 4. Older analyses from the Kramsta area (Kramsta massif and neighbouring gabbro boudins).

Locality	Fe, %	Ti, %	V, %	Source
1. Clax shaft, Kramsta . . . . .	23.4	3.10	0.20	B. Kjellberg
2. Bax, do . . . . .	21.3	—	0.16	"
3. Dax, do . . . . .	22.3	—	0.20	"
4. Örn mine, do . . . . .	15.2	—	0.11	"
5. Ax, Bax, Clax, Dax, do (M, N = 96) . . . . .	19.7	—	0.17	C. W. Carstens
6. Drill core 7, do (Bh 7 in figs. 8—9) . . . . .	21.7	—	0.16	Report 1943
7. Drill core 8, do (Bh 8 in figs. 8—9) . . . . .	19.8	—	0.11	"
8. Täkt mine, Storsveden (general sample) . . . . .	39.5	—	0.39	B. Kjellberg
9. Hag mine, do (do) . . . . .	21.1	—	0.17	"
10. Täkt mine, drill core 9, do . . . . .	12.2	—	0.08	Report 1943
11. Skog mine, drill core 10, do . . . . .	18.3	—	0.12	"
12. Björn mine, Gruvberget, (general sample) . . . . .	20.8	3.57	0.16	B. Kjellberg
13. Jupiter mine, drill core 13, do . . . . .	18.6	—	0.14	Report 1943
14. Drill core 11, Gillermyren . . . . .	16.1	—	0.09	"
15. Drill core 12, Öjeberget . . . . .	16.9	—	0.08	"

from Scottish Caledonian augite-peridotite (wehrlite). The hornblende of more acid rocks belonging to the same complex of Caledonian plutonics shows  $Ti = 0.58-1.54\%$ . Higher quantities of titanium cannot possibly be received in the hornblende lattice, however, as suggested *inter alia* by the data given by P. H. Lundegårdh in 1943 (p. 354). The writer there describes a hornblende containing  $2.3\%$  Ti, part of which has been exsolved and has originated numerous ilmenite microlites in regular distribution.

On the whole we are able to state that biotite and hornblende are more apt to take up titanium than pyroxene, and it does not thus exist any obstacles to the secondary formation of titaniferous iron ore during high-temperature alteration of basites in low-temperature facies, as already suggested by Ramberg (1948; see p. 22). Comparing mutually biotite and hornblende, G. de Vore (1955) has pointed out that 'biotite may have a greater capacity for adsorption than hornblende, possibly because of a higher tolerance for nondisplaceable imperfections and more unfilled lattice sites in the structure, as well as being more "polarized" than hornblende'.

Turning to vanadium, the differentiation as displayed in Table 2 is stronger than that of titanium. The maximum is reached in the late middle gabbro, whereas the introductory and final stages of differentiation contain little vanadium.

In Table 4 a number of older determinations of vanadium in ore-bearing gabbro from the Kramsta area are found. Samples nos 1—7 have been collected in the ore zone of the Kramsta massif (Figs. 8—9). Magnusson (Alarik, 1943) has calculated the average concentration in this zone as  $0.15\%$ . He points out that the concentration met with in the top level is higher

**Table 5. The ratio V : Fe in vanadium-rich gabbro from the Kramsta area and the Gartsbo massif. (Calculated from % by weight.)**

Ore-gabbro, Dax, Kramsta (Table 1) .....	0.0102
General sample from ore zone, Kramsta (do) .....	0.0090
No 1, Kramsta (Table 4) .....	0.0086
No 2, do (do) .....	0.0075
No 3, do (do) .....	0.0090
No 4, do (do) .....	0.0072
No 5, do (do) .....	0.0086
No 6, do (do) .....	0.0074
No 7, do (do) .....	0.0056
No 8, Storsveden (Table 4) .....	0.0099
No 9, do (do) .....	0.0081
No 10, do (do) .....	0.0066
No 11, do (do) .....	0.0066
No 12, Gruvberget (Table 4) .....	0.0077
No 13, do (do) .....	0.0075
No 14, Gillermymren (Table 4) .....	0.0056
No 15, Öjeberget (Table 4) .....	0.0047
Noritic gabbro, Gartsbo (Table 1) .....	0.0106

than at lower levels and refers to C. W. Carstens's outcrop average, which is 0.17 % (Table 4, no 5). The general sample from the top level analysed in Table 1, which has been collected by G. Stålhös, shows 0.22 % vanadium (Tables 1—2).

