GEOLOGINEN TUTKIMUSLAITOS

BULLETIN

DE LA

COMMISSION GÉOLOGIQUE

DE FINLANDE

N:o 181

ON THE CHARNOCKITES IN THE LIGHT OF A HIGHLY METAMORPHIC ROCK COMPLEX IN SOUTHWESTERN FINLAND

BY

KAUKO PARRAS

WITH 24 FIGURES, 13 TABLES AND ONE MAP

HELSINKI 1958

GEOLOGINEN TUTKIMUSLAITOS
BULLETIN DE LA COMMISSION GÉOLOGIQUE DE FINLANDE N:o 181

ON THE CHARNOCKITES IN THE LIGHT OF A HIGHLY METAMORPHIC ROCK COMPLEX IN SOUTHWESTERN FINLAND

BY
KAUKO PARRAS

WITH 24 FIGURES, 13 TABLES AND ONE MAP

HELSINKI 1958

Helsinki 1958. Valtioneuvoston kirjapaino

PREFACE

Part One of this paper deals historically with the development of the charnockite concept from its beginnings to its vastly broadened present, while Part Two contains an exposition of the author's own observations, made on a basis of regional geology, of charnockitic and associated rocks. The red thread running through this study is the mineral facies principle and its application to charnockites. At the same time, the principle itself is examined within the bounds of the results obtained.

The various phases of the work are discussed in the following, namely, in the opening chapter of Part Two. In this connection, I shall limit myself to acknowledging, first of all, the persons who have decisively aided me in carrying out my project. The late Dr. Erkki Mikkola, who trained me in field work, occupies a special place in my thoughts, which gratefully go back to the years before the outbreak of the Finnish-Soviet Winter War in 1939.

I owe sincere thanks to the following:

My teacher and former chief at the Geological Institute of Helsinki University, Pentti Eskola, Professor Emeritus, who has at all stages encouraged me in my work and who also took the trouble of studying the manuscript to the present paper, notably the first part of it.

Prof. Th. G. Sahama of the Geological Institute of Helsinki University, who over a period of many years has offered me his support in numerous ways. Of particular value to the present study has been his guidance in the investigation of trace elements as well as his painstaking critical examination of the English version of Part Two of the manuscript.

Dr. Ahti Simonen of the Geological Survey of Finland, who, through the department under his charge, has contributed to making possible the completion of this study.

Prof. Adolf A. T. Metzger of Åbo Akademi, who extended me a helping hand during the final, complicated stages of the work.

Prof. Aarne Laitakari, Director of the Geological Survey of Finland and a former superior of mine, who has given me his authoritative support also during my later years as an industrial geologist and who, above all, has made the publication of my present study possible by accepting it for inclusion in this series.

In addition, I wish to express my gratitude to all those persons who have assisted me in the various routine tasks connected with this study.

Finally, I want to acknowledge my debt to the Emil Aaltonen Foundation and the Outokumpu Oy Foundation (Pentti Eskola's Special Foundation) for the research grants awarded me.

Credit for the English version of this paper must go to Mr. Paul Sjöblom, M. A., who translated Part One and corrected Part Two.

Lohja, March 1958.

Kauko Parras

CONTENTS

PART I

THE CHARNOCKITES — AN INDEPENDENT PROBLEM OR PART OF A GREATER WHOLE?

LIMITING TERM AND ITS CONSEQUENCES

The present charnockite concept is a good example of how a term, applied more or less arbitrarily, is liable in time to receive interpretations deviating greatly from its original meaning. Thus the majority of the studies dealing with charnockites that have appeared in the past couple of decades start out by grappling with the said concept, and the present author feels that he cannot avoid doing likewise. At the same time, he will consider the general basis of his subject in the light of the views of some thirty other researchers, tentatively laying stress on those general features he deems fundamental to a study of the pyroxenic rocks of southwestern Finland (Part II).

Descriptions of charnockites and pyroxene granulites date back in the literature to the middle of last century, but the foundation to recent research in this particular field was laid by Sir Thomas Holland in 1893, when he applied the name "charnockite" to the magnetite-bearing hypersthene-microcline granite met with in India, near Madras (St. Thomas' Mount and Pallavaram). The name was given in honor of Job Charnock, founder of Calcutta, whose tombstone, erected in 1695, was observed to represent this type of rock. In 1900, in his classical work "The Charnockite Series, a Group of Archaean Hypersthenic Rocks in Peninsular India", Holland discussed his concept in more detail and expressed the solemn hope that the term would never be applied to similar petrographical rocks (op. cit., p. 131) found beyond the borders of India and already known to exist in Europe, Africa and North America. Holland said inter alia he did not wish to be instrumental in adding to the constantly growing petrographical terminology (op. cit., p. 131). But what did happen? The literature on charnockites, which during the past half a century and more has been expanded by the contributions of some 140 researchers (about one-fifth of whom have dealt with the subject from a more theoretical standpoint), has been led to a further augmentation of its vocabulary, contrary to the aim of Holland, what with the adoption of such terms as "adamellite", "akoafimite", "arendalite", "bahiaite", "birkremite", "bugite", "enderbite", "farsundite", "ivoirite", "mangerite", "opdalite", "sabarovite", etc. Moreover, the concept of granulite as regional formations (Saxony, Ceylon, Finnish Lapland) also includes charnockitic rocks. In addition to the foregoing, there are still the customary terms deriving from the mineral composition of rocks. For another thing, the majority of researchers have none the less made use of the word "charnockite" in one or another application; and simultaneously this concept has spread out beyond its original confines to the extent that its use in a precise sense nowadays calls for repetitive elucidation in one publication after the other. Thus, Holland's intention of keeping these rocks as a specialty confined to the borders of India in a precisely defined sense has been totally defeated, and within a few decades the charnockites have developed into a worldwide petrological problem, commanding the steady interest of extensive geological circles. Up to now, studies concerned with the subject have originated from the following regions of the earth belonging to the pre-Cambrian basement (the literary reference in brackets includes, in most cases, only the latest researcher):

DISTRIBUTION AS KNOWN AT PRESENT

AFRICA

Angola: (Mouta & O'Donnell, 1933).
Cape Province: Kakamas, (Poldervaart & Backström, 1949).
Dahomey: Togoland, (Robertson, 1924).
French Congo: Gabun, (Arsandaux, 1912).
Gold Coast: (Junner, 1940).
Ivory Coast: (Legoux, 1939).
Kamerun: Akoafim, (Schüller, 1949).
Kenya: Embu-Meru area, (Pulfrey, 1946; Schoeman, 1951).
Natal: Port Edward, (Gevers and Dunne, 1942).
Nigeria: Bauchi Province, (Falconer, 1911).
Sierra Leone: (Dixey, 1925).
Tanganyika: Njombe District, (Stockley, 1948).
Uganda: (Groves, 1935).

ANTARCTIC REGIONS

Adelie Land: (Stillwell, 1918).
Enderby Land: (Tilley, 1937).
MacRobertson Land: (Tilley, 1937).
Queen Mary Land: (Nockolds, 1940).

ARCTIC REGIONS

Ellesmere Island: (C. Bugge, 1910).

West Greenland: (Ramberg, 1948—1956).

East Greenland: (Wager, 1934; Kranck, 1935; Sahlstein (Sahama), 1935).

ASIATIC CONTINENT and U. S. S. R.

Eastern Tien-Shan: (Norin, 1937).

Eastern Siberia: Aldan River and southern Baikalia, (Korjinsky, 1936—1940).

Northern Siberia: Anabar and Hatanga rivers, (Moor, 1942).

Ukraine: Podolia, (Lebedev, 1939).

AUSTRALIA

South Australia: Eyre Peninsula, (Tilley, 1921).

SW Western Australia: (Prider, 1952).

"Central Australia": (Wilson, 1952).

CEYLON

Central and SW parts of the island: (Fernando, 1948).

EUROPE

Central Europe: Austria, Bavaria, Bohemia and Saxony, (Scheumann, 1954).

Finland: (see p. 36).

Norway: (J. Bugge, 1940 and 1945).

Scotland: (Davidson, 1943; Sutton & Watson, 1951).

Sweden: (Quensel, 1951).

INDIA

Southern and eastern parts of the peninsula: (Holland, 1893, 1900; Pichamuthu, 1953; Paulose, 1956).

MADAGASCAR

(Hatch and Baron, quoted by Pichamuthu, 1953, p. 29).

NEW CALEDONIA ISLAND

(?, quoted by Pichamuthu, 1953, p. 29).

NORTH AMERICA

Canada: Montreal, Québec, (Jeremine, 1949).

U. S. A.: Adirondack, Bucks Country, Maryland, Virginia, (Buddington, 1952).

SOUTH AMERICA

Brazil: Bahia Negra, (Washington, 1916).

CHARNOCKITES AS ORIGINALLY DEFINED

Holland meant by the charnockite series a collective designation for the comagmatic series of hypersthenic igneous rocks that in southern India form a uniform and precisely defined petrographical province and whose members show intrusive relations to the associated older schists and gneisses. The series was divided into ultrabasic, basic, intermediate and acid divisions, while the rock types falling into each division nevertheless continued to retain their customary names, deriving from their mineral composition, such as ''pyroxenite'', ''biotite-augite norite'', etc., excepting hypersthene microcline granite, to which the term charnockite was specifically applied. The series thus came to represent primary crystallization and normal magmatic differentiation in its total extent. However, as an objective scholar, Holland observed that ''there are some features which are sufficiently unusual in normal igneous rocks ...'' (op. cit., p. 244), meaning thereby, inter alia, structural features as well as the general occurrence of garnet as a constituent formed at the expense of pyroxene. In order further to clarify the consanguinity of the different members of his charnockite series, Holland pointed out (op. cit., p. 129): ''... there are many gneisses in India containing pyroxene which are not genetic relatives of the charnockite series, and should not therefore be grouped with them.'' As a special petrographic characteristic of his series, Holland emphasized, first of all, the unusually dark color marking the outward appearance of the rocks, which is due to the colored quartz (blue) and feldspars as well as ore minerals and which gives — especially to acidic rocks — a darker than normal shade. This makes the rocks look, at the same time, more basic than they are in reality. As for their structure, a linear arrangement of the constituent minerals is characteristic of nearly all the members of the series, in addition to which also banding and a general gneissose appearance, indicating ''signs of dynamo-metamorphism'', are features of several types (op. cit., p. 125). The texture, in regard to which Holland used the term ''structure'', is permanently ''even-grained, granulitic (panidiomorphic)'' (op. cit., pp. 125, 154, 239; cf. p. 30). Furthermore, under the microscope all the minerals, according to Holland, are markedly clear and ''fresh'' and exhibit the same special features throughout the whole series. In addition to the coloring of the light minerals, a ''microperthitic structure'' (perthite and antiperthite) and ''quartz de corrosion'' (myrmekite) characterize the intermediate and more acidic rock types. Of the FeMg-constituents the most fundamental is the ubiquitous highly pleochroic hypersthene, besides which the gneissic rocks practically without exception also contain pink garnet. Less consistently occur augite, brown hornblende and deep-brown biotite. Among accessories magnetite and ilmenite occur in considerable abundance, whereas sphene is totally lacking.

Without undertaking a more detailed perusal of Holland's main work, the present author affirms that, dating back to 1900 as it does, it still maintains its position as the masterful petrographic study on which charnockite research as a whole is based. And, in spite of the numerous more recent studies, no one really interested in the question should be satisfied merely a second-hand acquaintance with the Holland classic.

CURRENT ENLARGED CONCEPT AND GENERAL FEATURES CHRACTERIZING IT

In shifting to a study of the problem in its present magnitude, it should be remarked right at the start that, according to the current terminology, which evidently is becoming established, charnockites are divided into ultrabasic, basic, intermediate and acid varieties, the last-mentioned group including also the charnockite proper. This signifies that Holland's inconvenient nomenclature has become simplified in form and essentially broadened in content, inasmuch as the present terminology, contrary to the original concept of the charnockite series, does not necessarily mean consanguinity of origin of the several types but is more flexible as regards petrogenetic history. In the currently extended sense of the term, as based on the known distribution of charnockites, the author herein presents a number of general and common features characterizing these rocks, supplemented by marginal remarks, at the same time touching upon certain closely related questions.

1) Charnockites have up to now been met with only in pre-Cambrian shields, that is, in highly metamorphic areas denuded deepest into the earth's crust, where they form local and distinctly demarcated petrographical provinces. As a case approximating an exception to the rule, however, might be mentioned southwestern Norway, where the Arendal district touches on the Caledonian range. Moreover, be it remarked that the high degree of metamorphism exhibited by the rocks should not unquestioningly be accepted as a criterion of their relative age.

2) In numerous instances, the petrochemical similarity of the various rock types of the charnockite provinces to their surrounding rock complex is obvious, as a consequence of which many investigators consider charnockites products of plutonic metamorphism of their immediate environment, with the prevailing mineral assemblage exhibiting high PT-conditions and "dry" material.

3) As it will become clear from the following, representatives of all the main petrogenetic types have been described as charnockites, so that the

relationship between origin and composition becomes less unified. Weighing the problem in its present magnitude as a whole, the mode of origin of the rocks can no longer, in the author's view, be held as the essential criterion of the charnockite concept; rather is the significance of this in itself important question of genesis limited to characterization of the general geological features of the area involved and in that sense to the formation of a total picture.

4) Although the present author thus considers the original nature of charnockites less fundamental to the definition itself, it does not mean that the other rocks belonging in association with them must be also left in the background. On the contrary, the author particularly wants to emphasize the significance of arena-argillageous and argillo-calcareous sediments (marly) associated with (metamorphic) charnockites as factors filling out the regional-petrological total picture. With this in mind and in addition to the foregoing, the frequently made observation warrants mention that the charnockite milieu sometimes includes, besides the ''younger'', usually leucocratic granites, anorthosites and eclogites as well; the latter are, however, surprisingly scantily represented, in view of the fact that the charnockites are believed to have originated at great depths.

Instead of the charnockites being less uniform within the framework of their origin and general mode of occurrence, as mere petrographic types (understood in a restricted sense) they exhibit all the more clearly special common features, corresponding to the type areas of India, as recapitulated here in somewhat more detail:

5) As for outward appearance, first of all, the rock of acid and intermediate composition are characterized by their brownish gray, grayish yellow, greenish and even bluish color, deriving essentially from colored quartz and feldspars and giving the rocks a darker shade than the presence of mafic constituents would bring about. The brownish color of the weathering surface, in particular, is enhanced by the Fe-rich orthorhombic pyroxene, which changes to a rusty brown. The structure naturally accords with the genetic-tectonic history of the rocks in question, but the author wishes to emphasize that, according to numerous descriptions, a parallel arrangement of the minerals, at least, as well as banding and a gneissose appearance are sooner prevalent than rare, compared to a directionless structure.

6) Fundamental especially to the texture of metamorphic charnockites, in regard to which various current terms have been used, are the even grain of the constituents and the absence of crystal forms, owing more or less to simultaneous crystallization, while at the same time all the minerals are under the microscope notably clear and fresh. Furthermore, noteworthy is the tendency in certain rock types of the mafic mineral assemblage to

form common aggregates, whereas in others the dark constituents tend distinctly to arrange themselves into monomineral bands. The present author refers, in addition, to the most recent exchange of opinions concerning these structural and textural matters (cf. Quensel, 1951, pp. 232, 304; Eskola, 1952, p. 166; Pichamuthu, 1953, p. 8; cf. p. 29).

7) Among the most distinct common features are the constituent minerals and the peculiarities pertaining to them. As regards FeMg-minerals the ubiquitous orthorhombic pyroxene occurs either exclusively or accompanied by one, some or all of the following: ± clinopyroxene (diopsidic), ± brown hornblende, ± reddish brown biotite, ± pink garnet. The ultrabasics are generally characterized by olivine, together with pyroxenes and amphiboles. Among those listed the following three, perhaps, deserve most attention: orthorhombic pyroxene is represented by Fe-rich hypersthene, the special characteristics of which include, in addition to the frequently observed abnormality of its chemical composition (aluminous), the variability of the pleochroism and the nearly always observed oblique extinction. A strong pleochroism or its total absence appears to be a regional phenomenon; but taken summarily it is strongest in the hypersthene of basic and weakest in that of acidic rocks. The contrary, however, may also be observed. The pleochroism and the oblique extinction have received numerous differing explanations, to which the present author, for his part, has added one more in another connection (Part II). Hornblende and biotite, which, according to Eskola's well-known mineral facies definition, ought not to belong to the mineral paragenesis of granulite facies and thus neither among the typomorphic constituents of the charnockites, nevertheless occur quite generally as stable crystalline phases of these rocks. Explaining this matter continues to cause difficulties. The present author wishes to point out tentatively, at the very beginning, that the said minerals deviate, among other peculiarities, in their very color from the normal (amphibolite facies), as well as in their content of volatiles (and alkalies), which has been ascertained to be only one-half that usually met with. In sum, therefore, it might be stated that the main constituents of the mafic mineral assemblage of the charnockites are represented by dry minerals, characterized at the same time by a high density and an abnormality of features appearing in one way or another. Futhermore, their order of crystallization is reversed, in principle, compared with Bowen's well-known fractional crystallization series, since hornblende occurs in basic rocks, whereas rhombic pyroxene, especially, is a fundamental, even an exclusive constituent of acidic types, too, including pegmatitic segregations. Since, moreover, garnet is likely to occur independent of the acidity of the rock, like pyroxene, the petrogenesis of charnockites proves to be a rather complicated process, the interpretation of which along a magmatic line seeks support from e. g.

exceptional crystallization conditions and dry magma, whereas the "red thread" running through the metamorphic argument is charnockitization, or presented as a schematic reaction series (corresponding to a basic composition):

$$\text{hornblende} \xrightarrow{\text{acidification of the plagioclase}} \text{diopside}$$

$$\text{diopside} + \text{plagioclase} \xrightarrow{\qquad\qquad} \begin{cases} \text{hypersthene} + \text{garnet} + \\ \text{secondary quartz} \end{cases}$$

8) The previously mentioned coloring of the light minerals is a phenomenon caused by different inclusions, such as rutile, and it varies from area to area, especially in regard to quartz. Further, in numerous studies emphasis has been placed on the sparse twinning of plagioclase in general or the lack of albite twinning in particular, as well as the absence of zoning, which last-mentioned feature is a more regular observation. The author wants to point out that a poorly developed twinning and the absence of zoning are characteristic of metamorphic rocks on the whole. Potash feldspar is customarily reported to be orthoclase, but the determinations are based on the absence of cross-hatched twinning and on extinction angle observations, which as such do not suffice as proof of a separation of potash feldspars from each other. In addition, Naidu (1954) reported that all the potash feldspar of the Indian charnockites is exclusively microcline. This circumstance has significance insofar as the monoclinic symmetry of potash feldspars is commonly held to be a higher temperature form than the triclinic.