The ratio V : Fe has been calculated in the late middle gabbro samples contained in Tables 1 and 4. The values will be found in Table 5. They are highly variable. Of course it would have been better to calculate the ratio V : Fe<sup>3+</sup>. In the samples contained in Table 4 only total iron has been determined, however. Nockolds and Mitchell (1948), who have studied the ratio V : Fe<sup>3+</sup> in a series of Caledonian plutonic rocks in Scotland, state that this ratio, too, seems to be quite irregular.

De Vore (1955) mentions that vanadium 'seems to be a borderline element and is highly fractionated only where there are large differences between the anion polarizabilities of the different minerals'.

Vanadium is met with in most rock-forming minerals though it has a decided preference for entering magnetite (Wager and Mitchell 1951, Howie 1955). Ilmenite, clinopyroxene, hornblende, and biotite are also apt to receive significant quantities of vanadium (Wager and Mitchell 1945, P. H. Lundegårdh 1946, Nockolds and Mitchell 1948, Wager and Mitchell 1951, Howie 1955).

A number of chemical analyses of magnetite separated from the rich-ore gabbro of the Kramsta area has been collected in Table 6. The enrichment of vanadium in magnetite is here displayed in an almost excellent manner, despite the strong variation of the V : Fe ratio as shown in Table 5.

This enrichment is an interesting phenomenon. As we have seen earlier, the Kramsta rich-ore gabbro shows the highest degree of oxidation of the samples analysed with respect to their contents of  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$ . The ionic radii of  $\text{Fe}^{3+}$  is 0.67 Å and of  $\text{V}^{3+}$  0.65 Å, whereas the ionic radius of  $\text{V}^{4+}$  is only 0.61 Å. During crystallizations of magmas, the  $\text{Fe}^{3+}$  and  $\text{V}^{3+}$  ions are captured almost simultaneously by the growing lattices of the rock-forming minerals apt to receive these ions, whereas  $\text{V}^{4+}$ , owing to its smaller radius and higher charge, will be captured before  $\text{Fe}^{3+}$ . (Compare Goldschmidt, 1945.)

It seems probable that the crystallization of the gabbro magma in the laccolith later divided into the boudins of the Kramsta area has started under the influence of the surrounding supracrustal complex, which has acted as an oxidizer. Divalent iron has thus in part been oxidized to trivalent iron, and most trivalent vanadium has changed to quadrivalent vanadium. Oxidic ore has crystallized and has moved towards the bottom of the laccolith, there admixing with crystals of the early pyroxene, viz. the augite, and restricted quantities of plagioclase so as to originate the rich-ore gabbro. This fraction has been highly apt to capture all quadrivalent vanadium, as is also shown by the analyses in Table 1. (The  $\text{V}_2\text{O}_3$  reported in Table 1 does not require trivalency of the vanadium present in the rocks analysed.)

Chromium and nickel are normally captured early in suites of magmatic differentiation, according to Goldschmidt's classical statements. (See, *inter alia*, Goldschmidt, 1945. Compare also Wager and Mitchell 1943, P. H. Lundegårdh 1946 and 1949, Nockolds and Mitchell 1958, Howie 1955.) The chromium contents are low in most members of the gabbro suite of Central and Northern Helsingland. Only the davainitic gabbro displays the characteristics of an early differentiation product of an orogenic (cp. p. 15) basic magma, viz. the following order of distribution:  $\text{Cr} > \text{Ni} > \text{Co}$ . (See P. H. Lundegårdh, 1949 and 1950.)