9) The general, abundant occurrence of perthite and antiperthite, in addition to myrmekite, must be considered especially characteristic of acidic and intermediate charnockites. These microstructures of feldspars possess an obvious characterizing significance as regards the crystallization conditions of rocks, to the extent, in fact, that their various modes of occurrence have even been stressed as mineral facies indicators (cf. Eskola, 1952, pp. 148—149).

10) A fundamental feature of the accessory minerals is the abundance of magnetite and ilmenite in the acidic types as well, where rutile likewise occurs, chiefly as needle-like inclusions in the quartz. On the other hand, with the exception of "non-charnockitic" calcareous rocks, sphene is totally lacking; and this mineral — or, more broadly speaking, the incorporation of titanium in the different crystalline phases — possesses a considerable significance in mineral facies.

PETROGENESIS

THEORETICAL TRENDS AND MINERAL FACIES PRINCIPLE

During the course of more than half a century, many different theories on the mode of origin of charnockites have been presented, some of them being based — with certain reservations, to be sure, — on magmatic differentiation by crystallization of the calc-alkali suite, some on the metamorphic recrystallization of the igneous rocks thus produced, some on the ultrametamorphism of the older complex of heterogeneous origin, and some on more or less complicated combinations of the others. The very multiplicity of the reasoning indicates that "all roads lead to Rome", i. e. to the charnockitic mineral assemblage, regardless of the original nature of the material providing the point of departure, just so long as the bulk composition (concentration of components) remains within known bounds and the guiding factors are specific PT-conditions. Starting from this premise, the author, for his part, deems it more important to underscore the similarity (or possible dissimilarity) of charnockites in the light of the principle of mineral facies and to examine regional questions as a petrological whole, instead of concentrating on these rocks merely as petrographic oddities and endeavoring to characterize their genuineness or non-genuineness on the basis of their mode of origin. Since, however, probing into origins, significant itself, constitutes the most essential part of nearly all charnockite research up to the present, the author feels obliged to present a fairly broad, generally chronological review of the matter, supplemented by pertinent remarks. For this purpose, a number of studies have been selected which expressly disclose both the differences of opinion held and the gradual extension of the charnockite concept to its current breadth.

COMPARATIVE REVIEW OF RESEARCH HISTORY

Although the names Holland and charnockite are inseparably bound together, it should nevertheless be borne in mind that the charnockite concept as a general petrological problem began to develop — not in India alone, but in various parts of the world and approximately at the same time — about the middle of last century. Thus, before the year 1900 pyroxene granulites and other hypersthenic rocks had been described not only from India and Ceylon but also from Madagascar (Hatch, 1889), Africa (Kenya) (Rose, 1863), Saxony (Naumann, 1858 and Lehmann, 1884), Austria, Bavaria, Bohemia, Norway (Vogt, 1893 and Kolderup, 1896), Canada (Adams, 1896) and the U. S. A. (C. H. Williams, 1886—1894 and J. F. Kemp, 1893). These classical studies largely favor a magmatic origin, albeit the admission is made that the intrusive nature of, especially, pyroxene granulites (Saxony) cannot be demonstrated. Holland, for his part, noted an evident petrographic similarity existing between his own charnockites and the non-Indian pyroxene granulites, while at the same time they all appeared "as members of the Archean crystalline series ..." (op. cit., p. 204). As an example of the parallel advances made in different parts of the globe during this classical stage of research, it might be pointed out that, precisely in the same year of 1893 that Holland defined his term "charnockite", quite independently of the former, Vogt produced his report from the Egersund region of southwestern Norway on norites, labradorites and hypersthene-potash feldspar granite. Vogt regardet these rocks as comagmatic. Subsequently, in his chief work, Holland remarked (p. 135) — referring particularly to the granite: "Such a description applies exactly to the rock which is known to us in South India as charnockite." Holland's view was further bolstered by Kolderup's (1896, et seq.) more detailed report on the same rocks (Holland, 1900, p. 209; see p. 29). Be it mentioned in this connection that Kolderup later gave these charnockitic types the names of "mangerite" and "birkremite" (Kolderup, 1903, p. 98).

In addition to the noritic and labradoritic rocks of Norway, Holland also focussed attention on the "pyroxene-granulites" and anorthosites of Canada and the U. S. A. (op. cit., pp. 204, 207—208), and thus the next step in the development of the charnockite question is represented by Rosenbusch's (1910, p. 183) "Charnockit-Anorthositreihe" and Goldschmidt's (1916 and 1922) "Anorthosite-Charnockite Group" as well as, a bit later, Suter's (1922, pp. 307—330) "Charnockit-Anorthosit-Provinzen", which, well known general petrologically, represent the magma type poor in water and are based on the corresponding rock formations of the Bergen—Egersund—Soggendal areas (southwestern Norway) and of Canada and the Adirondacks. The present author does not intend, however, to delve into the genetic relations between anorthosites and charnockites but will confine himself to noting, in this connection, that the question has been subsequently dealt with on the basis of differentiation through crystallization of a magma by e. g. Buddington (1939—1952) and Balk (1931, 1944), in reports on the massifs of the Adirondacks. The latter stresses that volatiles play a greater role in the consolidation of anorthosites than previously suspected. Further, Quensel (1951, pp. 309—311), among others, takes a negative stand toward the genetic kinship of the said rock groups. J. Bugge (1943, pp. 80—81) remarks, again, that the anorthosites of southwestern Norway must continue to be regarded as products of magmatic differentiation. In contradiction to all the others cited in the foregoing, Ramberg (e. g. 1948c, pp. 326—327) holds that the rocks generally belonging to the charnockite-anorthosite series are products of plutonic metamorphism and metasomatism.

To return to a chronological sequence, we meet simultaneously with Goldschmidt the known work "The charnockite series of igneous rocks" by Washington (1916), which, built up on a microscopic-petrographic and petrochemical bases, represents the culmination of the magmatic outlook in charnockite research, inasmuch as opinions after this gradually begin to lean in favor of metamorphic reconstruction.

Vredenburg (1918) is probably the first, in studies relating to India, seriously to shake the comagmatic viewpoint upheld by Holland and esteemed as authoritative for nearly two decades. Basing his conclusions mainly on observations made by others, Vredenburg argued in favor of the charnockites of South India, as represented by their present types, as having most evidently originated as the result of metamorphism. He pointed out that the charnockites as well as khondalites represented the high temperature metamorphic facies of preceding volcanic rocks and, correspondingly, sedimentary formations (dharwars). He likewise called attention to the hybrid and, by and large, synthetic nature of intermediate charnockite types as an impregnation result produced by acidic material (op. cit., p. 444). This observation, incidentally, is made from time to time in subsequent studies as characterizing the intermediate type.

About the same time as Vredenburg, the metamorphic trend was started in the charnockite areas situated outside the boundaries of India by Stillwell (1918, Antarctic Continent), who explained that the hypersthene granulites of Adelie Land represented in origin a series of primary igneous rocks thoroughly recrystallized under the conditions of kata-zone metamorphism.

Although the regional-metamorphic mode of origin of charnockites had a theoretical champion in Harker (1909) already during the initial stage of the evolution of the question, it was not until the emergence of Vredenburg and Stillwell that a notable change of direction in the petrogenetic interpretation of the said rocks actually could be recorded, while the subject gradually began evolve, along with the growth in research, into a "problem" both in India and beyond. The views herein discussed at first, however, remained more or less mediatory. Thus, for instance, Evans (1921) and Rama Rao (1924 et seq.) regarded noritic rocks as the crystallization products of contaminated magma that had assimilated aluminous sediments — and this interpretation, with its numerous variations, has received wide application also in subsequent studies.

In continuing to pursue the gradually accelerating evolution of the charnockite question along its metamorphic course, attention at this point should be called to Tyrrell (1926, et seq.) and his plutonic metamorphism, applied to which principle the mode of origin of the said rocks requires no further exposition on the part of Tyrrell.

The next landmark along the metamorphic line is Groves (1935, Uganda, Africa), who in his masterly and logical study, "The Charnockite Series of Uganda ...", brought out in particular the microscopic-petrographic and mineralogic-petrochemical clues that later researchers favoring the metamorphic approach have pursued in their own areas and, proceeding in accordance with regional-primary special features, reached in principle the same terminal point. The essential thing about Groves' study is the fact, that, first among western charnockite investigators, perhaps, he (cf. Korjinsky, p. 19) underscored the petrogenesis of these rocks in a mineral facies spirit and called attention particularly to the deviating composition of FeMg-minerals, their reversed sequence of crystallization (Holland likewise) and microscopic-petrographic abnormalities in general, interpreting them as resulting from recrystallization under raised PT-conditions, whereupon noncharnockitic rock has evolved into a rock with charnockite mineral composition without the bulk chemical composition having fundamentally changed.

Bezborodko (1931, Ukraine, U. S. S. R.) appears to have been the first to call attention to the plagioclase-dominance of the acidic members of the charnockite family in lieu of the potash feldspars ("bugite", "sabarovite"). The same matter was stressed by Tilley (1936 and 1937, Antarctic Regions), who, in addition to his charnockite material from Enderby Land, perceived the plagioclase-rich acid type to be common in the other then known charnockite provinces, too, including the Holland type areas, and gave this hypersthene-plagioclase (oligoclase-andesine) granite, which was further marked by a strong formation of antiperthite, the name "enderbite" in distinction to Holland's "charnockite proper" with its dominance of potash feldspar (microperthite) (1936, p. 314). Tilley perceived the enderbitic composition to belong among the questions still awaiting an answer which concern the differentiation of acidic charnockites. In the same connection, he also took note of the perthitic and antiperthitic textures typical of these rocks that "might be accounted for by consolidation of a comparatively dry magma, crystallization being arrested at a high temperature due to the paucity of water in the magma" (1937, p. 15).

To linger a while longer in the company of the enderbite question, Schüller (1949, Kamerun, Africa) has also delved into it in his work, considering it in a petrochemical light with the aid of rock analyses from various charnockite areas. As his result, Schüller reports (p. 582) that the molecule ratio alkalifeldspars/anorthite remains unaltered and wholly independent of its silica content, which varies in the analyses used as follows: SiO_2 75.50—47.44 %. Inasmuch as this, combined with the occurrence of orthorhombic pyroxene in acidic rocks as well, does not in the least accord with Bowen's known reaction series, Schüller considers it to argue strongly against the enderbites' being true magmatic rocks.

The term enderbite given by Tilley has been well received by contemporary charnockite researchers, but, in the opinion of the present author, there is room for critical wariness in its application: Tilley quite obviously intended his enderbite concept to concern expressly the acidic members of magmatic differentiation and these alone, whereas the term has subsequently been applied also to metamorphic and simultaneously, from the viewpoint of chemical composition, even intermediate charnockites of heterogeneous origin. Accordingly, it seems to the present author that the enderbite concept, too, is sliding away from its original meaning and is primarily being twisted to signify the commonest pyroxene-plagioclase charnockites of the sub-acidic — intermediate group in general. In other words, one further source of confusion is being created.

Among the most striking studies from a theoretical point of view are those of Korjinsky (1936—1940, U. S. S. R.), relating to the extraordinarily extensive Archaean complex of eastern and southeastern Siberia. The Aldan massif belonging to these formations includes e. g. the diopside-plagioclase-scapolite- and biotite-garnet-cordierite gneisses as well as, associated with them, hypersthene-plagioclase gneisses, all of which are regarded by Korjinsky as sedimentogeneous rocks by origin and which had metamorphized under the PT-conditions of the Aldan facies. As for the hypersthene-plagioclase gneisses, Korjinsky describes them as ''absolutely'' identical to the charnockites of India and feels justified in calling them ''charnockite crystalline schists'' (1936 c, p. 73). The Aldan facies of Korjinsky corresponds to the granulite facies of Eskola in respect to mineral assemblages, but is built up on a different basis, namely, the instability of Ca- and Mg-silicates under CO_2-pressure (carbonatization) in such a way that upon a rise in this pressure only the association hypersthene + plagioclase is, in the main, stable at great depths — in addition to quartz and carbonates. In other words, according to Korjinsky, the hypersthene-plagioclase gneisses and charnockites as a whole represent among all known rocks those of most deep-seated origin in the earth's crust, whereas, again, the eclogites, in especial, contrary to Eskola's (1921) well-known theory, are notably more superficial, corresponding to rocks of medium-depth formation (1937, p. 393). Since the present author does not intend to deal with eclogites at greater length in other connections, be it added at this point, first, that the absence of these rocks from the charnockitic milieu — in spite of the favorableness of the bulk chemical composition presupposed by eclogites — is really noteworthy. As the best known of occurrences, perhaps, there are the ones described by Ghosh (1941, p. 14) and Rama Rao (1945, p. 46) in India and by Sahlstein (Sahama) (1935) in East Greenland. In the second place, attention should be called e. g. to the genetic view held by Backlund (1936), according to which, contrary to Eskola's theory, the eclogites had not formed so much in response to hydrostatic pressure as to chearing stress, thereby sooner corresponding in character to tectonites than representatives of great depths. Among subsequent works following the Backlund line, the latest should be referred to, namely, Dengo's study (1950) on the eclogitic and glaucophane amphibolites of Venezuela, wherein (p. 877) it is stated in summary: "One fact seems to be clear, that there are high density rocks which formed under conditions of regional dynamothermal metamorphism of intermediate grade, and not necessarily under uniform pressure or under high grade metamorphism."

J. Bugge (1940—1945, Norway) divides the Kongsberg-Bamble formation of Arendal, southern Norway, into two different petrogenetic parts: The "Old Complex", comprising metamorphic representatives of arenaceous, argillaceous and calcareous sediments, together with banded gneisses, and the "Younger Complex", formed "during or after the migmatization period" of the former (1943, p. 10). To this last-mentioned group belong e. g. the charnockitic rocks, which Bugge terms arendalites (1940, p. 11). Arendalites are thus migmatitic rocks, which, on the one hand, exhibit a "more transgressive character" and, on the other, grade over into banded gneisses, and which have originated pretty much in situ "by a metasomatic transformation of a pre-existing rock complex» under PT-conditions of the granulite facies (1943, pp. 141—142). In his more recent report (1945, p. 32) Bugge stresses the decisive role in arendalization played by diffusion and reactions taking place in a solid state. He describes the relations between intrusive types and banded gneisses, for example, as follows (p. 38): "The magmatic character sometimes exhibited by the arendalites must be explained by the effect of exothermic reactions during the homogenization, causing a local heating of the rocks as compared to the surrounding rocks." Limiting himself to this brief reference, which does not do justice to Bugge's manifaceted investigations concerning the petrogenesis and the application of the facies principle, the present author wishes, with an eye on his own area, to point, in addition, to the views expressed by Bugge in regard to the Kongsberg-Bamble formation's belonging to the deepest parts of Svionic series exposed in southern Norway and southern Finland (1943, pp. 135—137). As is known, the occurrence of this "charnockitic horizon" also in southwestern Sweden has subsequently been verified, thanks to the investigations of Quensel (1951) (see p. 27).

In his theoretical examination of the Archaean rock crust of India, Dunn (1942) focusses special attention on the part played by water in regional metamorphism (p. 233): In connection with folding, the water is squeezed out from deep-seated sediments, etc., — they dry up; and if the temperature be high enough to melt them, a dry palingenetic magma forms, which in turn tends to press away from its original environment up to higher levels, behaving there after the fashion of intrusives. Thus would be comprehensible, according to Dunn, the occurrence e. g. of the charnockites of India in association with dry sedimentic rocks — khondalites. Furthermore, water escaping from one spot tends, at the same time as it carries along certain substances, to cause far-reaching changes in previously crystallized rocks elsewhere, at higher levels. Thus would be explained differences in degree of metamorphism in quite narrow bounds without their necessarily being due altogether to differences in PT-conditions. In this connection, the present author would like to mention also the views presented by Yoder, Jr. (1952 and 1955) in regard to the water content as an essential factor in mineral facies; the matter will be discussed in Part II.

Gevers and Dunne (1942, Natal, South Africa) describe, in addition to the normal granites of their area, "migmatitic charnockitic rocks" as well as garnet and hypersthene granulites, all of which are closely inter-related. In clarifying the petrogenesis of these rocks, their point of departure is a metamorphic "fundamental complex" of heterogeneous origin, in connection with the later folding of which there took place an intrusion at the same time of "old granites". In the further formulation of the genetic history following this epoch, there then appear in turn such concepts as anatexis, assimilation, granitization, hybrid, migmatization, palingenetic fusion, etc., with the whole story ending up as follows (p. 213): "Needless to say, it is not suggested that normal charnockites were in their entirety produced by a simple process of fusion and subsequent crystallisation of pre-existing hypersthene-granulites. The process visualised is one of palingenesis and widespread granitisation varying in intensity from place to place." As for the charnockites in themselves, they are represented only by acidic and sub-acidic types, in the naming of which the authors, wanting to respect Holland's well-known wish in the matter, apply the form "charnockitic" (p. 184) and regard them, in spite of a rather complicated descriptive style, as "normal", while, on the other hand, they totally shut out beyond the pale of this term the "pyroxene granulites" of identical mineral paragenesis, evidently on account of the magmatic nature of the first-mentioned.

Pulfrey (1946, Kenya, Africa), whose district of investigation is a small part of the large area of Equatorial Africa, into which the most African charnockite occurrences are concentrated, beginning from Sierra Leone in the west continuing to Kenya in the east, represents in his approach all the contrariness of the metamorphic-secondary mode of origin. According to Pulfrey's description which avoids use of the term charnockite, the members of "a suite of hypersthene-bearing plutonic rocks in the Meru District" range in composition from the ultrabasic to the granodioritic; at the same time, the suite shows "the operation to some degree of differentiation by crystal sinking in situ" (p. 83). This primary-magmatic character — without appreciable indications of regional metamorphism — is also exhibited by the crystallization order of the mafic minerals, which clearly brings out the tendency of successive reaction series, in accordance with Bowen's principle (p. 85).

Schoeman (1951, Kenya, Africa), whose research territory is situated close to the preceding, has reached quite the same conclusions as Pulfrey as regards the genesis of the basic members in his description of the "Charnockitic Suite" (Schoeman, p. 41), but he deviates in respect to the intermediate and acidic migmatitic charnockitic gneisses surrounding the basic massif, considering the latter mainly to be granitization products of the former (pp. 42—45).

The charnockitic rocks of Australia, which have been the object of research for decades, occur in separate areas of the pre-Cambrian shield in the central, western and southern parts of the continent. Without delving into the details, the present author wishes to call particular attention to the studies of Prider (1944—1952) and Wilson (1947—1952). The latter, in his latest work, dealing with the charnockite problem as a whole, gives a clear general picture of the petrogenesis (Wilson, 1952, p. 16), which concludes as follows: "20. The opposing assertions that 'all charnockites are igneous', and that 'all charnockites are metamorphic' are both inadequate. In Australia there are rocks almost identical with representatives of the whole 'charnockite series' of Madras. Although most of the Australian charnockites are of metamorphic origin, there are important representatives of the intermediate and acid charnockites of Central Australia which are of magmatic origin." This generalized conclusion by Wilson is of singular importance in the respect that, in the opinion of the present author, it also amounts to a general summary of the questions relating to the origin of charnockites met with in the different parts of the world.

Ramberg (1948—1956, West Greenland), whose name is known in the sphere of metamorphic petrology, deals with charnockites and associated non-charnockitic rocks expressly as a mineral facies totality, while in regard to questions bearing on genesis he adheres strictly to the metamorphic line. According to Ramberg, the mixed gneiss complex preceding the present charnockite province of West Greenland became caught at lower levels of the crust in a sphere of high grade regional metamorphism corresponding to PT-conditions of the granulite facies, whereupon the chemically bound water was squeezed out, the rocks became thoroughly recrystallized and in part re-activated, so that e. g. the present enderbitic gneisses (corresponding to the former hornblende-biotite gneisses) in turn penetrated the norites, or former diabases. The present high facies complex as a whole is represented by the norite-anorthosite-enderbite-charnockite series, together with the marbles, khondalites, kinzigites and graphite gneisses. In spite of the local massive structure and magmatic character, the charnockitic rocks of West Greenland are thus the products, according to Ramberg, not of magmatic differentiation but high grade regional metamorphism (e. g. 1948a, p. 325 and 1949, p. 35).

Presented in this generalized form, as it has been done consistently, Ramberg's genetic definition accords with the views of other investigators supporting a metamorphic mode of origin. However, unnoticed thereby would remain the fundamental discrepancy between the theories of Ramberg and the others concerning the relation of the bulk chemistry of the metamorphic charnockite provinces in respect to their surroundings. The discrepancy lies in the circumstance that whereas the others, starting with Vredenburg, regard the charnockites as being isochemical (chemically equivalent) with the surrounding non-charnockitic rocks and use precisely this observation as one argument in favor of metamorphic recrystallization, a negative stand toward the isochemical thesis must be taken on the basis of Ramberg's conclusions. According to the latter's observations, there is a great difference between the bulk chemical composition of the charnockitic formation and the lower facies complex bordering on it in West Greenland (e. g. 1951, p. 29), which theoretically generalized means that rocks metamorphized under high facies conditions taking place at considerable depths tend to become more basic than at higher levels as compared to their original state. The reason is that the H_2O, Si, K, Na and O_2 are first squeezed out at a depth from recrystallizing mineral lattices and then diffused through solid rocky matter upward to higher levels, bringing about there, under low facies conditions, hydrous minerals, granitization, etc. (e. g. 1951, p. 33). Passing over the mechanism of the theory in question as irrelevant to the theme at hand, the present author wishes to emphasize the matter simply in a mineral facies sense and as concerns expressly reconstructed rocks, i. e. the possible dependence of the bulk chemistry (of individual rock varieties and also the regional complex) on the stability of the minerals under diverse PT-conditions. This is a circumstance that confronts Eskola's mineral facies principle with difficulties by requiring in the principle that during recrystallization the bulk composition of the rock does not change, no matter in what direction the PT-conditions might change. Further, there comes to the fore the antithesis Eskola/Korjinsky (cf. pp. 19, 33), with the facies system of the latter being based exactly contrariwise on the dependence on depth and CO_2-pressure (carbonatization) of certain crystalline phases and, at the same time, also of the bulk chemistry of rocks.

After following the history of research in the field under consideration outside India nearly up to the present day, the author will now review developments taking place in the meanwhile within the original country:

The very existence of some fifty different researchers offers, in the first place, proof that the charnockite question has continued to receive attention also within the Indian internal sphere — though, to be sure, it should be borne in mind that vast territories are involved. In any event, the scientific labors of decades has led to a division of the entire Indian Peninsula into two differing geological parts, the charnockitic and the non-charnockitic, with the first-mentioned comprising, albeit not quite uniformly, the eastern and southern regions of the country. As for solutions to the problem itself, again, the present author has gained the general impression that a number of India's own contemporary geologists persist in upholding the thesis of magmatic differentiation, whereas the majority nevertheless adhere, even grimly, to the metamorphic line first laid down by Vredenburg (1918). Confining himself to the most recent publications alone, the author calls attention to the following five:

Ghosh (1941, Bastar State and western Jeypore, eastern India) regards the charnockites of his area as variants of diopside gneisses, which, in turn, represent originally impure calcareous sediments: Diopside gneisses that already once before had undergone metamorphism were again exposed to first soda- and then potash-metasomatism under risen temperatures owing to the influx of granitic magma, while the FeMg-constituents (aided by feldspars) underwent alterations from one mineral into another. Accordingly (op. cit., p. 2), "the 'differentiation' effect observed in this suite of rocks is not of magmatic character, but is one connected with metamorphism and hybridism." The changes of this — in detail seemingly complicated — metamorphism, resulting in rocks of synthetic character, are elucidated by Ghosh by means of a detailed microscopic-petrographic description, together with mineral-chemical equations.

Of all charnockite investigators proper, Rama Rao (1924—1945, Mysore, western S India) appears to have, perhaps, the longest experience in the field behind him and, especially, to be the most productive in the publishing sphere. In respect to his detailed and many-sided observations and views on the total charnockite question in the Mysore area, the present author will limit himself to the following petrogenetic summary review, adding the remark that some of the ideas expressed go back as far as the 1920's, chronologically speaking, i. e. back to the initial stages of the metamorphic approach:

According to Rama Rao, every kind of primariness, excepting the bulk composition, perhaps, of certain types, is alien to charnockites, whereas diversity or origin and the secondariness marked by metamorphic reconstruction are dominating features. In respect to origin, the "hypersthene granulites" of Mysore are divisible into three main categories: 1) Sedimentogeneous rocks, whose original chemical composition has varied within extensive bounds and whose representatives, subsequent to metamorphic recrystallization, are now correspondingly met with as acidic, intermediate and basic charnockites. 2) Basic magmatic rocks, which upon intruding have assimilated e. g. aluminous sediments and which now occur as hypersthene gabbros, norites and pyroxenites, corresponding to basic and ultrabasic charnockites. 3) The numerous granitization products of basic charnockites (magmatic as well as sedimentogeneous), caused by younger granitic intrusions and now represented by intermediate and acidic charnockites. Rama Rao underscores the fact that basic streaks and patches in acidic types do not signify differentiation by crystallization of a magma, as e. g. Holland decided in regard to corresponding cases, but true xenoliths deriving from some older rock formation (op. cit., p. 106). Thus, the charnockites or hypersthene granulites of Mysore do not represent consanguinity of origin but have formed through recrystallization "— from repeated metamorphism and granitization — of a complex series of diverse types and different modes of origin and age relations" (op. cit., p. 1). Together with hypersthene granulites, rich in calcium and aluminum and, at the same time, deviating from the charnockites in mineral associations, all of which Rama Rao refers to under the common term of "charnockitic rocks" (op. cit., p. 89) and which jointly form the present high-grade metamorphic province.

Rajagopalan (1946 and 1947, Madras, eastern S India) is one of India's comtemporary petrologists who continue to hold fast to the igneous origin of charnockites — though, to be sure, the area of investigation of these men is comparatively limited. Thus, Rajagopalan has focussed his attention on the very area embraced by Holland's type (St. Thomas' Mount), the rocks of which he aspires to demonstrate, solely on the basis of a mineralogical description (1946) and by adapting a few (new) rock analyses to Niggli's diagrams, to represent the igneous rocks produced through differentiation by crystallization of calc-alkalic magma. He attributes the previously known abnormalities, namely, at the basic end monoclinic pyroxene pro hornblende and at the acidic end aluminous hypersthene pro biotite, to the dryness of the charnockitic magma (1947, p. 252).

Rode (1948, Palamau, Bihar, NE India) explains the ultrabasic and basic charnockites of his area to represent in composition products of the differentiation of hornblendic magma, whereas the intermediate and more acidic types are injection products of older peninsular granites and gneisses (op. cit., p. 299) caused by the same basic intrusion at a depth, while the entire system is characterized by hyperthenization of the hornblende. On the other hand, in the rocks of the sedimentogeneous khondalite series (quartzites, calc-silicate rocks, graphite-sillimanite-garnet-cordierite-bearing schists, mica schists), which Rode considers to belong stratigraphically to the more superficial levels, the effects of the said basic intrusion are not be discerned (op. cit., p. 302). As for the khondalites, the present author's impression is that the mineral paragenesis of, at least, certain types presuppose as such granulite facies PT-conditions, or the same as the mineral assemblage of charnockites, too. In other words, the khondalites in question have likewise already undergone a high temperature (regional) metamorphism. Besides, these rocks occur, according to Rode, in the field in closest connection with charnockitic rocks (op. cit., p. 301).

Pichamuthu's (1950—1953, India) "The Charnockite Problem" (1953) is a splendid résumé and reference work, in which the research material from outside India is presented as such in the form of brief quotations, while a critical and broader examination of the subject is restricted to the internal Indian sphere. "In my opinion", he remarks on p. 126, "the charnockite problem can be solved only in India, and that too in the localities which furnished the material for Holland." Thus, as his total view of petrogenesis, Pichamuthu states (op. cit., pp. 63, 143, 146, 148) that the charnockites of India are divisible into two categories, of which the older have originated during regional metamorphism from the earliest peninsular gneisses and dharwar schists, whereas the re-activated types of the later stage represent the results of palingenetic fusion and of extensive metasomatism. These groups are separated from each other by the intrusion period of basic and acidic vein rocks.

This current stage in the development of the charnockite question in the country of its origin leads the present author to the following observations. First, after more than half a century there has taken place a return to regional metamorphism, or, in principle, the same approach to the problem as had been taken even before Holland, who in at least a couple of instances refers to it as a previously aired idea (1900, pp. 123, 195). Second, the post-Holland and purely Indian internal trend of thought has led to the same reconstruction-dominated lines characterizing the results arrived at in different parts of the world. Furthermore, as to the drawing up of a common and universally applicable pattern based on the mode of origin, the complications caused in this respect by special regional features cannot evidently be eliminated any more easily in India than elsewhere (cf. Pichamuthu), simply because the petrographic similarity between certain charnockite types does not necessarily mean uniformity as well in their more or less variegated past. To this it may, of course, be pointed out that "the wolves must be separated from the lambs" and therefore, analogously with the granite problem, one must realize that there are "charnockites and charnockites." As a matter of fact, Holland in principle already realized this (1900, p. 210), although it has been overshadowed by his strong primary-magmatic emphasis and left unnoticed.

Moving on, again, to consider the studies carried out in regions outside India, the author would now like to shift his attention to Buddington (1952 and earlier, U. S. A.), whose views, based on very extensive material, rigidly oppose all metamorphic-secondariness. Thus, in his latest study, dealing with the chemical petrology of Adirondack igneous rocks (1952), lucidy rejects the interpretations based on plutonic-metamorphic reconstruction as inadequate to explain the mode of origin of the charnockitic rocks of the Tupper-Saranac complex. As Buddington sees it, the charnockitic suites of the said complex are members of original magmatic crystallization differentiation with the FeMg-phases at the same time being primary (op. cit., pp. 58—61), excepting garnet, which is a later product of regional dynamothermal metamorphism (granulite facies) (op. cit., p. 79). The present author wishes to remark that, in examining charnockites specifically from the standpoint of mineral facies, all this is in agreement with the facies principle, which lays down that the charnockitic mineral assemblage is determined in accordance with isophysical conditions and the concentration of components, regardless of whether primary magmatic crystallization or metamorphic secondary recrystallization is involved.

Quensel (1951, SW Sweden), recently describing the charnockites of the Varberg district, has also included a many-sided general review of the literature relating to earlier theories, with the evident intention of formulating a general pattern for the petrogenesis of charnockites. Inasmuch as this "charnockite synthesis" of Quensel's, together with certain other views of his, provides a suitable basis for the perusal of the foregoing as a whole, the present author, whose own area of research in southwestern Finland belongs, in addition, to the same Fennoscandian pre-Cambrian rock crust (Part II), wishes to consider some of the viewpoints presented in Quensel's work at somewhat greater length:

The pyroxenic rocks of southwestern Sweden, covering an area of only 150 km^2, form "the charnockite series of the Varberg district", the basic members of which are of primary igneous origin and which have obvious non-charnockitic equivalents in the surrounding gneiss complex. The intermediate members of the series, again, are hybrid rocks by nature, not representing any petrographically uniform type, whereas the felsic charnockites correspond in part to the plutometamorphic alterations of the orthogneisses of the vicinity, and in part products of homogenization of the hybrid rocks (op. cit., p. 314). (It will be noticed that the word "series" is here used in a fairly broad sense). Moreover, the reddish aplitic granite predominating in the area has given Quensel matter for thought (op. cit., pp. 260—262, 307—309, 314), and he regards this type a somewhat late intrusion of the palingenetically activated parts of the gneiss complex surrounding the charnockites, an intrusion whose contribution to the formation of the hybrid rocks is obvious. This question relating to the "younger hypersthene-free granites" is a genaral feature also of other (metamorphic) charnockite provinces, including the type areas in India, and furthermore the genesis of the aplitic rock variety under consideration in any specific regional description have been given quite diverse explanations (e. g. Holland, 1900, p. 145; Vredenburg, 1918, p. 444; Ghosh, 1941, p. 52; Gevers and Dunne, 1943, pp. 202—204; Rama Rao, 1945, p. 163; Pichamuthu, 1953, p. 139; and others). As for the charnockites of Varberg's region as petrographic types, according to Quensel, fundamental to them are the same special features which are general and common to all the other metamorphic charnockites round the globe, too, and the petrogenetic key to which is charnockitization, or the production of pyroxenes and garnet at the expense or in lieu of hornblende (op. cit., pp. 274—278). Emphasizing the anti-stress nature of mafic minerals and high density as evidence of their crystallization at great depths under conditions of uniform pressure, high temperature and dryness (op. cit., p. 311), Quensel further recommends the placing of typical charnockites, as belonging to Eskola's system as a special charnockite facies, between the granulite and eclogite facies (op. cit., p. 306). For hornblende and biotite, which ought not to occur higher than the amphibolite facies, constitute nevertheless, on account of their general occurrence as charnockite minerals, those well-known stumbling blocks which it has been customary to try to circumvent in some way and which Quensel likewise gets by along the route of the prevailing manner of explanation, representing these minerals as indicating a disequilibrium between the different constituent minerals. In his facies examination, carried out on this basis, Quensel ends up with a kind of sliding scale system whereby the simultaneously occurring FeMg-phases "... may represent relics of a previous metamorphic period or a commencing stage of the charnockitic transformation or new-formed minerals of a terminating metamorphic period" (op. cit., p. 307). In his view, therefore, the pyroxenes and garnet are the only mafic minerals of importance in the charnockite facies (op. cit., p. 306).

Moving on to Quensel's general definition of charnockites, it agrees in the main with that presented by Varberg as regards the origin of the rocks, the latter, in turn, being in principle in agreement with Vredenburg (1918), Groves (1935), Legoux (1939), Ghosh (1941) and Rama Rao (1945), (Quensel, p. 315). Hence, Quensel regards the petrogenetic history of real and true charnockites as containing by and large, the following (op. cit., pp. 291, 311): Charnockites are regenerated products of deep-seated metamorphism involving older rock formations of heterogeneous origin, the chemical composition of which depends on that of the surrounding rock complex and the reconstruction of which has taken place under conditions of great uniform pressure, high temperature and exceptional dryness. As regards the origin of the different rock types, the basic ones have been observed generally to correspond to igneous rocks of gabbroic composition, whereas the intermediate ones have been quite as generally interpreted as certain kinds of hybrids without petrochemical equivalents within the adjacent formations. The acidic charnockites, on the other hand, like the basic ones, are to be derived from corresponding non-charnockitic members of the surrounding area.