The next stage of basic magmatic differentiation normally shows  $\text{Ni} > \text{Co} > \text{Cr}$ . This stage is in Table 2 represented by two gabbros showing increasing contents of vanadium though still retaining an earlier position regarding the An percentage of the plagioclase and the Mg: Fe ratio (determined only in one sample, however) than the genuine ore-gabbro.

In the latter chromium is frequently lacking, and in the final norite encountered in the south-eastern part of the Kramsta massif nickel, too, has been reduced to quantities below the sensitivity of spectrum analysis. The differentiation in the Kramsta massif earlier suggested and thus checked cannot possibly be due to metamorphism because the statistical probability of a secondary development of a normal magmatic geochemical trend similar to that displayed in Tables 1—2 is very small. A strong metamorphism should have certainly effected an oxidation implying the formation of highly mobile complex anions containing, *inter alia*, vanadium and chromium. Gabbro varieties almost free from these elements would in such a case form anomalies. An increase of the ore quantities in certain gabbro varieties owing

**Table 6. Iron, vanadium, titanium, phosphorus, and sulphur in magnetite<sup>1</sup> separated from the noritic gabbro of the Kramsta area.**  
Data in parentheses refer to total rocks.

Locality	% by weight of				
	Fe	V	Ti	P	S
Ore zone: Bax, Clax, Gax, top level, Kramsta <sup>2</sup>	64.0 (23.4)	0.785 (0.185)	3.72 (3.20)	trace (0.044)	0.8 (0.39) <sup>3</sup>
Do: rich-ore portions from drill cores (M, N = 6), do	60.3 (20.4)	0.765 —	6.07 —	— —	— —
Do: general sample from top level, do	60.8 (21.8)	0.84 (0.17)	— —	— —	— —
Gruvberget	63.1 —	0.81 —	— —	— —	— —
Skog mine, Storsveden	63.4 —	0.83 —	— —	— —	— —
Chemical analyses taken from Kjellberg 1930 and Kramsta report 1943.					

<sup>1</sup> Incl. microscopical intergrowths of exsolved ilmenite. (See p. 21.)

<sup>2</sup> Ratio ilmenite : magnetite *c.* 1 : 5.

<sup>3</sup> Contained in pyrrhotite essentially.

to metamorphic dissociation in the sense of Ramberg (1948) is on the other hand highly probable. (Compare p. 22.)

The distribution of manganese is even, whereas the distribution of cobalt is rather irregular. In the Kramsta massif, however, cobalt tends to vanish in the late gabbro.

For the purpose of comparison a number of Swedish rocks similar to the titaniferous gabbro of Central and Northern Helsingland have been collected in Table 3. The gabbro at Rackeby on the south shore of Lake Venern, in Northernmost Vestergötland, resembles the Kramsta gabbro in many respects though its ore has been more uniformly distributed all through the rock. The Rackeby gabbro has recently been studied by G. Stålhös (1958), who has shown that it displays a gabbro-norite grading into uralite-gabbro. Secondary garnet-amphibolite has been locally observed.

The bulk composition of the Rackeby gabbro reflects a late differentiation product of a basic magma. *Schlieren* of earlier anorthosite have, however, been seen, and local finds of rich-ore gabbro have also been reported. Landergrén has analysed for the present paper a rich-ore sample collected by Stålhös:

Fe .....	37 %	V .....	1,100 p. p. m.
Ti .....	4.5 %	Cr .....	200 "
		Co .....	180 "
		Ni .....	150 "

Chromium and vanadium have, indeed, been very strongly enriched in this variety as compared with the general sample displayed in Table 3. No doubt we have to deal here with a gabbro of earlier formation than the common

gabbro of the massif, viz. an equivalent to the early middle gabbro of Helsingland as exemplified by the metagabbro near Ängesholm (Table 2).

### Petrographic Parallels

The gabbro of Central and Northern Helsingland in many respects differs essentially from the Svecofennian primorogenic basites, which never show enrichments of vanadium-bearing titaniferous ore. Only the Svecofennian serorogenic ultrabasic gabbro of Roslagen, Eastern Uppland, contains quantities of titanium and vanadium which are comparable to those of the Helsingland gabbro. The diallage gabbro (eucrite) of Rådmansö thus shows  $V = 0.16 \%$  (P. H. Lundegårdh 1947, p. 40) and the norite (hypersthene-eucrite) at Grovstanäs  $Ti = 0.92 \%$  and  $V = 0.10 \%$  (Table 3). The composition of the plagioclase of the Roslagen gabbro is, however, by far more basic than that of the Helsingland gabbro. The eucrite thus shows  $An = 90 \%$  and the hypersthene-eucrite  $An = 86-87 \%$  (P. H. Lundegårdh 1947, p. 40). Besides, the Roslagen ultrabasic gabbro is structurally non-deformed.

On the other hand the Rackeby norite in Vestergötland above described might be paralleled with the Helsingland gabbro. The bed-rock surrounding the Rackeby norite belongs to the 'iron-gneiss' complexes of South-Western Sweden, whereas the norite itself is younger. Stålhös (1958) assumes it to have intruded simultaneously with the various other noritic gabbros in Southern Sweden, such as the Stavsjö norite (Askund 1925, P. H. Lundegårdh 1950 b) and the norite of the Göteborg (Gothenburg) region (P. H. Lundegårdh, 1953). These gabbros belong to the introductory phase of an orogenesis later manifested by the tectonization of part of the gabbros and the simultaneous formation of the Askim—Åmål—Kroppefjäll—Filipstad—Småland granites — an evolution classed as Late Gothian by P. H. Lundegårdh (1953, p. 5), who has then in part re-defined a term introduced by Wahl (1936) and widened by Magnusson (1936).

The Late Gothian norite and the titaniferous Helsingland gabbro have not only most petrographic and chemical features of their own in common but both of them are also associated with hornblende-bearing<sup>1</sup> granites which are most frequently porphyritic, with coarse microcline individuals. These are the porphyritic primorogenic granite of Helsingland and the Askim—Filipstad granites of Southern Sweden.

<sup>1</sup> The hornblende frequently enters among the main minerals.