Quensel's summary, embodying the foregoing points of view, amounts to a kind of petrogenetic "statistical synthesis" of charnockites, wherein only and expressly a mode of origin based on reconstruction has been taken into account (op. cit., p. 233) and in the frames of which, examining the various occurrences round the earth, he conducts a strict boundary survey to separate true charnockites from false ones. Here he goes so far as to leave the question open, at the very least, in respect to the mangerites and birkremites of e. g. the Bergen-Egersund regions — the reason being, at least on the part of the Bergen area, a non-metamorphic petrological milieu (op. cit., p. 310). Yet Holland himself resorted to superlatives in stressing the petrographic analogousness of the rocks of Egersund and India, while Kolderup in his day had available for direct comparison rock specimens of Madras (Holland, 1900, pp. 135, 209; cf. p. 16). The present author would like to point further to what later disciples of the magmatic school, such as Rosenbusch, Goldschmidt, Suter, Washington and, recently, Buddington (1939, p. 228 and 1952, p. 60), have written about the same Bergen-Jotun series, which, like the well-known massifs of Canada and the U. S. A., consist of crystallization differentiation series, where orthorhombic pyroxene, in particular, occurs, ranging from basic to acidic members. This occurrence of pyroxenes independent of the acidity of rocks is precisely the fundamental petrological problem that makes charnockites charnockites, regardless in what way — whether under conditions of falling or rising temperature — the equilibria have been attained and regardless of whether the genetic interpretations concerning them statistically favor the metamorphic-secondary rather than the primary-magmatic mode of origin. And furthermore, while Quensel in his study carried out on a mineral facies basis rejects or at least leaves in the background the application of the facies-concept to magmatic rocks, he stresses, on the other hand, a factor unrelated to this concept, namely, the tectonic history of the rocks and the structural and textural diversities belonging in its sphere. He sets up banding, whatever the cause, and gneissose structure generally as the boundary line separating e. g. the hypersthene granulites of Finnish Lapland from "true" charnockites (cf. Quensel, 1951, p. 304; Eskola, 1952, p. 166). "Only occasional granulose flow structure in the charnockitic rocks . . .," as stated by Quensel (loc. cit.), is in agreement, to be sure, with Tyrrell's definition relating to plutonic metamorphism, but not with nearly all the charnockite descriptions, starting from Holland, who e. g. on p. 221 remarks: "Directly connected with the schlieren phenomena, but of a special kind, is the banding so often, or rather generally, exhibited by the charnockite series." Quite the same idea concerning the decisive significance of texture as a factor disregarding the considerations of the mineral facies was put forth slightly before Quensel also by A. Schüller (1949, p. 584): "Diese massig körnige Textur unterscheidet die Charnockite wesentlich von den Granuliten (Schüller, 1948), oder auch von den letzteren verwandten poikiloblastischen Pyroxengneisen (K. Parras, 1941), mit denen sie die trockene Mineralfazies gemein haben."

Returning once more to the general definition: If and when, accordingly, the charnockite concept is examined in its present broad sense and on a mineral facies basis, the present author considers it less logical to reject the non-metamorphic magmatic representatives of these rocks as "not genuine", in spite of the fact that even the rocks of the type regions in India are nowadays depicted as dissimilar in respect to original material and more or less metamorphic in genesis. Moreover, if we take into account Holland's original meaning as regards the consanguinity of his charnockite series, we are confronted with the paradoxical conclusion that expressly these primary magmatic pyroxene rocks (from outside India), though rejected owing to their non-metamorphic nature, in reality belong to the same regional differentiation series and thus are ultimately truer charnockites than the charnockites themselves — assuming, of course, that at the same time they are characterized by the petrographic special features of the rocks in question.

GENERAL NATURE OF DESCRIPTIONS AND APPLICATION OF MINERAL FACIES PRINCIPLE TO CHARNOCKITES

As regards, first of all, the manner of treating the subject at hand, the author would divide the descriptions within his knowledge into two general categories: 1) those in which the main weight of the study has been laid on the initial character and mode of origin of the rock material, as well as on the consideration of the resultant (more general petrological) circumstances, and 2) those in which clarification of the PT-conditions, the equilibria between the crystalline phases and, on the whole, the significance of the mineral facies points of view ranks foremost. Such a division between the studies carried out during the last couple of decades indicates immediately that, judged severely, those included in the latter category numerically represent practically nothing but an exception to the rule.

As a general feature relating to the content of the descriptions, in turn, it is to be remarked that as fundamental to the entire collection of studies as is, on the one hand, the similarity of certain petrographic peculiarities, just as fundamental, on the other hand, is the divergence of opinion in regard to mode of origin, with the matter thereby getting its often reiterated "problematic" character. The present author has not been able to avoid the impression that the majority of the numerous and worthy contemporary charnockite researchers have striven to delve into the matter by focussing their attention primarily on the question as to from what initial material and how these rocks have originated, but have left in the background the facies significance of the end product, i. e. the charnockitic mineral assemblage, as the tie holding the entire problem together. Thus charnockite research has become bound up more and more with the celebrated dispute between the magmatists and the transformists. Consequently, pondering on this basis will continue to proceed in a vicious circle. Of course, all this has been a necessary condition toward the formation of our current concept of the diverse modes of origin of charnockitic rocks; but the matter boils down precisely to the sense in which this appreciation is made use of in the total clarification of the problem. In the light of the aspirations just referred to, the present author, for his part, considers expressly the diversity of origin of charnockites as the best possible proof of the applicability and justification of the mineral facies principle as a unifying classification, though nevertheless independent of the origin and mode of crystallization, in respect to rocks in which an equilibrium between certain crystalline phases corresponding to a certain chemical bulk composition (concentration of components) has been reached under isophysical conditions, though from different directions and along different routes. To be sure, it cannot be maitained that the mineral facies principle is wholly alien even to those more recent studies focussing on the questions of "from what original material?" and "in what way?"; but, without becoming involved in numerous examples, the bottommost aim and application of this approved principle are nevertheless left at the halfway point when, on the one hand, the mineral assemblage of the rocks described as charnockites are recognized to represent exceptional PT-conditions prevailing at great depths and yet, on the other hand, those rocks are bypassed or rejected as non-charnockitic that on the basis of local field relations clearly are linked to the approved and that contain expressly the same critical and typomorphic minerals as the others, deemed genuine, but deviate in some other respects from them. These "other respects" are, for their part, more or less subjectively colored, but, eliminating the details, the present author wishes to express as his view that magmatic character or its absence has been held as the paramount demarcation line. Inasmuch as, in the last-mentioned instance, the field relations of the rocks exhibit, furthermore, a transition toward types deviating from charnockites in respect to the mafic constituents, such pyroxene gneisses have had to be shoved aside as ungenuine. The question has thus once more reverted to one of origin, but this time with the circumstances caused by the more or less obscure primary sedimentary structure and by the outward appearance in general. Naturally, holding fast to magmatic character, we would be able to retain at least something of Holland's original idea in this respect. However, drawing the line among strongly metamorphized rocks is a doubtful procedure. Yet, if and when it appears possible, the present author would uphold the application of the term charnockite also to these pyroxene gneisses shown to be sedimentary — either as such or with the prefix "para", viz., "paracharnockite". Applying this latter alternative need not, however, perforce require the addition of the prefix "ortho" to the term for "genuine" magmatic types. Accordingly, the representatives of a magmatic character would continue to be included among charnockites regardless of whether they be considered primary-magmatic or palingenetically activated, whether corresponding to a normal differentiation composition or hybrid or in some way contaminated, and without taking into account whether they be products more of primary crystallization or metamorphic recrystallization. The paracharnockites would include, again, rocks of provable sedimentary nature but at the same time, needless to add, of charnockitic mineral paragenesis, whose mineral facies identicalness with the magmatic types would be immediately apparent and most simply from the foregoing grouping.

SUMMARY OF THEORIES CONSIDERED

By means of the foregoing historical review of charnockite research, the author has endeavored, among other things, to give a picture of the diversity prevailing in the descriptive material embodied by the literature on charnockites up to the present. On the contrary, if we wished to peruse the accumulation of theories in a unifying light, by seeking common features, two main trends of though would come to the fore distinctly: 1) the primary-magmatic, based on the differentiation by crystallization of plutonic igneous intrusions, and 2) the metamorphic-secondary, based on recrystallization and, in general, reconstruction. Both trends, moreover, are chronologically so arranged that the magmatic trend dominated exclusively after Holland for a couple of decades, while the great majority of descriptions dating from the period beginning in the 1920's favor the metamorphic approach. In the magmatic sphere, including the later studies, too, the grouping continues to be clear according to whether the differentiation is considered to have proceeded from normal, exceptionally dry or contaminated magma. On the other hand, the finding of more far-reaching analogies among studies based on metamorphism is limited to a few descriptions at a time, owing to the diversity of the original material as well as the nature and kind of the metamorphism undergone by it. As one effort at grouping the present author submits that based on the origin of the rock-forming material, making it possible to consider as contrasting groups such descriptions, on the one hand, as explain original magmatic rocks to have recrystallized in a solid state under conditions of plutonic metamorphism, and, on the other, as are built up on the chemical and fabrical reorganization of the supracrustal original material in the different processes of ultrametamorphism. As a third and less uniform main group would be various combinations of the preceding ones. Further, not to be overlooked in the formulation of genetic interpretations is the significance, in principle, of similarity — observed or assumed — in the bulk chemistry of the charnockitic rocks in respect to their adjacent non-charnockitic rock formations, while a contrast is provided by such as do not exhibit this chemical equivalence or are built up, more theoretically, to be sure, on the basis that the original bulk composition of the rocks might become different in the different PT-conditions (cf. p. 23).

ANALOGY IN MINERAL FACIES OF CHARNOCKITES AND ASSOCIATED SUPRACRUSTAL ROCKS

As it has probably already become clear, the aim of the present author in the study at hand is to call the attention of the reader also to the supracrustal rocks associated with the charnockites and to deal with the question by and large as a regional petrological totality rather than a separate and independent problem. Accordingly, brief consideration will now be given the position and significance of these charnockitic derivatives in the lithological milieu, where the charnockites play only a certain petrographic-petrochemical role.

As regards, first of all, the high metamorphic representatives of arena-argillaceous or residual-hydrolyzatic sediments (garnet, cordierite, biotite, sillimanite), be it reiterated that, according to numerous descriptions, they occur quite regularly in association with (metamorphic) charnockites in Greenland as well as in Australia, and in southern Norway as well as in Siberia. Moreover, worth keeping in mind are the khondalites of India and, in this connection, especially their Al-rich, high facies varieties, which also within their own areas would complement the total petrological picture rather than dispersing it or otherwise operating as a complicating factor (cf. Rode, p. 25). Futhermore, the said garnet-cordierite-sillimanite gneisses have long been known in the classical granulite formations of Saxony, Ceylon and Finnish Lapland. The acidic garnet-cordierite granulites of the last-mentioned territory are, in addition, according to Eskola (1952, p. 167), nearly identical to corresponding rocks widely distributed, notably in areas of pyroxenic rocks, in southwestern Finland. The present author has proposed, for his part, that this coarse-grained, veined gneiss, known as kinzigite, be termed "lutogenite" in order to stress its residual-hydrolyzatic character (Parras, 1946).

Besides aluminous sedimentary rocks and, most commonly, in association with them, there occurs quite as generally the high metamorphic products of Ca-rich sediments, the majority of them being represented by argillo-calcareous (marly) and calcareous sandstone material. Also the amphibolitic composition as well as the originally volcanic material belong in this association of rocks, which is likely to be nearly an exclusive initial rocky matter in regional charnockitization, as e. g. in the case of the diopside gneisses in the areas of Bastar State and Western Jeypore in India (Ghosh, 1941; cf. p. 24).

As for the mineral assemblages of these impure calcareous sedimentary rocks, the present author would like to call the attention of the reader at this point especially to the scapolite-bearing diopside gneisses and amphibolites, which have been mentioned in numerous studies — notably the former — and which are not foreign even to Holland's type area (Holland, 1900, p. 232; Muthuswamy, 1951, Pallavaram, Madras; Paulose, 1956, Cape Comorin). On the basis of his own observations, moreover, the author will subsequently (Part II) offer a detailed exposition to demonstrate that the carbonate-scapolite, meionite, of the charnockite province of West Uusimaa, in southwestern Finland, possesses the same significance, from the standpoint of mineral facies, as the almandite-pyrope and orthorhombic pyroxene in the fields with a chemical composition corresponding to their own components.

The occurrence or absence of the said associated rocks is, of course, no criterion of the charnockite concept any more than e. g. whether in any specified locality varieties representing a sub-acidic or basic bulk composition are principally met with, for in either case the question boils down merely to the narrowness or extensiveness of the petrochemical field constituting the charnockitic milieu. In any event, it may be noted that the same partial — or, sooner, arbitrary — application of the mineral facies principle revealed e. g. by the rejection or acceptance as charnockites of rocks belonging to the same complex on grounds other than those dictated by their common mineral paragenesis marked by known peculiarities (cf. pp. 21, 31—32) is brought out also in dealing with the said Al- or Ca-rich rock types. Their general fate has been, customarily after a brief description, to fade away into the background as unconnected with the matter at hand or be relegated among inexplicable matters. However, by proceeding in this fashion, while at the same time accepting a various primary material and metamorphic mode of origin for charnockites, on the one hand, but, on the other, casting beyond the pale of the totality members that have undergone the same ordeal, so the speak, simply because their composition would not allow the production of a charnockitic mineral assemblage, one's total conception of the petrographic-petrochemical nature and assemblages of minerals originated under isophysical conditions of the complex under consideration is liable to prove to be quite one-sided. The entire study, moreover, faces the danger of becoming overloaded with details involved in research on charnockites, when treated merely as petrographic oddities.

CHARNOCKITES AND GRANULITES AS A FACIES WHOLE

Granulites, understood in the sense of the formations met with in Saxony, Ceylon and Finnish Lapland, excited interest by virtue of their special characteristics as early as the first stage of charnockite research (cf. p. 15), and from the very start both "case histories" have been bound up more or less together. The reason for this is that in the said investigation areas of the Archaean rock crust representatives of each suite of rocks occurred in the closest association. Without going into what has been reported on the petrogenesis and nature of granulites during the course of several decades, the present author wishes to refer only to the brief but so much the weightier recent work "On the Granulites of Lapland" (1952) by that mineral facies master Eskola himself. In this report he sets forth the conception he has developed over a period of years about the genesis of the granulites of northernmost Finland, regarding the main part of the Al-rich garnet-quartz-feldspar granulites as the original representatives of the argillageous and sapropelic sediments (almandite-pyrope, cordierite, biotite, sillimanite, graphite), while, on the other hand, the charnockitic or enderbitic rocks corresponding to an intermediate composition are by origin magmatic intrusives (cf. hybrid rocks, p. 17), with the basic and ultrabasic types representing metamorphized volcanic or hypabyssic rocks (op. cit., p. 168). All these main types, together with their several varieties, are grouped by Eskola under the general term of granulites, which on the basis of their mineral assemblages belong to one and the same isophysical, though not isochemical, totality, namely the granulite facies. This facies, moreover appears to be "identical with that facies represented by the charnockites, the specific characteristics of the foliated granulites being due to their tectonic history" (op. cit., p. 133).

The granulite concept as it involves Finnish Lapland thus also takes in, according to Eskola's definition, the charnockitic rocks. The same holds true likewise of, for instance, Ceylon (Adams, 1929), in respect to the genuineness of the charnockites and schistose granulites met with there no doubts seem to have been entertained. Without taking into account now the special features of the rock fabric and instead placing main emphasis on the prevalence of the bulk composition and mineral paragenesis represented by e. g. silicic aluminous granulites in the various charnockite provinces, the thought cannot be avoided that — considered in a broad sense — the same things are involved but presented under different names.

In general and with the matter as a whole in view, the present author thus, for his part, takes the stand that in charnockite studies and in the interpretations relating to the total concept ventured upon in different quarters decisive significance should be attached to the mineral facies principle. Such an approach would eliminate from comparative studies built up on a basis independent of the origin of the rocks the disruptive effect of the special features incorporated into regional genetic history, and the rocks termed charnockites would prove thereby to be less problematical as a facies concept.

EARLY STUDIES ON ROCKS WITH CHARNOCKITIC AFFINITIES IN FINLAND

Pyroxene-bearing granodiorites from Ostrobothnia in West Finland have been described by Mäkinen (1916) and Väyrynen (1923). The latter based his more detailed study on the reactions and equilibria of the different phases, without, however, trying to stress the charnockitic nature of the said rocks (cf. Groves, p. 18). Belonging to the same early stage of research in this particular field, though with a clearer parallel with charnockites drawn, is Hackman's (1923) pyroxene granodiorite description from the island of Kakskerta in Southwest Finland. The question of the pyroxene-bearing members of the granulite formation in Finnish Lapland, together with their mineral paragenetic analogousness with charnockites, has been dealt with by Sahama (1936). Moreover, Wilkman (1938), in his explanatory text to the map sheet of Central Finland, has described hypersthene gneisses as well as pyroxene granites and pyroxene diorites. Parras (1941), Hausen (1944), Metzger (1945) and Hietanen (1947) have treated in their regional studies the pyroxene-bearing rocks met with there as an internal question of the Svecofennidic formation of southwestern Finland. Metzger emphasizes, among other things, the significance of the pyroxene diorite intrusions as an indication of the location of his area on a relatively high level in the Svecofennidic mountain range, whereas Hietanen has concentrated on the problem of trondhjemites and charnockites as differentiation products of the same parent magma. Charnockitic rocks have also been taken into account in Simonen's (1948) petrochemical study on the Svecofennidic territory of southwestern Finland. Eskola's (1952) stand on the charnockite — granulite question has already been briefly pointed out in the foregoing. Minor parts of the map area described by the present author (Parras, 1941) are included in the recently issued map sheets on the Karkkila (Härme, 1954) and Suomusjärvi (Salli, 1955) regions.

Although the present author's own research area represents a part of the Svecofennian formation of Archaean age in southern and southwestern Finland, which part also includes other separate pyroxenic rock formations, he is going to refrain in Part II, to follow, wholly from examining them in closer detail and from making comparisons as well as from delving into the special problems of the Svecofennian formation. Instead, he is going to concentrate, in addition to the customary petrographic description, on stressing among his own observations those deemed significant in the light of the examination carried out on the basis of Part I of the charnockite question as a whole.

Lohja, October 1956.

BIBLIOGRAPHY

This list includes works in which charnockitic rocks or closely related matters are dealt with in one way or another.

ADAMS, F. D. (1896) Report on the geology of a portion of the Laurentian area lying to the north of the Island of Montreal (Que.). Geol. Survey Canada, Ann. Rept., 1891.

—»— (1929) The geology of Ceylon. Can. J. Research 11.

ADAMSON, O. J. (1942) The granite pegmatites of Hitterö, southwestern Norway. Geol. Fören. Förh. 64, p. 100.

ALLARDYCE, J. (1836) On the granitic formation and direction of the primary mountain chains of South India. Madras J. Lit. and Sci. 4.

ARSANDAUX, H. (1912) Sur la présence au Gabon de roches appartenant à la série de la charnockite. C. R. Acad. Sci. Paris 154.

BACKLUND, H. G. (1907) Über ein Gesteinmassiv im nördlichen Sibirien. Trav. Musée géol. Pierre le Grand, 1. p. 130.

—»— (1936) Zur genetischen Deutung der Eklogite. Geol. Rundschau 27, S. 47—61.

BAGGHI, T. C. (1952) On the possible origin of the »Porphyroblastic Granite» and Charnockites in Birmahrajpur Sub-division, Bolangir-Patna District, Orissa. Quart. J. Geol. Mining Met. Soc. India 24.

BALK, R. (1931) Structural geology of the Adirondack anorthosites. Min. Petr. Mitt. 41, pp. 308—434.

—»— (1944) Comments on some Eastern Adirondack problems. J. Geol. 52, pp. 289—318.

BARON, R. (1895) Geological notes of a journey in Madagascar. Quart. J. Geol. Soc. London 51.

BARTH, T. F. W., CORRENS, C. W., ESKOLA, P. (1939) Die Entstehung der Gesteine. Berlin.

BARTH, T. F. W. (1945) Geological map of western Sørland. Norsk Geol. Tidsskr. 25.

—»— (1952) Theoretical petrology. New York.

BEETZ, P. F. W. (1933) Geology of south-west Angola, between Cunene and Lunda Axix. Trans. Geol. Soc. S. Africa 36.

BENZA, P. M. (1836) Memoir on the geology of the Neilgherry and Koondah Mountains. Madras J. Lit. and Sci. 4.

BEZBORODKO, N. I. (1931) Sur la pétrogenèse des roches foncées de la Podolie et des régions voisines. Trav. Inst. Min. Acad. Sci. U. S. S. R. 1 (Russian with French summary).

—»— (1934) Sabarovite, the extreme acid member of the pyroxene-tonalite range in Podolia. J. Geol. Ukrainian Acad. Sci. 1 (Russian with English summary).

BLANDFORD, H. F. (1858) On the geological structure of the Nilghiri Hills. Records Geol. Survey India 1.

BOWEN, N. L. (1948) The granite problem and the method of multiple prejudices. Geol. Soc. America, Mem. 28.

BUDDINGTON, A. F. (1939) Adirondack igneous rocks and their metamorphism. Geol. Soc. America, Mem. 7.

—»— (1950) Composition and genesis of pyroxene and garnet related to Adirondack anorthosite and anorthosite-marble contact zones. Am. Mineralogist 35, pp. 659—670.

—»— (1952) Chemical petrology of some metamorphosed Adirondack gabbroic, syenitic and quartz syenitic rocks. Am. J. Sci., Bowen Volume, pp. 37—84.

BUGGE, C. (1910) Petrographische Resultate der 2ten Fram-expedition. Kgl. Norske Vidensk. Selsk. Skr., Mat.-Nat. Kl. 1910, 22.

BUGGE, J. A. W. (1940) Geological and petrographical investigations in the Arendal district. Norsk Geol. Tidsskr. 20.

—»— (1943) Geological and petrographical investigations in the Kongsberg-Bamble formation. Norges Geol. Unders. 160.

—»— (1945) The geological importance of diffusion in the solid state. Avhandl. Norske Vidensk.-Akad. Oslo, Mat.-Nat. Kl. 1945, 13.

CHACKO, I. C. (1921) A sketch of the geology of Travancore. Records Dept. Geol. Travancore 1.

CHATTERJEE, S. C. (1952) The charnockites of the Mor Valley, Santhal Parganas, Bihar. Proc. Indian Sci. Congr., Pt. 3.

COATES, J. S. (1935) The geology of Ceylon. Ceylon J. Sci. 19.

COOMARASWAMY, A. K. (1903) Contributions to Ceylon geology. Geol. Mag. 10, p. 348.

CROOKSHANK, H. (1938) The western margin of the eastern Ghats in southern Jeypore. Records Geol. Survey India 73, p. 398.

DAVIDSON, C. F. (1943) The Archaean rocks of the Rodil District, South Harris, Outer Hebrides. Trans. Roy. Soc. Edinburgh 61.

DENGO, G. (1950) Eclogitic and glaucophane amphibolites in Venezuela. Am. Geophys. Union, Trans. 31, pp. 873—878.

DIXEY, F. (1925) The geology of Sierra Leone. Quart. J. Geol. Soc. London 81, p. 195.

DUNN, J. A. (1932) Reaction minerals in a garnet-cordierite gneiss from Mogok. Records Geol. Survey India 65, pp. 445—456.

—»— (1942) Granite and magmation and metamorphism. Econ. Geol. 37, p. 231.

ESKOLA, P. (1921) The mineral facies of rocks. Norsk Geol. Tidsskr. 6.

—»— (1939) Die metamorphen Gesteine. BARTH-CORRENS-ESKOLA: Die Entstehung der Gesteine. Berlin.

—»— (1952) On the granulites of Lapland. Am. J. Sci., Bowen Volume, pp. 133—171.

—»— (1957) On the mineral facies of charnockites. J. Madras Univ., B. 27, pp. 101—119.

EVANS, J. W. (1921) Discussion on Tilley's paper: The granite-gneisses of southern Eyre Peninsula (South Australia) and their associated amphibolites. Quart. J. Geol. Soc. London 77, p. 133.

FALCONER, J. D. (1911) The geology and geography of Northern Nigeria. London.

FERMOR, L. L. (1936) An attempt at the correlation of the ancient schistose formations of Peninsular India. Mem. Geol. Survey India 70, p. 42.

FERNANDO, L. J. D. (1948) The geology and mineral resources of Ceylon. Bull. Imp. Inst. 46, p. 303.

FOOTE, R. B. (1883) Geology of Madura and Tinnevelly districts. Mem. Geol. Survey India 20.

GEVERS, T. W. and DUNNE, J. C. (1942) Charnockitic rocks near Port Edvard in Alfred Country, Natal. Trans. Geol. Soc. S. Africa 45, pp. 183—214.

GHIKA-BUDESTI, ST. (1938) Le caractère pétrographique de la série éruptive du Jebel Sarro, Anti-Atlas morocain. C. R. Acad. Sci. Paris 207.

GHOSH, P. K. (1941) The charnockite series of Bastar State and Western Jeypore. Records Geol. Survey India 75, Prof. Paper 15.

GOLDSCHMIDT, V. M. (1916) Petrographische Untersuchungen im Hochgebirge des südlichen Norwegens IV. Kgl. Norske Vidensk.-Selsk. Skr., Mat.-Nat. Kl. 1916, 2, p. 136.

—»— (1922) Stammentypen der Eruptivgesteine. Skr. Norske Vidensk.-Akad. Oslo, Mat.-Nat. Kl. 1922, 10.

GROVES, A. W. (1935) The charnockite series of Uganda, British East Africa. Quart. J. Geol. Soc. London 91.

HACKMAN, V. (1923) Der Pyroxen-Granodiorit von Kakskerta bei Åbo und seine Modifikationen. Bull. Comm. géol. Finlande 61.

HALLOWES, K. A. K. (1923) Basic and ultrabasic members of the charnockite series in the Central Provinces. Records Geol. Survey India 55, p. 254.

HARKER, A. (1909, 1932) Metamorphism. London.

HATCH, F. H.(1888) On a hornblende-hypersthene-peridodite from Loiskua, a low hill in the Taveta district, at the south foot of Mount Kilimanjaro. Geol. Mag. 25, p. 257.

HAUSEN, H. (1944) Geologische Beobachtungen im Schärenhof von Korpo—Nagu Südwest-Finnland. Acta Acad. Aboensis, Math. et Phys. 14, 12.

HIETANEN, A. (1947) Archean geology of the Turku district in southwestern Finland. Bull. Geol. Soc. America 58, pp. 1019—1084.

HOLLAND, TH. H. (1893) The petrology of Job Charnock's tombstone. J. Asiatic Soc. Bengal 62.

—»— (1900) The charnockite series, a group of Archaean hypersthenic rocks in Peninsular India. Mem. Geol. Survey India 28.

—»— (1901) Geology of the neighbourhood of Salem, Madras Presidency. *Ibid.* 30.

HÄRME, M. (1954) Geological map of Finland. Sheet-2042. Karkkila. Explanation to the map of rocks (English summary).

IYENGAR, P. S. (1920) The acid rocks of Mysore. Bull. Mysore Geol. Dept. 9.

JAYARAMAN, N. (1938) The colour of the blue quartz of the charnockites of South India. Current Sci. (India) 6.

—»— (1939) The cause of the colour of the blue quartzes of the charnockites of southern India and of the Champion gneisses and other related rocks of Mysore. Proc. Indian Acad. Sci. 9.

—»— (1940) On the origin of the charnockites. J. Indian Inst. Sci. 23 A.

JEREMINE, E. (1949) Sur quelques eoches intrusives et métamorphiques de la province de Québec. Mém. Soc. Vaudoise Sci. Nat. 9.

JOHANNSEN, A. (1937) A descriptive petrography of the igneous rocks. Pt. 3, p. 212. Chicago.

JUNNER, N. R. (1940) Geology of the Gold Coast and Western Togoland. Bull. Gold Coast Geol. Survey 11.

KENT, L. E. (1938) The geology of a portion of Victoria country, Natal. Trans. Geol. Soc. S. Africa 41.

KING, W. & FOOTE, R. B. (1864) On the geological structure of parts of the districts of Salem, Trichinopoly, Tanjore and South Arcot in the Madras Presidency. Mem. Geol. Survey India 4.

KOLDERUP, C. F. (1896) Die Labradorfelsgebiet bei Ekersund und Soggendal. Bergens Museums Aarb. 1896, 5.

—»— (1904) Die Labradorfelse in dem Bergensgebiete. *Ibid.* 1903, 12.

—»— (1914) Egersund. Norges Geol. Unders. 71.

—»— (1933) The anorthosites of Western Norway. Rept. 16th Intern. Geol. Congr., U. S. A.

—»— (1934) The geology of parts of southern Norway. Proc. Geol. Assoc. 45, Pt. 1.

—»— & KOLDERUP, N. H. (1940) Geology of the Bergen Arc System. Bergens mus. årb. 1940, 20.

KORJINSKY, D. S. (1936a) Paragenetic analysis of quartz-containing, almost calciumless crystalline schists of the Archaean complex of the South of Baikal-Sea. Mém. Soc. Russe Minér. 2, pp. 247—277 (Russian with English summary).

—»— (1936b) Archaean marbles of the Aldan platform and the problem of the depth facies. Trans. Centr. Geol. Prosp. Inst. 71 (Russian with English summary).

—»— (1936c) Archaean complex of the Aldan massif (Siberia). *Ibid.* 86 (Russian with English summary).

—»— (1937) Dependence of mineral stability on the depth. Mém. Soc. Russe Minér. 66 (Russian with English summary).

—»— (1940) Factors of mineral equilibria and depth facies of metamorphism. Bull. Acad. Sci. U. S. S. R. 5 (Russian with English summary).

KRANCK, E. H. (1935) On the crystalline complex of Liverpool Land. Medd. Grønland 95.

KRENKEL, E. (1925) Geologie Afrikas. 1. Teil. Berlin.

KRISHNAN, M. S. (1943) Geology of India and Burma. Madras.

—»— (1951) Bezwada gneiss, khondalite and leptynite. Records Geol. Survey India 81.

LACROIX, M. A. (1899) Contributions to the study of pyroxenic varieties of gneiss and of scapolite bearing rocks. Records Geol. Survey India 24.

—»— (1910) Sur l'éxixtence à la Côte d'Ivoire d'une série pétrographique à celle de la charnockite. C. R. Acad. Sci. Paris 150.

LEBEDEV, P. I. (1939) The Podolian charnockite formation. Rept. 17th Intern. Geol. Congr., U. S. S. R. 2, p. 71.

LEELANDA RAO, N. (1954) Dyke rocks of Pallavaram. J. Madras Univ., B. 24.

LEGOUX, P. (1939) Le massiv de Man (Côte d'Ivoire). Essai de géologie pétrographique. Gouvernement général de l'Afrique occidentale francaise. Bull. de Service des Mines 3, Dakar.

LEHMANN, J. (1884) Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine mit besonderer Bezugnahme auf das Sächsische Granulitgebirge, Erzgebirge, Fichtelgebirge und Bairisch-Böhmische Mittelgebirge. Bonn.

MACGREGOR, A. G. (1931a) Clounded feldspars and thermal metamorphism. Min. Mag. 22, p. 524.

—»— (1931b) Scottish pyroxene-granulite hornfelses and Odenwald beerbachites. Geol. Mag. 68, p. 506.

MACGREGOR, A. M. (1930) Geology of the country between Gatooma and Battlefields. Bull. Geol. Survey S. Rhodesia 17.

MAHADEVAN, C. & NARASINGA RAO, A. (1948) Optically positive hypersthene from charnockites of Guntur district. Current Sci. (India) 17.

METZGER, A. A. T. (1945) Zur Geologie der Inseln Ålö und Kyrklandet in Pargas-Parainen, SW. Finnland. Acta Acad. Aboensis, Math. et Phys. 15, 3.

MIDDLEMISS, C. S. (1896) Notes on the ultrabasic rocks and derived minerals of the chalk (magnesite) hills and other localities near Salem, Madras. Records Geol. Survey India 29.

MOOR, G. (1940) The charnockite series of the Anabar pre-Cambrian and similar metamorphic formations. Acad. Sci. U. S. S. R. Sér. Géol. 6 (English summary).

—»— (1942) On the primary nature of the metamorphic formation of the Anabar pre-Cambrian. *Ibid.* 3 (English summary).

MOUTA, F. and O'DONNELL, H. (1933) Carte géologique de l'Angola Republica Portugesa. Lisbon.

MUTHUSWAMI, T. N. (1951) Scapolite calc-granulite, Pallavaram. J. Madras Univ., B. 21, pp. 249—255.

—»— (1953) Amphibole-granulite facies charnockites. Proc. Indian Acad. Sci. B. 37.

MÄKINEN, E. (1916) On the pre-Cambrian geology of Central Österbotten in Finland. Bull. Comm. géol. Finlande 47 (Swedish with English summary).

NAIDU, P. R. J. (1943a) Inclined extinction in the hypersthenes of charnockite. Current Sci. (India) 12, pp. 157—158.

—»— (1943b) Pigeonite in the abnormal dolerite dykes of charnockite areas in Mysore. *Ibid.* 12, p. 114.

—»— (1950) The twin laws of the plagioclase of charnockites. *Ibid.* 19.

—»— (1954) Minerals of charnockites from India. Schweiz. Min. Petr. Mitt. 34.

NARASIMHA RAO, A. (1950) Geology and petrology of Kondavidu Hill range, Guntur district, Madras Presidency. Quart. J. Geol. Mining Met. Soc. India 22.

NARAYANASWAMI, S. (1949) The geology and mineral resources of the Tiruchendur and southern and eastern portions of the Nanguneri taluk, Tinnevelly district. Fort St. George Gazette.

NAUMANN, C. F. (1858) Lehrbuch der Geognosie. Leipzig.

NOCKOLDS, S. R. (1940) Petrology of rocks from Queen Mary Land. Australian Antarctic Expedition 1911—1914. Scientific reports A 4, p. 31.

NORIN, E. (1937) Geology of Western Quruq Tagh, Eastern Tien-Shan. Reports Sci. Expedition to the NW. Provinces of China. Geology 3, p. 72.

OLDHAM, R. A. (1893) Manual of the geology of India. Calcutta.

OUCHTERLONY, J. (1848) Geographical and statistical memoir of the Neilgherry Mountains. Madras J. Lit. and Sci. 15.

PARRAS, K. (1941) Das Gebiet der Pyroxen führenden Gesteine im westlichen Uusimaa in Südfinnland. Geol. Rundschau 32, S. 484—507.

PASCOE, E. H. (1950) A manual of the geology of India and Burma, 1, Calcutta.

PAULOSE, C. V. (1956) Charnockites and associated rocks of the Cape Comorin area, S. India. Bull. Mysore Geol. Assoc. 9, p. 1.

PEACOCK, M. A. (1931) Classification of igneous rock series. J. Geol. 39.

PICHAMUTHU, C. S. (1953) The charnockite problem. Mysore Geol. Assoc. Bangalore, India.

POLDERVAART, A. and BACKSTRÖM, J. W. V. (1949) A study of an area at Kakamas (Cape Province). Trans. Geol. Soc. S. Africa 52.

POLKANOV, A. A. (1937) On the genesis of the labradorites of Volhynia. J. Geol. Ukrainian Acad. Sci 3, p. 51.

POLOVINKINA, Y. I. (1931) Two new occurrences of charnockite rocks in the Ukraine. Trans. Geol. Prosp. Survey U. S. S. R. 94 (English summary).

PRIDER, R. T. (1944) The petrology of part of the Toodyay District. J. Roy. Soc. W. Australia 28.

—»— (1945) Charnockitic and associated cordierite-bearing rocks from Dangin, Western Australia. Geol. Mag. 82.

—»— (1950) The western Australian pre-Cambrian shield. Australian Natl. Univ.

—»— (1952) South-west Yilgarnia. Mawson Volume, Univ. Adelaide.

Prior, G. T. (1903) Contributions to the petrology of East Africa. Min. Mag. 13.

Pulfrey, W. (1946) A suite of hypersthene-bearing plutonic rocks in the Meru district, Kenya. Geol. Mag. 83, p. 67.

Quensel, P. (1951) The charnockite series of the Varberg district on the south-western coast of Sweden. Arkiv Min. Geol. 1, 10.

Rajagopalan, C. (1946) Studies in charnockites from St. Thomas' Mount, Madras. Pt. 1. Proc. Indian Acad. Sci. 24.

—»— (1947) Studies in charnockites from St. Thomas' mount, Madras. Pt. 2. *Ibid.* 26.

Rama Rao, B. (1945) The charnockite rocks of Mysore (Southern India). Bull. Mysore Geol. Dept. 18. (12 earlier publications are listed in this paper.)