## Literature Cited

- B. G. I. U. = Bulletin of Geological Institution of Upsala.  
 G. F. F. = Geologiska Föreningens i Stockholm Förhandlingar.  
 K. V. A. = Kungliga Vetenskapsakademien.  
 S. G. U. = Sveriges Geologiska Undersökning.
- Alarik, A. L:son, and co-workers, 1943: Utredning rörande Kramstafältet (Kramsta report). In stencil.
- Backlund, H. G., 1937: Die Umgrenzung der Svecofenniden. B. G. I. U., 27.
- Blomberg, A., 1895: Praktiskt geologiska undersökningar inom Gefleborgs län. S. G. U., C 152.
- De Vore, G., 1955: The role of adsorption in the fractionation and distribution of elements. Journ. Geol., 63.
- Eckermann, H. von, 1952: The rocks and contact minerals of the Mansjö mountain. G. F. F., 44.
- 1936: The Loos-Hamra region. G. F. F., 58.
- Goldschmidt, V. M., 1945: The geochemical background of minor-element distribution. Soil Science, 60.
- Heinrich, E. Wm, 1956: Microscopic petrography. Mc Graw-Hill Book Co., Inc.
- Hietanen, Anna, 1947: Archean geology of the Turku district in Southwestern Finland. Bull. Geol. Soc. America, 58.
- Hjelmqvist, S., 1950: The titaniferous iron-ore deposit of Taberg in the south of Sweden. S. G. U., C 512.
- Howie, R. A., 1955: The geochemistry of the charnockite series of Madras, India. Trans. Royal Soc. Edinburgh, 62: III.
- Igelström, L. J., 1883: Bidrag till frågan om malmernas af Tabergstypen geognosi, G. F. F., 6.
- Kjellberg, B., 1930: Några tekniska rön beträffande Kramsta, Gruvbergets och Storsveds vanadinförande titanjärnmalmförekomster i Järvsö socken av Gävleborgs län. Tekn. Tidskr., avd. Bergvetenskap, 60.
- Landergren, S., 1948: On the geochemistry of Swedish iron ores and associated rocks. A study on iron-ore formation. S. G. U., C 496.
- Lundegårdh, P. H., 1943: The Grovstanäs region. An ultra-basic gabbro massif and its immediate vicinity. B. G. I. U., 29.
- 1946: Rock composition and development in Central Roslagen, Sweden. K. V. A., Arkiv f. kemi, mineralogi och geologi, 23 A.
- 1947: Den ultrabasisiska gabbroen i Roslagen. Summary: The ultra-basic gabbro of Roslagen, Central Sweden. S. G. U., C 484.
- 1949: Aspects to the geochemistry of chromium, cobalt, nickel and zinc. S. G. U., C 513.
- 1950: Aspects to the geochemistry and petrology of plutonic ultra-basites in Sweden. G. F. F., 72.
- 1950 b: Några noriter från Östergötland och Småland. G. F. F., 72.
- 1953: Petrology of the Mölndal—Styrsö—Vallda region in the vicinity of Gothenburg. S. G. U., C 531.
- 1956: Hamrängesyngkinalens ytbergarter och deras metasomatiska omvandling. Summary: The Hamränge syncline and its metasomatism. G. F. F., 78.
- Magnusson, N. H., 1936: Om cykelindelningen i det svenska urberget. G. F. F., 58.
- 1949: Berggrunden i Sveriges geologi, sec. ed. Svenska Bokförlaget/Norstedts.

- Magnusson, N. H., 1953: Malmgeologi. Jernkontoret.  
— 1957: Berggrunden i Sveriges geologi, third ed. Svenska Bokförlaget/Norstedts.
- Mitchell, R. L., 1943, 1945, 1951. See Wager.  
— 1948: See Nockolds.
- Nockolds, S. R., and Mitchell, R. L.: The geochemistry of some Caledonian plutonic rocks: A study in the relationship between the major and trace elements of igneous rocks and their minerals. *Trans. Royal Soc. Edinburgh*, 61: II.
- Parwel, A., and Wickman, F. E., 1954: Några preliminära resultat av åldersbestämningar på svenska pegmatiter. *G. F. F.*, 76.
- Ramberg, H., 1948: Titanic iron ore formed by dissociation of silicates in granulite facies. *Econ. Geol.*, 43.
- Ramsay, W., 1909: *Geologins grunder*. Helsingfors.
- Redaelli, L., 1957: A petrological investigation in Lake Norra Dellen by means of frog-man equipment. *S. G. U.*, C 548.
- Sahlin, I., 1931: En grafisk metod för beräkning av järnmalmers oxidationsgrad. *Jernkontorets Ann.*, 86: 9.
- Sederholm, J. J., 1920: Några huvuddrag i mellersta Fennoskandias urbergsgeologi. *G. F. F.*, 42.
- Simonen, A., 1953: Stratigraphy and sedimentation of the Svecofennidic, early Archean supracrustal rocks in Southwestern Finland. *Bull. Comm. géol. Finlande*, 160.
- Stålhös, G., 1958: Rackebymassivet. Ett västsvenskt norit-gabbrointrusiv. Summary: The Rackeby norite-gabbro massif, Western Sweden. *S. G. U.*, C 558.
- Törnebohm, A. E., 1877: Om Sveriges viktigare diabas- och gabbro-arter. *K. V. A., Handl.*, 14.
- Wager, L. R., and Mitchell, R. L., 1943: Preliminary observations on the distribution of trace elements in the rocks of the Skaergaard intrusion, Greenland. *Min. Mag.*, 26.
- 1945: Distribution of vanadium, chromium, cobalt, and nickel in eruptive rocks. *Nature*, 156.
- 1951: The distribution of trace elements during strong fractionation of basic magma — a further study of the Skaergaard intrusion, East Greenland. *Geochimica et Cosmochimica Acta*, 1.
- Wahl, W., 1936: Om granitgrupperna och bergskedjeveckningarna i Sverige och Finland. *G. F. F.*, 58.
- Wickman, F. E., 1954: See Parwel.