Ramberg, H. (1948a) Titanic iron ore formed by dissociation of silicates in granulite facies. Econ. Geol. 43, p. 553.

—»— (1948b) On sapphirine-bearing rocks in the vicinity of Sukkertoppen, West Greenland. Medd. Grønland 142, 5.

—»— (1948c) On the petrogenesis of the gneiss complex between Sukkertoppen and Christianshaab, West Greenland. Medd. Dansk. Geol. Foren. 11, pp. 312—327.

—»— (1949) The facies classification of rocks: a clue to the origin of quartzo-feldspathic massifs and veins. J. Geol. 57.

—»— (1951) Remarks on the average chemical composition of granulite and amphibolite- to -epidote amphibolite facies gneisses in West Greenland. Medd. Dansk Geol. Foren. 12.

—»— (1952) The origin of metamorphic and metasomatic rocks. Chicago.

—»— (1956) Pegmatites in West Greenland. Bull. Geol. Soc. America 67.

Ramdohr, P. (1949) Charnockite aus Kamerun. Thorbecke-Festschrift 1949.

Ray, S. and Roy, S. K. (1944) Inclined extinction in Indian hypersthenes. Quart. J. Geol. Mining Met. Soc. India 16.

Read, H. H. (1935) The gabbros and associated xenolithic complexes of the Haddo House district, Aberdeenshire. Quart. J. Geol. Soc. London 91.

Reynolds, D. L. (1935) The genetic significance of biotite-pyroxenite and hornblendite. Min. Petr. Mitt. 46.

Robertson, T. (1924) The crystalline metamorphic rocks from Southwest Togoland. Geol. Mag. 61.

Rode, K. P. (1948) On the charnockite rocks of Palamau, Bihar, India. Schweiz. Min. Petr. Mitt. 28, pp. 288—302.

Rose, G. (1863) Beschreibung der von Herrn von der Decken gesandten Gebirgsarten aus Ost-Afrika, grösstenteils vom Fusse des Kilimandjaro. Z. Allg. Erdkunde, Berlin.

Rosenbusch, H. (1910) Elemente der Gesteinslehre. Stuttgart.

Rosenqvist, I. Th. (1956) Granulitt-mangeritt-eklogitt. Norsk. Geol. Tidsskr. 36.

—»— (1951, 1952) (See Part II, References).

Rosiwal, A. (1891) Beiträge zur geologischen Kenntniss des östlichen Afrika. II: Über Gesteine aus dem Gebiete zwischen Usambara und dem Stefanie-See. Denkschr. f. Wissensch., Wien, 58.

Sahlstein (Sahama), Th. G. (1935) Petrographie der Eklogiteinschlüsse in den Gneisen des südwestlichen Liverpool-Landes in Ost-Grönland. Medd. Grønland 95.

Sahama, Th. G. (1936) Die Regelung von Quarz und Glimmer in den Gesteinen der Finnisch-Lappländischen Granulitformation. Bull. Comm. géol. Finlande 113.

Salli, I. (1955) Geological map of Finland. Sheet—2023. Suomusjärvi. Explanation to the map of rocks (English summary).

Sampat Iyengar, P. (1920) The acid rocks of Mysore. Bull. Mysore Geol. Dept. 9.

SCHEUMANN, K. H. (1954) Bemerkungen zur Genese der Gesteins- und Mineral-fazies der Granulite. Geologie 3 : 2.

SCHOEMAN, J. J. (1948) A geological reconnaissance of the area west of Kitui Township. Geol. Survey Kenya, Rept. 14.

—»— (1951) A geological reconnaissance of the country between Embu and Meru. *Ibid.* 17.

SCHÜLLER, A. (1948) Petrogenetische Studien zum Granulitproblem an Gesteinen der Münchberger Masse. Heidelberger Beitr. Miner. Petr. 1, S. 269.

—»— (1949) Ein Plagioklas-Charnockit vom Typus Akoafim und seine Stellung innerhalb der Charnockit-Serie. *Ibid.* 1, S. 573.

SEN GUPTA, K. K. (1916) On the hypersthenization of monoclinic pyroxenes. J. Asiatic Soc. Bengal, N. S., 12.

—»— and CHATTERJEE, S. C. (1936) On the geology of the Cochin State. Quart. J. Geol. Mining Met. Soc. India 8.

SHACKLETON, R. M. (1946) Geology of the country between Nanyuki and Maralal. Geol. Survey Kenya, Rept. 11.

SIMMONS, W. C. (1921) A rapid geological survey of part of Bunyoro. Ann. Rept. Geol. Survey Uganda for 1920, p. 29.

SIMONEN, A. (1948) On the petrochemistry of the infracrustal rocks in the Svecofennidic territory of southwestern Finland. Bull. Comm. géol. Finlande 141.

SLATER, H. K. (1908) Report on the iron-bearing rocks in the neighbourhood of Maddur and Malvalli. Records Mysore Geol. Dept. 8.

SMEETH, W. F. (1926) Some views about the Archaeans of Southern India. Records Mysore Geol. Dept. 23.

SRIRAMA RAO, M. (1946) Geology and petrology of the Bezwada and Kondapalle hill ranges. Proc. Indian Acad. Sci. 24.

—»— (1947) Geology and petrology of the Bezwada and Kondapalle hill ranges, Part 2. Charnockites and associated rocks and chromite. *Ibid.* 26.

STEWART, F. H. (1946) The gabbroic complex of Belhelvie in Aberdeenshire. Quart. J. Geol. Soc. London 102, pp. 465—498.

STILLWELL, F. L. (1918) The metamorphic rocks of Adelie Land. Australian Antarctic Expedition 1911—1914, Scientific Reports A, 3.

STOCKLEY, G. M. (1948) Geology of the north-west and central Njombe district, Tanganyika Territory. Dept. Lands and Mines, Geol. Div., Tanganyika, Bull. 18.

SUBRAMANIAN, A. P. (1956) Mineralogy and petrology of the Sittampundi complex, Salem district, Madras State, India. Bull. Geol. Soc. America 67.

SUNDIUS, N. (1946) Berggrundskarta över Stockholmstrakten. Sveriges Geol. Unders. Ser. Ba 13.

SUTER, H. (1922) Zur Klassifikation der Charnockit-Anorthosit-Provinzen. Schweiz. Min.-Petr. Mitt. 2, p. 307.

SUTTON, J. and WATSON, J. (1951) Abstract of communications of the metamorphic history of the Archaean rocks of Loch Torridon, Ross-shire and of Scourie, Sutherland and on a chronological classification of the Archaean rocks of the maintland of North-West Scotland. Quart. J. Geol. Soc. London 106.

TEALE, E. O. and OATES, F. (1943) The mineral resources of Tanganyika Territory. Dept. Lands and Mines, Geol. Div., Tanganyika, Bull. 16.

TEALL, J. J. H. (1907) The geological structure of the North-West Highlands of Scotland. Mem. Geol. Survey G. Britain.

TEMPERLEY, B. N. (1938) The geology of the country around Mpwapwa. Dept. Lands and Mines, Geol. Div., Tanganyika, Short Papers 19.

Tilley, C. E. (1921) The granite gneisses of the Southern Eyre Peninsula (South Australia) and their associated amphibolites. Quart. J. Geol. Soc. London 77.

—»— (1936) Enderbite, a new member of the charnockite series. Geol. Mag. 73.

—»— (1937) Rocks from Enderby Land, Antarctica. Part 1. Rocks from MacRobertson Land, Antarctica. Part 2. B. A. N. Z. Antarctic Research Expedition. Rep. A. 2.

Tsuboi, S. (1949) On the genetic relations of igneous pyroxenes. Proc. Japan Acad. 25.

Tröger, W. E. (1935) Spezielle Petrographie der Eruptivgesteine. Berlin.

Turner, F. J. (1948) Mineralogical and structural evolution of the metamorphic rocks. Bull. Geol. Soc. America 30.

Turner, F. J. and Verhoogen, J. (1951) Igneous and metamorphic petrology. New York.

Tyndale-Biscope, R. (1931) Geology of the country around Shamva, Mazoe District. Bull. Geol. Survey S. Rhodesia 18.

Tyrrell, G. W. (1916) A contribution to the petrography of Benguella. Trans. Roy. Soc. Edinburgh 51.

—»— (1926, 1948) The principles of petrology. London.

Vogt, J. H. L. (1893) Bildung von Erzlagerstätten durch Differentiationprozesse in basischen Eruptivmagma. Z. f. prakt. Geol.

Vredenburg, E. W. (1918) Considerations regarding a possible relationship between the charnockites and the Dharwars. J. Asiatic Soc. Bengal, N. S. 14.

Väyrynen, H. (1923) Petrologische Untersuchungen der granodioritischen Gesteine Südostrobothniens. Bull. Comm. géol. Finlande 57.

Wager, L. R. (1934) Geological investigations in East Greenland. Medd. Grønland 105, 3.

—»— and Deer, W. A. (1939) The petrology of the Skaergaard intrusion. Kangerdlugssuag, East Greenland. *Ibid.* 105, 4.

Washington, H. S. (1916) The charnockite series of igneous rocks. Am. J. Sci. 41.

Watson, T. L. and Cline, J. H. (1916) Hypersthene syenite and related rocks of the Blue Ridge region, Virginia. Bull. Geol. Soc. America 27.

Wilkman, W. W. (1938) Geological map of Finland. Sheet—C 3. Kuopio. Explanation to the map of rocks (English summary).

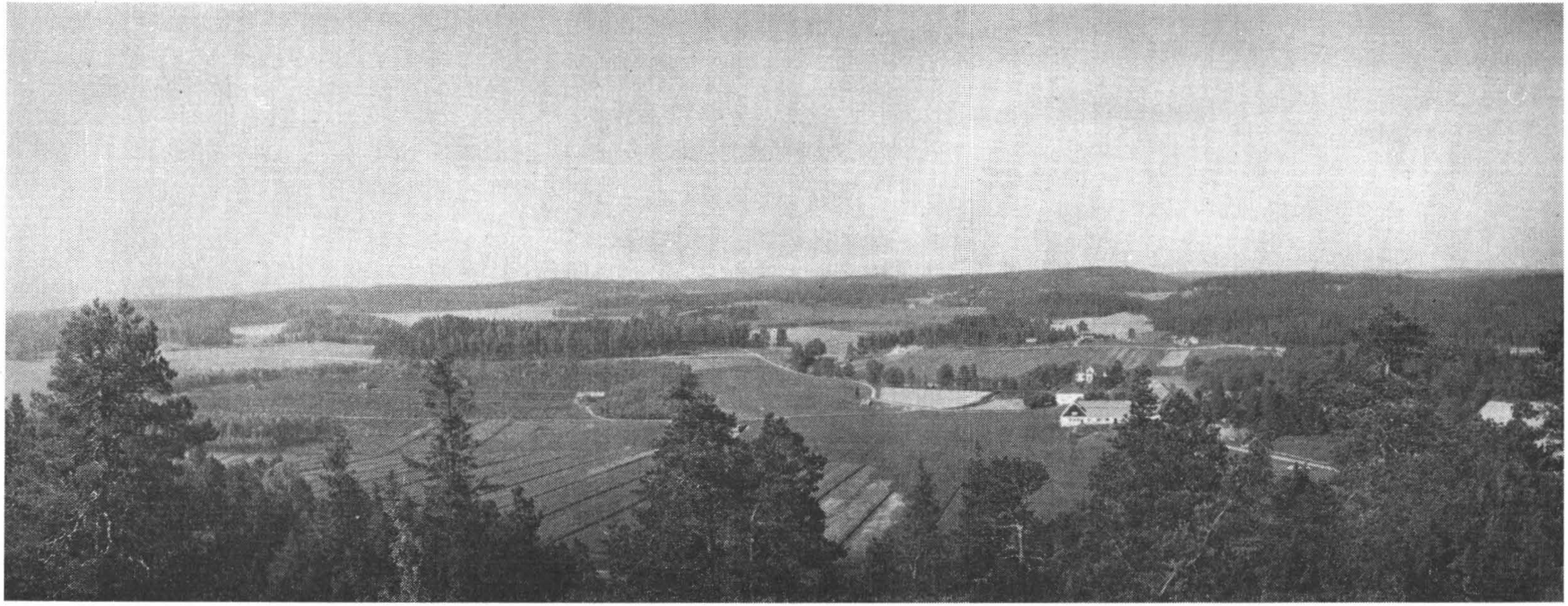
Wilson, A. F. (1947) The charnockitic and associated rocks of North-Western South Australia. Pt. 1. The Musgrave Ranges. Trans. Roy. Soc. S. Australia 71.

—»— (1948) Idem, Pt. 2. Dolerites from the Musgrave and Everard Ranges. *Ibid.* 72.

—»— (1950a) Some unusual alkali-feldspars in the Central Australian charnockitic rocks. Min. Mag. 29.

—»— (1950b) Fluorescent feldspar and zircon as petrological aids. *Ibid.* 29.

—»— (1952) The charnokite problem in Australia. Mawson Volume, Univ. Adelaide, pp. 203—224.



Typical landscape of West Uusimaa. 12 km N of the Lohja church. Photo Erkki Mikkola.

PART II

THE WEST UUSIMAA COMPLEX (WUC)

COURSE AND SCOPE OF INVESTIGATION

The bulk of the material for this investigation was collected in the field during the period of 1936—1939 in connection with the beginning of a geological remapping of southwestern Finland undertaken by the Geological Survey. The author's paper on the pyroxene gneisses of western Uusimaa (Parras, 1941) belongs to this early stage of the work. Only to a minor degree was the material for the present study collected during the revisional field work carried out in 1943. The determinations of trace elements by optical spectroscopy, the mineral separations using Clerici's solution, some optical determinations as well as a minor paper on the garnet-cordierite gneisses (Parras, 1946) originate from the period immediately after World War II. The work was temporarily interrupted when the author joined the limestone industry in 1946.

After his appointment as a geologist by the limestone company of Lojo Kalkverk Ab — Lohjan Kalkkitehdas Oy, the author was enabled to carry out investigations of the marginal transition zone on the southern boundary of the area in connection with his regular duties. In the course of years, the observations, rather extensive already from the previous stages of the work, accumulated. Their publication, however, was confined to a very brief general paper (Parras, 1954).

Up to the year 1946, the relationship between the charnockitic area under consideration and the non-charnockitic rocks surrounding it was studied as an internal problem of the Svecofennian mountain range. Later on, however, the author considered it more appropriate to discuss the entire charnockite problem as a background for his own study (Part I). Thus, in Part II of this paper, he will restrict himself to the internal questions of his own area. Later on and in another connection the original topic, mentioned in the foregoing, will be reviewed. For that reason, a part of the material already studied has been temporarily left aside and, on the other hand, another part of it had to be expanded, as for instance the number of thin sections examined, which increased to 1500. For the same reason, the author will not in this paper touch upon those recent investigations that, in some way, deal with his area. The geological map reproduced at the end of the work, which has been borrowed from an earlier paper (Parras, 1941), will serve as the basis of this study.

SYMBOLS FOR MINERALS

In regard to the abbreviations used for the names of minerals, no uniformity seems to have been reached in English geological literature. The following list includes common abbreviations, with the initials used in capitals. This is the system favored by P. Eskola (1952), and adopted and supplemented by the present author.

Acc	accessories	Mei	meionite
Amf	amphibole	Mar	marialite
Ap	apatite	Mi	microcline
Bi	biotite	Ol	olivine
Cal	calcite	Or	orthoclase
Chl	chlorite	Pfs $\left\{\begin{matrix}\text{Or}\\\text{Mi}\end{matrix}\right.$	potash feldspars
Crd	cordierite		
Di	diopside	Pla	plagioclase
En	enstatite	Px	pyroxene
Ep	epidote	Qua	quartz
Fsp	feldspar	Scp	scapolite
Gar	garnet	Sill	sillimanite
Grf	graphite	Sph	sphene
Grs	grossularite	Spi	spinel
Ho	hornblende	Wo	wollastonite
Hy	hypersthene	Zr	zircon
Ma	iron ores		

LIST OF MATERIAL

Table 1 (pp. 116—123) presents a list of the rock specimens in regard to which detailed data are given in this paper. The localities where the specimens have been collected and the names of the analysts are mentioned only in this table. In the text, the specimens are indicated solely by their current numbers. The gaps occurring in the numerical order of the specimens in the table are caused by restrictions made in the material used.

GENERAL GEOLOGICAL OUTLINES

NAME, LOCATION, TERRAIN

The region here under consideration belongs to the Svecofennian formation of early Archaean age of southern and southwestern Finland. In the last few years, in accordance with the name given by the present author

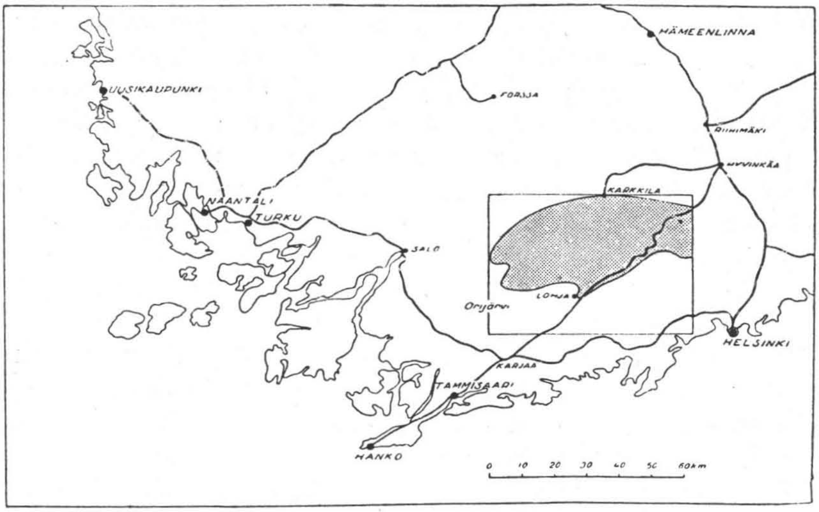


Fig. 1. Location of the West Uusimaa Complex (WUC) in southwestern Finland.

in an earlier paper (Parras, 1941), this region has been called "the pyroxene gneiss area of western Uusimaa". From now on, the author suggests the name "West Uusimaa Complex", abbreviated WUC, to be adopted for this region. The area in question forms an oval, not a full 100 km in length and 20 to 40 km in width. Its long axis is parallel to the general Svecofennian east-westerly strike. The center of this region is situated approximately 50 km from Helsinki to NW (Fig. 1). The region is highly cultivated and includes alternating agricultural and forest areas. The topographical altitudes fluctuate within the limits of 130 m. Large glacial deposits and lakes being lacking, the outcrops are mostly sufficient to enable the construction of a comparatively detailed geological map.

PETROGRAPHIC AND TECTONIC UNCONFORMITY BETWEEN WUC AND SURROUNDINGS

Geologically the Svecofennian territory of southern and southwestern Finland forms a rather variegated picture, further complicated by the occurrence of the WUC. To obtain a general view of this area, the reader is referred to recent publications issued by the Geological Survey of Finland, including the explanations to the geological map sheets. The authors of these papers tend to include in one single orogenic cycle the entire Svecofennian territory with the highly crystalline representatives of the geosynclinal deposits and volcanics (supracrustal rocks) as well as the intrusive (infracrustal) rocks.

The geological map does not show the rock crust surrounding the WUC. In brief, the surrounding bedrock may be outlined as follows: The areas to the north of the complex are mainly composed of basic volcanics, gabbros and Mi granites. The schists are of secondary importance. The boundary between the WUC and the surroundings strikes from E to W and is quite clear and sharp. Dislocations have possibly accentuated its sharpness. Farther west, the complex runs into a Mi granite area, then turns towards SW and, apparently immediately, there meets the famous Orijärvi region and its leptites. The boundary line between the WUC and the Orijärvi region is less abrupt, but still sufficiently clearly defineable. The region around Lohja on the geological map has erroneously not been included in the WUC, to some extent because of the scarcity of outcrops. The Lohja region, with which the author is occupied at present, contains sedimentary rocks of extreme composition. Especially the observations based on drillings have shown that the field in question is very illustrative both petrochemically and from the point of view of the mineral facies principle. More to the east, on the southern boundary of the complex, a large Mi granite area is encountered again. The easterly continuation of the complex, not indicated on the map, disappears there among different kinds of crystalline schists.

The WUC is clearly distringuished from its environment, which belongs to a petrographically and petrochemically rather heterogeneous rock crust with prevailing amphibolite facies. The same rock types occur irregularly and repeatedly over the whole area of the WUC. The basic rocks, however, form an exception to this rule. The mineral assemblages are critical or typomorphic in respect to the granulite facies.

The structual geology of the surroundings of the WUC is characterized by an intense isoclinal folding with axes gently plunging to the east or west. The entire WUC follows completely the same direction both in its oval form on the map and in regard to its internal b-axis. Notwithstanding this similarity outlined on a large scale, the WUC deviates in its minor structural features from the environment almost as clearly as it does petrologically. In contrast to the more rectilinear and rigid forms of the gneisses and schists of the rock crust outside the map area, the internal pattern of the WUC forms curvings and branchings or even ring-shaped zones, while the infracrustal rocks simultaneously conform with the swirls of the supracrustal framework. The conformity is strengthened by the foliation, which, in its turn, is concordant with the strike and dip of the bedding. The dip is mostly gentle, 20° to 50°. The tectonic b-axis striking E—W and plunging gently E may be determined from major folds and also from the lineation. It should not be confused with the equally gentle axes of the minor folds following the bedding. The deviation of the axes of these minor folds from the

E—W direction appears most clearly in areas where the strike of the strata of the major folds is N—S.

Epitomizing the observations available so far that deal with the relationship between the WUC and the lithological materials of its environment, the following opinion could not be avoided. Especially in the S and SW parts of the WUC, the petrographic differences between the rocks of this complex and of its environment do not only imply a difference in the conditions of metamorphism but also indicates a difference in the composition of the supracrustal framework (Parras, 1954). Two explanations may be found for this last-mentioned statement that either represent separate alternatives or are valid jointly: 1) The WUC represents materially a different stratigraphic horizon than do the rocks of the surroundings. The relative location of these horizons depends upon the axial culminations and depressions and, in addition, is possibly stressed by dislocations. 2) The present bulk composition of the rocks of the WUC depends upon the stability of the crystalline phases and is essentially dictated or, at least, affected by the PT-conditions. That would mean that the chemistry depends much more upon the physical conditions than has been believed (cf. pp. 19, 23, 33). Some observations would point in favor of this interpretation. For the present, however, the author will ignore them.

Placed into the Svecofennian frames, the general genetic interpretation of the rocks of metamorphic charnockite provinces (Part I) as being "derived from country rocks through high-grade metamorphism" appears to the present author inapplicable.

CLASSIFICATION OF ROCKS

According to current classification applied to the rocks of the Svecofennian zone in southern Finland, the rocks of the WUC may be grouped as follows:

Supracrustal rocks

Dark MeiDi amphibolites
Light Px amphibolites (basic charnockites)
Px gneisses (acid to intermediate paracharnockites)
GarCrd gneisses or kinzigites (lutogenites)

Infracrustal rocks

Peridotites (ultrabasic rocks)
Gneissose Px granodiorites (acid to intermediate charnockites)
Mi granites and pegmatites

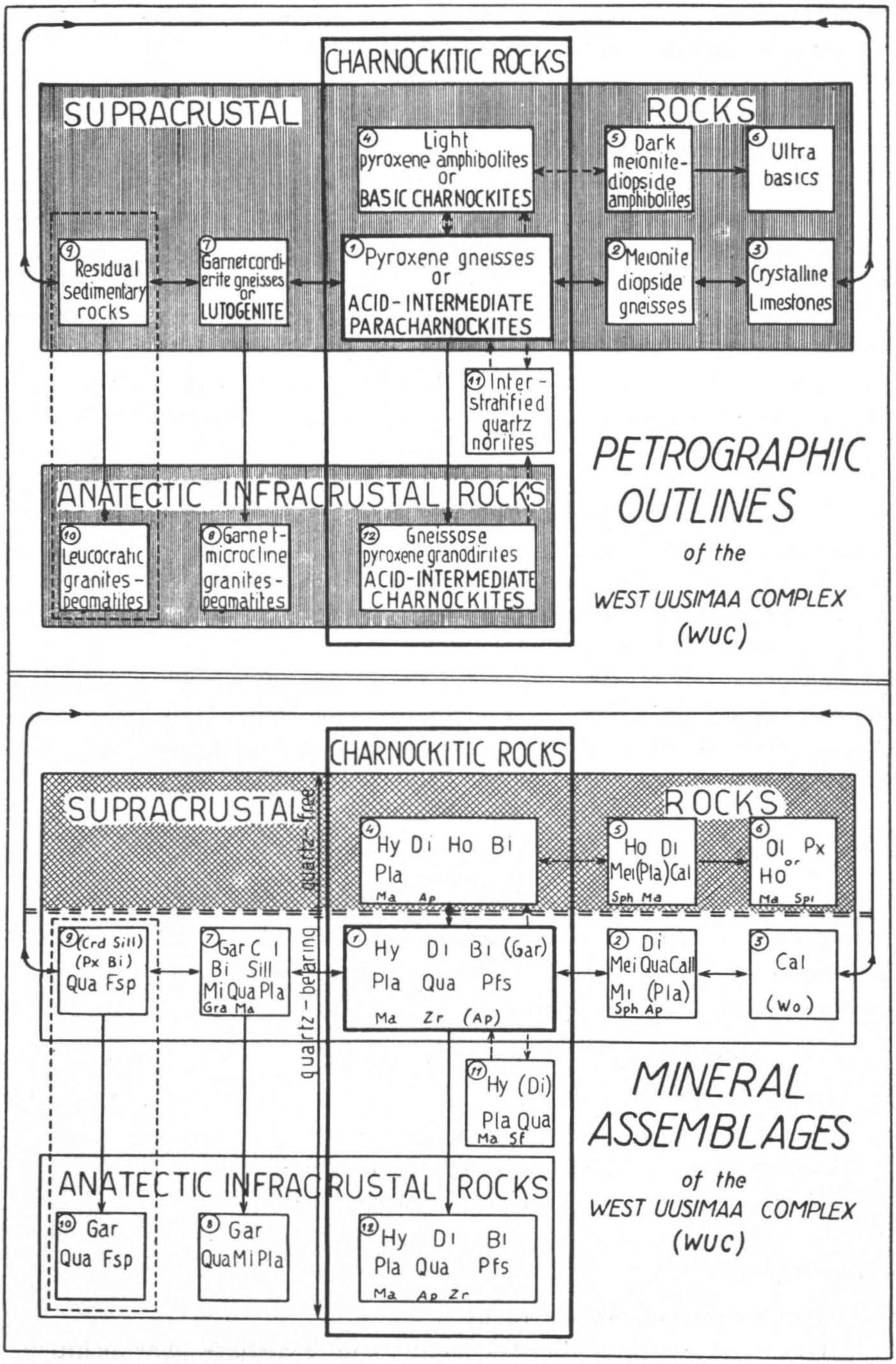


Fig. 2. For explanation see text.

This classification implies the Px granodiorites to be true igneous rocks belonging to the synkinematic intrusives of the Svecofennian mountain range. In the opinion of the author, however, the Px granodiorites of the WUC appear to be anatectic, like the Mi granites, formed by refusion and mobilization of the supracrustal framework. This mode of origin was already mentioned as a possible one in an earlier paper (Parras, 1941, pp. 495—496). Also the ultrabasic rocks lack the characteristics of true peridotites. All the rocks of the WUC have originated through ultrametamorphism of supracrustal material. On the other hand, the adoption of the name "paracharnockite" for the supracrustal Px gneisses (p. 32) is merely intended to distinguish these rocks from the igneous-looking Px granodiorites. The name paracharnockite is not intended to stress the demarcation line between the "true" and the "false" charnockites, nor will the author insist on the adoption of the notoriously mistreated name charnockite for the rocks of the WUC. The names in question are used in the present paper merely for characterizing the typical mafic mineral assemblages.

Taking into account the fact that plagioclase mainly predominates over potash feldspar in charnockitic rocks of the WUC, the name "enderbite" would be more appropriate (pp. 8, 18—19). If the rock is argillitic in composition, then the name "lutogenite" is used instead of "kinzigite" in order to point out the genesis of the rock.

Supplied with the remarks presented in the foregoing, the rock classification as used in this paper is summarized in Fig. 2 (upper part). The following supplementary explanations may be added:

The scheme includes the petrographic types of the WUC with their characteristic names in the squares numbered 1—12.

The mineral assemblages of all these rock types are representatives of the same mineral facies.

Petrogenetically, the scheme splits into two parts, the supracrustal and the anatectic infracrustal field. Both fields include representatives of the charnockitic rocks. If the presence of the orthorhombic pyroxene is taken as the sole criterion for the charnockitic rocks, then this classification is not indisputable. Orthopyroxene is not rare in the ultrabasics (6) nor in the arkosic rocks (9).

Petrochemically, the supracrustal field of the scheme represents a rather extensive variation in the composition of the primary material. Starting from the paracharnockites (1) to the right, there are impure calcareous sedimentary rocks (2) followed by pure limestones (3). To the left, a transition through argillites (7) into representatives of the residual sediments (9) takes place. In the interior of the WUC, the extreme members of the rock series mentioned are very sparsely represented. They are, however, characteristic of some marginal parts of the complex, as at the Lohja region and, to some extent, at the NW margin of the complex. Above the paracharnockites in the scheme of Fig. 2, there are the groups of basic rocks (4, 5, and 6). These groups differ from the sedimentary rocks, among other things, also in their trace element content. The chemistry of the anatectic rocks — the charnockites (12) and the granites rich in potassium (8, 10) — does not differ from that of the plutonic rocks of the calc-alkali suite. Finally, according to the silica content, the rocks in the scheme may be divided into two kinds, quartz-free and quartz-bearing. The former may partly occur in the charnockite group (12) as well (Fig. 2, lower part).

In the field, the sequence of the stratified rocks may be the same as in the scheme. The latter, however, does not represent any general columnar section, but mainly outlines the petrochemical and petrogenetic relationships of the different rock types. Before entering into a description of these groups, the mineral assemblages will be surveyed.

MINERAL ASSEMBLAGES

The mineral assemblages of the rocks discussed in the foregoing are presented in the bottom part of Fig. 2. The order of the constituents, separately of mafic and of felsic, corresponds to their relative amounts. These assemblages are characterized by phases typical of the granulite facies. Another paragenetic scheme may be constructed (Fig. 3) arranging the main constituents + sphene according to their compositions (excluding the assemblages of the ultrabasics). Regarding this scheme the following remarks are made:

The symbols for the minerals are indicated on the horizontal row. To the right of the center of this row, the mafic constituents are arranged according to the increasing (Ca + Mg)-content. The felsic constituents are placed to the left of the center.

The row consisting of the mineral symbols divides the field into two parts. The quartz-free field as above this row, and the quartz-bearing field is below it.

The total picture has a clear tendency to be symmetric. The petrochemical interpretation of this scheme is as follows: Each horizontal row composed by the squares (I—VI) represents the maximum amount of the co-occurring crystalline phases and, thus, characterizes the bulk chemistry of the rock. The horizontal rows correspond to the petrographical groups of Fig. 2 as follows: I dark MeiDi amphibolites, II light Px amphibolites, III lutogenites, IV—V charnockitic rocks, VI MeiDi gneisses.

The aim of the scheme of Fig. 3 is to illustrate that, when discussing the equilibria between the crystalline phases, it is necessary to deal with

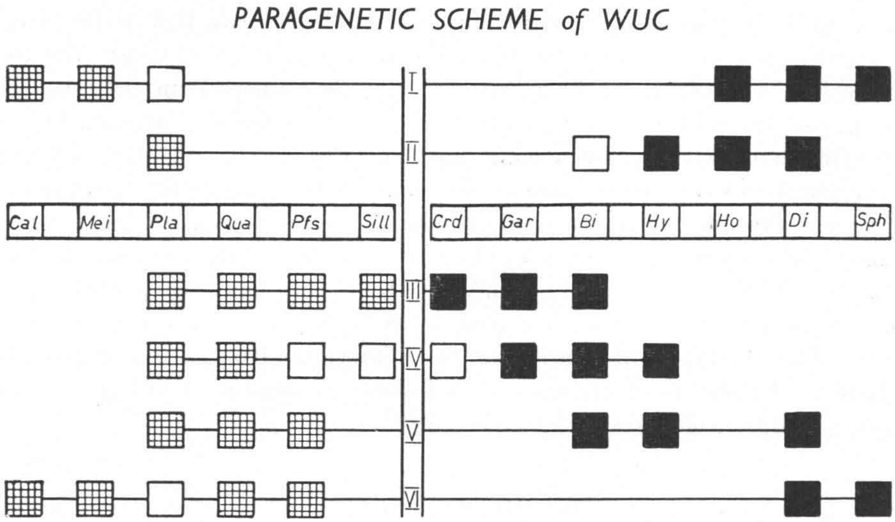


Fig. 3. Mineral parageneses (excepting those of the ultrabasics) of the rocks of the WUC. Solid black squares = mafic minerals. Cross-hatched squares = felsic minerals. Blank squares = minerals which may or may not be present (unstable).

the bulk chemistry and not with a part of it only. Thus, for instance, the presence of CO_2, TiO_2, and SiO_2 should not be neglected, the concentration of which may have a decisive importance to the stabilities of some particular minerals.

PETROGRAPHIC TYPES AND THEIR GENETIC RELATIONSHIPS

In the following, the petrography of the rock groups of Fig. 2 is briefly described. The chemical analyses, the modes and the grain sizes of the rocks are summarized in Table 2 (pp. 124—127) to which reference is here made. Except for the details given in the chapter entitled ''Mineralogy'', the microscopic petrography of the rocks is here limited to the following general remarks. The rocks of the WUC appear under the microscope to be remarkably clear and fresh. No granulation and no significant secondary alteration is detectable. This is a feature characteristic of charnockitic rocks in general all over the world.

1. PYROXENE GNEISSES OR PARACHARNOCKITES

(Anal. Nos. 24, 25, 26, 27, 28, and 29)

The prototype of this group (HyBi ± Di) is in its appearance a veined and banded, medium-grained rock, which on a large scale is very monotonous (Fig. 4). On its weathered surface, rusty or dark brownish shades caused by hypersthene occur. Because of the relatively dark plagioclase, the fresh surface is also darker than usually in rocks of similar composition. This rock group includes rather fine-grained or more massive varieties or ones displaying irregular grain size and banding (Fig. 5). In the QuaFsp veins and segregations the orthorhombic pyroxene is always typically coarser than in the crystalloblastic mass. Among the more calcareous rocks, the BiDi gneisses (Nos. 28 and 29) represent extreme members of the paracharnockites. These rocks are even-grained, with or without fine banding, greenish gray, and less gneissose, intercalating with more ferruginous or more calcareous layers. The thickness of the strata may fluctuate from a few centimeters to tens or hundreds of meters. This feature is typical of the whole sedimentary (supracrustal) series of the WUC.

2. MEIONITE-DIOPSIDE GNEISSES

(Anal. No. 33; closely related rock types are Nos. 30, 31, 40, and 41)

Notwithstanding the fact that, on the scale used in the geological map, these impure calcareous sedimentary rocks cannot be distinguished from other Px gneisses, they have been here taken to form a separate group. By excluding these rocks from the paracharnockite group, the importance of meionite is emphasized as a constituent in rocks of calcareous bulk composition. Rock types transitional between the paracharnockites and the MeiDi gneisses occur in which the stability (paracharnockites) or instability (MeiDi gneisses) of biotite forms the boundary line between these groups. The pure Di gneisses (Nos. 30, 31, 40, and 41) are classed with the latter group as well. These rocks contain varying amounts of quartz and feldspars (see Fig. 14, p. 86). In contrast to the arena-argillaceous lutogenites, the original material for the pure Di gneisses represents that of the arena-calcareous sediments. The presence of a residual component in these gneisses is indicated by the abundance of zircon (p. 111) and zirconium (p. 76). The QuaFspDi types are greenish, usually massive, without any banding. The MeiDi types, rich in carbonates, on the contrary, have a regular and rectilinear banding, and thus they represent the another extremity. This banding strongly supports the view that it represents the primary sedimentogeneous structure (metamorphic differentiation?) (Fig. 9, p. 65). All these rocks are even-grained with a medium grain size and a beautiful granoblastic texture.