**SVERIGES GEOLOGISKA UNDERSÖKNINGS SENAST  
UTKOMNA PUBLIKATIONER ÄRO:**

**Ser. Aa. Geologiska kartblad i skalan 1 : 50 000 med beskrivningar.**

Priset för karta i ser. Aa med beskrivning är 10:— kr, för karta enbart 8:— kr.  
(Price: map sheet + descriptive text Sw. cr. 10:—, map sheet Sw. cr. 8:—)

- N:o 187 *Värvik* av W. LARSSON och R. SANDEGREN. 1956  
 > 188 *Avesta* av G. LUNDQVIST och S. HJELMQVIST. 1946  
 > 189 *Falun* av O. KULLING och S. HJELMQVIST. 1948  
 > 190 *Söderfors* av R. SANDEGREN och B. ÅSKLUND. 1948  
 > 191 *Untra* av R. SANDEGREN och P. H. LUNDEGÅRDH. 1949  
 > 192 *Onsala* av R. SANDEGREN och P. H. LUNDEGÅRDH. 1952  
 > 193 *Gränna* av P. GEIJER, B. COLLINI, H. MUNTHE och R. SANDEGREN. 1951  
 > 194 *Säter* av S. HJELMQVIST och G. LUNDQVIST. 1953  
 > 195 *Särvö* av P. H. LUNDEGÅRDH och R. SANDEGREN. 1953  
 > 196 *Västerås* av P. H. LUNDEGÅRDH och G. LUNDQVIST. 1954  
 > 197 *Laholm* av W. LARSSON och C. CALDENIUS. T. v. utan beskrivning  
 > 198 *Halmstad* av W. LARSSON och C. CALDENIUS. » » »  
 > 199 *Uppsala* av P. H. LUNDEGÅRDH och G. LUNDQVIST. With English summaries. 1956

**Ser. Ad. Agrogeologiska kartblad i skalan 1 : 20 000 med beskrivningar.**

Priset för karta i ser. Ad med beskrivning är 8:— kr, för karta enbart 6:— kr.  
(Price: map sheet + descriptive text Sw. cr. 8:—, map sheet Sw. cr. 6:—)

- N:o 1 *Hardeberga* av G. EKSTRÖM. 1947, karta med beskrivning  
 > 2 *Lund* » » » 1953, » » »  
 > 3 *Revinge* » » » t. v. utan beskrivning  
 > 4 *Löberöd* » » » t. v. » »  
 > 5 *Örtofta* » » » t. v. » »  
 > 6 *Kävlinge* » » » 1955, t. v. » »  
 > 7 *Teckomatorp* » » » 1955, t. v. » »  
 > 8 *Trollenäs* » » » 1955, t. v. » »  
 > 9 *Bosjökloster* » » » 1956, t. v. » »

*Årsbok 48 (1954)*

- N:o 536 GAVELIN, S., A telluride assemblage in the Rudtjebäcken pyrite ore, Vesterbotten, N. Sweden. 1954. . . . . 1,00  
 > 537 JERLOV, N. och KULLENBERG, B., Undersökning rörande spridning och avsättning av i vattnet suspenderat slam vid utstjälpning av muddar i Byfjorden våren 1953. English summary. 1954 . . . . . 2,00  
 > 538 TULLSTRÖM, H., Hydrogeologiska förhållanden inom Slite köping på Gotland. English summary. 1955 . . . . . 1,50  
 > 539 JÄRNEFORS, B., Skredet vid Intagan år 1648. 1957 . . . . . 2,00  
 > 540 BYSTRÖM, A. M., Mineralogy of the Ordovician bentonite beds at Kinnekulle, Sweden. 1956 . . . . . 4,50

*Årsbok 49 (1955)*

- N:o 541 PILAVA-PODGURSKI, N., Nya geologiska undersökningar vid Utö järnmalmsfält. English abstract. 1956 . . . . . 3,00  
 > 542 HJELMQVIST, S., On the occurrence of ignimbrite in the Pre-Cambrian. 1956 . . . . . 1,00  
 > 543 KAUTSKY, G., Ein Beitrag zur Stratigraphie und dem Bau des Skelleftefeldes, Nordschweden. Mit 4 Tafeln. 1957. . . . . 6,00  
 > 544 LUNDEGÅRDH, P. H., Petrology of the Uppsala region, Eastern Sweden. With one plate. 1957 . . . . . 6,00

*Forts. å omslagets 4:de sida*

Årsbok 50 (1956)

N:o 545	BÄTH, M., An earthquake catalogue for Fennoscandia for the years 1891—1950. 1956 . . . . .	3,00
» 546	ÅHMAN, E., De glasiga diabasgångarna i Djupviks kalkbrott, Björkviks sn, Södermanland. — With English abstract. 1957 . . . . .	2,00
» 547	LUNDBLAD, B., On the stratigraphical value of the megaspores of <i>Lycostrobis scottii</i> . 1956 . . . . .	1,00
» 548	REDANELLI, L., A petrological investigation in Lake N. Dellen by means of frog-man equipment. 1957 . . . . .	2,00
» 549	LUNDEGÄRDH, P. H., The titaniferous ore-bearing gabbro of Helsingland Central Sweden. 1957 . . . . .	2,00

Årsbok 51 (1957)

» 550	LUNDQVIST, J., Övre Klarälvsdalens kvartärgeologi. — With English summary. 1957 . . . . .	5,00
» 551	LUNDQVIST, J., Geokronologiska undersökningar i Värmland. Med en plansch — With English summary 1957 . . . . .	2,50
» 557	LUNDQVIST, G., C 14-analyser i svensk kvartärgeologi. — With English summary. 1957 . . . . .	2,00

Ser. Ba.

N:o 14	Jordartskarta över södra och mellersta Sverige. Efter de geologiska kartbladen sammandragen vid S. G. U. av K. E. Sahlström. Skala 1:400000	
	Mellersta bladet, tryckt 1947 . . . . .	15,00
	Södra bladet, tryckt 1948 . . . . .	15,00
	Norra bladet, tryckt 1949 . . . . .	15,00

Ser. Ca.

N:o 21	LUNDQVIST, G., Beskrivning till jordartskarta över Kopparbergs län. Skala 1:250 000. 1951 . . . . .	20,00
» 27	CALDENIUS, C., and LUNDSTRÖM, R., The landslide at Surte on the river Göta älv. — Special chapters by B. FELLENIUS and E. MOHRÉN, With 5 plates. 1956 . . . . .	16,00
» 31	BORELL, R., och OFFERBERG, J., Geokronologiska undersökningar inom Indalsälvens dalgång mellan Bergeforsen och Ragunda. — Med 6 planscher With English summary. 1955 . . . . .	3,50
» 37	GAVELIN, S., och KULLING, O., Beskrivning till berggrundskarta över Västerbottens län. Karta i skala 1:400000. With English summaries. 1955	45,00

Rapporter och meddelanden i stencil

1.	Utredning rörande det svenska jordbrukets kalkförsörjning 1—2. 1931 (Kartorna utgångna) . . . . .	15,00
2.	Sveriges lodade sjöar. Sammanställning av K. E. Sahlström 1945 . . . . .	3,00
3.	Rapport över manganmalmsletningen i Jokkmokks socken 1940—48 av O. H. ÖDMAN. Med 4 kartor . . . . .	4,00

PRINTED IN SWEDEN

Distribueras genom

Generalstabens Litografiska Anstalts Förlag, Drottninggatan 20. Stockholm 16.