3. CRYSTALLINE LIMESTONES

Within the WUC there are a few, comparatively small deposits of coarse-grained limestone. They seem to prefer the company of lutogenites and of

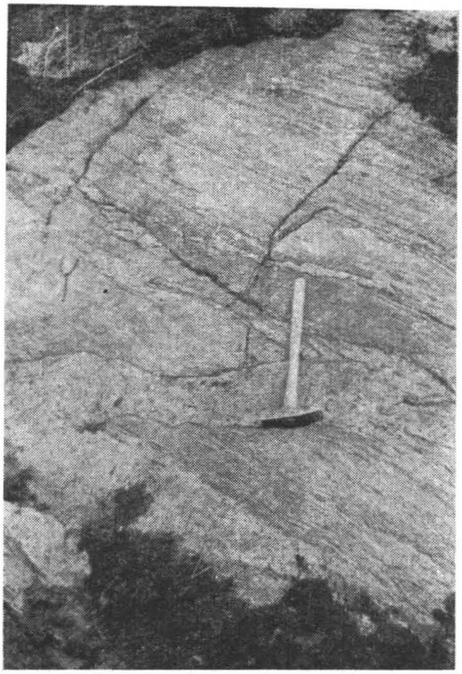


Fig. 4. Prototype of the pyroxene gneisses (paracharnockites). 4 km N of the Vihti church, WUC. Photo Parras.

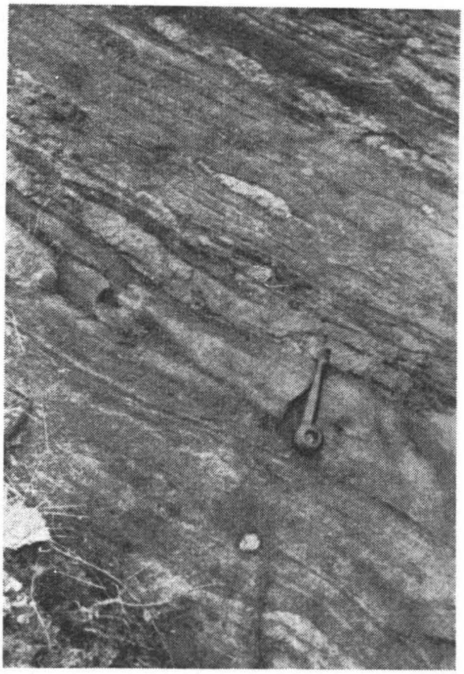


Fig. 5. Banded type of the pyroxene gneisses (paracharnockites). 3 km NE of the Vihti church, WUC. Photo Parras.

the charnockitic rocks, but not, as could be expected, the neighborhood of the rocks of related calcareous composition. The Lohja region is rich in limestone deposits, and also the paracharnockites and the extreme components of the lutogenitic primary material are those which there form the guide horizons for the limestones. Within the WUC skarns are entirely unknown, whereas wollastonite occurs exceptionally (p. 81). Within the Lohja region, on the other hand, skarns are known and wollastonite is common.

4. LIGHT PYROXENE AMPHIBOLITES OR BASIC CHARNOCKITES

(Anal. Nos. 44 and 45)

This group includes rock types of varying appearance. All of them contain, however, comparatively small amounts of hornblende, compared with the amount of pyroxenes. The main part of the rocks of this group obviously has originated from the hypabyssal rocks. Some of them possibly have derived either from volcanic or from sedimentogeneous material (cf.

trace elements). The prototype (No. 44) is a coarse medium-grained, more or less distinctly banded rock, which, despite its gneissose structure, appears rather homogeneous. The orthorhombic pyroxene of this rock is in general coarser than in other rock types, and sometimes it occurs as poikiloblastic crystals up to few cm in length. A noritic dyke rock (No. 45) deviates most from the prototype. Its texture may approach an ophitic pattern. In the field, however, this rock occurs concordantly and, classed purely on a genetic basis, it would be placed with group 11 of the scheme of Fig. 2. The geological map does not show correctly the amount of occurrences of the light Px amphibolites, because this rock type also occurs as thin layers, especially in the paracharnockitic environment.

5. DARK MEIONITE-DIOPSIDE AMPHIBOLITES

(Anal. Nos. 47 and 49)

This is a uniform group, which includes the main host rock of hornblende within the WUC. It is a medium-grained rock made up of calcite-scapolite bands, up to a few cm thick, alternating with layers composed of mafic constituents. Some of the dark bands may be fine-grained and entirely massive. In addition, stripes rich in sphene are not very rare. The texture is always granoblastic. Contrary to similar Di amphibolites occurring outside the WUC, which have been explained as being of purely sedimentogeneous origin, the author has in an earlier paper (1941) considered a volcanic origin most probable for the dark MeiDi amphibolites. Not going into details observed in the field or in the petrofabrics, the author refers to the trace element determinations (p. 70) that indicate clearly enough the deviation of the trace element concentrations of the MeiDi amphibolites from those of the other supracrustal rocks of the complex. The MeiDi amphibolites of the WUC show signs of volcanic activity. The primary material from which they have been derived has been that of calcareous tuffites and of beds of basic volcanics.

6. ULTRABASICS

Within the WUC, the ultrabasics occur in the form of minute lenses, always accompanying the MeiDi amphibolites, into which they grade in many different ways. Also the trace element contents indicate a close relationship between these two. The ultrabasics of the WUC represent either primary accumulations or metamorphic derivatives, both from the basic volcanics; or, then, they represent the products of both kinds.

7. GARNET-CORDIERITE GNEISSES OR LUTOGENITES

(Anal. Nos. 53 and 57; closely related are Nos. 57, 106, 107, and 108)

In the scheme of Fig. 2, the paracharnockites grade to the right into MeiDi gneisses. This is a result of the change in the primary composition of sediments that have been enriched in calcium. The gradation to the left can likewise be observed. There GarHy gneisses will result (Nos. 106, 107, and 108), but they grade further into GarCrd gneisses (Nos. 53 and 57). Ample material obtained from drillings in the Lohja region made it evident that the gradation of paracharnockites into the lutogenites mainly depends on differences in the primary bulk composition of the material and not on the granitization (potash metasomatism) of the intermediate material (paracharnockites).

Following the suggestion made in an earlier paper (Parras, 1946), the GarCrd gneisses are called lutogenite *(lutum* = clay) in this paper instead

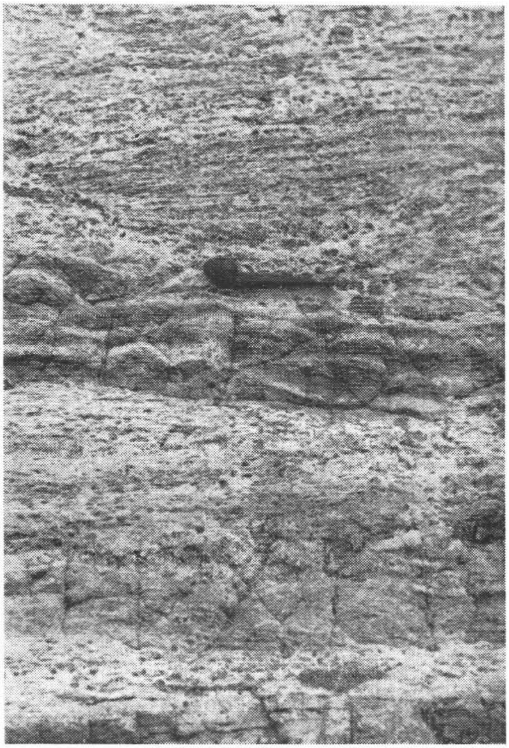


Fig. 6. Coarse-grained garnet-cordierite gneiss = lutogenite. 3 km SE of the Nummi church, WUC. Photo Parras.

of kinzigite. The term kinzigite means primarily metasomatic vein rocks met with in Germany (op. cit., p. 2). The proposal of a new name is justified even more, because the lutogenite is considered as belonging to the granulite facies and, on the other hand, because the term kinzigite has been used in Finland in a rather broad sense. The term lutogenite is not intended to be restricted to the WUC only.

The lutogenite is a coarse-grained, venitic rock, in which the quartzo-(potash)feldspathic veins and lenses, often containing large crystals of garnet and cordierite, alternate with strips richer in the MgFe-constituents. On a larger scale, strata of irregularly variable thickness may sometimes be observed. Fine-grained noritic streaks are not unknown (Fig. 6). Varieties richer in granitic components or even large portions composed of GarMi granite (group 8) are associated with the normal type of lutogenite. The granitic portions found in the lutogenites have apparently received their material from the pre-lutogenitic residual-hydrolyzatic sediment itself (Parras, 1946). Neither the study of trace elements, nor the zircon (rounded grains) contradicts this statement; rather is the contrary true. Although the name lutogenite admittedly stresses the argillitic component of the rock, the origin of the material for the MgFe-phases, on the other hand, corresponds to the composition of the argillitic part of the rock and is decisive in the naming of the rock.

Finally, it should be borne in mind that the GarCrd gneisses of Södermanland in Sweden (op. cit., p. 2), which are very similar in appearance to those of the WUC, gave P. J. Holmquist the idea for his well-known hypothesis of ultrametamorphism as well as for the conception of venite as opposed to the arterite of J. J. Sederholm. The hypothesis of partial anatexis proposed by P. Eskola directly leans toward the said idea of Holmquist.

8. GARNET-MICROCLINE GRANITES AND PEGMATITES

(Anal. No. 104, average mixture of 12 samples)

These "younger granites" are non-foliated, light pinkish rocks. In the finer-grained varieties some structural features may be interpreted as being relics of the original stratification in arenaceous material. The view of the author as to the origin of the rocks belonging to this group was presented in connection with lutogenite. In the field, they are in concordance with the main structural features on a large scale, but in details the GarMi granites and pegmatites occur as penetrating rocks. This behavior does not, however, prevent these rocks from belonging to the last products of the same processes that also gave the country rocks their present appearance.

There is no reason why these potash granites must be considered as representatives of some later intrusion (see pp. 65—66).

9. RESIDUAL SEDIMENTARY ROCKS

The most easily recognizable residual sedimentary rocks occur in the marginal parts of the WUC, especially within the Lohja region. There they occur together with other sedimentary rocks of extreme composition, showing a more clearly marked tendency to be sorted during the exogenic differentiation than do the sediments of the interior of the complex. The potash feldspar usually prevails; more seldom are they quartzitic. The lutogenitic and charnockitic MgFe-minerals may be present, though in very subordinate amounts.

The arenaceous material within the WUC is mainly included in the granitic component of the lutogenite, to some extent also in that of the MeiDi gneisses. In addition, it is very probably represented in the silicic charnockites as well (p. 63). If the tendency of the incomplete exogenic differentiation is viewed on a larger scale, then the rhythm of the geological processes within the Svecofennian territory has been essentially different from what it was during the formation of the Karelidic geosyncline (Parras, 1946, p. 4).

10. LEUCOCRATIC GRANITES AND PEGMATITES

This group includes especially the granitic rocks of the Lohja region. The composition and color of these rocks vary, depending upon the horizon of the arenaceous rocks to which they adjoin. In other words, they depend upon the material, of which they are the anatectic derivatives (Parras, 1954). Once more the present author refers the reader to the evidence obtained from the drillings, the material of which will not, however, be treated in this paper.

11. INTERSTRATIFIED QUARTZ NORITES

(Anal. No. 9)

The quartz-bearing type is more common than the basic varieties, and it occurs in a paracharnockitic (rarely in a lutogenitic) environment. It forms concordant fine-grained bands and layers, and the spongy crystals of pyroxenes are somewhat bigger than the grains of the light constituents. Among the accessories, the oxidic iron ore is always more abundant than in other rock types (p. 109). Very similar are also the ghostly inclusions in the anatectic charnockites. After all, the origin of the noritic rocks may vary. The main part of them, however, probably represents the former intermediate and basic dyke rocks.

12. GNEISSOSE PYROXENE GRANODIORITES OR CHARNOCKITES

(Anal. Nos. 1, 2, 3, 5, 12, 13, 14, 16, and 17; closely related is No. 68)

The tendency of a gradation of the paracharnockites into the igneous-looking charnockites, especially parallel to the general strike, is elucidated by the geological map. It is often impossible to classify the transitional forms with any in the two groups mentioned. In the field, if there is nothing to be used for immediate comparison, the determination of the rock boundary is rather arbitrary. On the other hand, because both groups include members of similar bulk chemistry (as pointed out later), the author wants to remark that the analyses represent well-defined types only, excluding transitional types. The charnockites are characterized as follows: They form conformable small lenses, mainly preferring small swings and swirls of the supracrustal framework, or also as larger bodies in conformity with the main structural features. The prototype is middle- and even-grained rock, displaying a distinct parallel arrangement of its constituents (syn-metamorphic flow structure). At the first glance, the rock appears homogeneous. Actually,

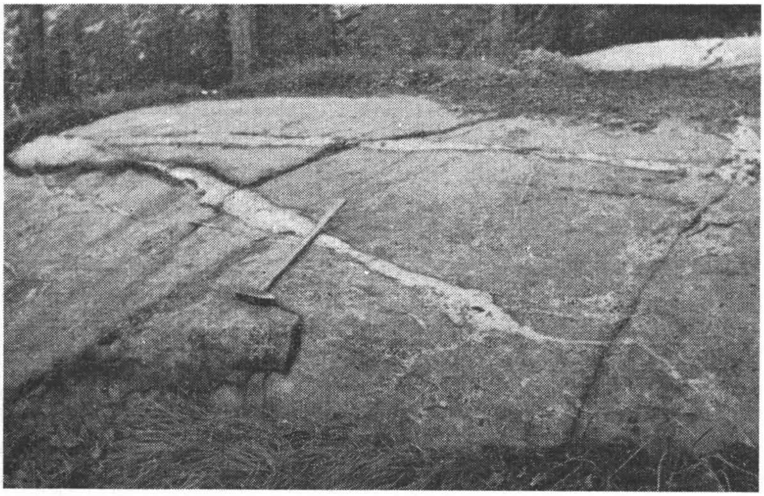


Fig. 7. Pyroxene granodiorite (charnockite). The coarse-grained quartz-plagioclase-hypersthene segregations on the right continue as quartz-potash feldspar veins to the left. 7 km SE of the Pusula church, WUC. Photo Parras.

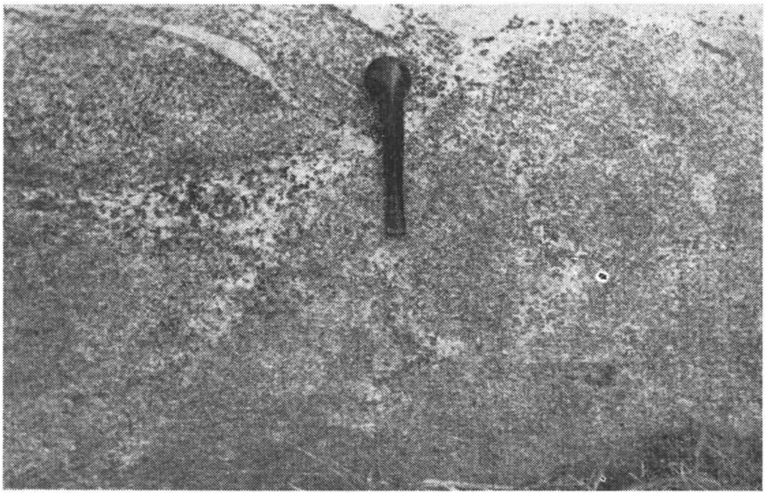


Fig. 8. Detail of Fig. 7, bottom right. Photo Parras.

however, its composition changes gradually and irregularly. The color of the rock, both on the weathered and on the fresh surface, is typically that of charnockites. The presence of irregularly shaped and indistinctly bounded, coarse QuaFsp segregations, which contain likewise coarse orthorhombic pyroxene, is a feature quite characteristic of these rocks. The veins containing prevalent plagioclase may grade into lens-formed QuaPfs pegmatites (hair-perthite, untwinned), which have undoubtedly been derived from the host rock itself (Figs. 7 and 8). Both in its appearance and in its composition, similar material occurs also in the form of irregularly crisscrossing pegmatitic veins. Compared with the paracharnockites, the charnockites differ from them through lack of concordant fine veins and bands, and through the presence of the contact effects (p. 64) and of fragments. Furthermore, the charnockites contain pyroxene crystals more homogeneous than are the spongy ones of the paracharnockites. The former contain antiperthite, which is only exceptionally present in the latter type. The texture of the charnockites is rather hypidiomorphic instead of the more xenomorphic granular texture of the paracharnockites. These are the microscopically determinable differences between the two rock types, though not always dependable. Joining the main type here described, there sometimes occur more fine-grained or more massive silicic varieties (Anal. No. 1), which, in regard to the amounts of feldspars, correspond to the original charnockite of Holland. These rocks have been earlier regarded as "true" Hy granites by the present author. At present, however, this type is, in the opinion of the author, more or less reconstructed arkose.

ON CONTACT RELATIONS

As an example of the supracrustal rocks, the light Px amphibolites show contacts against the MeiDi gneisses that look sharp. A set of thin sections made across the contact shows, however, that fading signs of a contact effect are detectable within half a meter's distance from the contact. On the amphibolite side of the boundary, the orthorhombic pyroxene has been gradually replaced by a monoclinic one and by hornblende indicating an evident increase in lime in the rock. On the other hand, no noteworthy difference is observed in the fabric or grain size. On the gneiss side of the contact, the banded fabric becomes disturbed and particularly the monoclinic pyroxene becomes coarser and turbid. This mineral becomes filled with opaque inclusions and there appear ample exsolution lamellae (p. 103). Of course, the transfer of matter across the contact may be explained, if so wanted, through diffusion in the solid state. Regarding the exsolution lamellae in pyroxene, however, a local increase in temperature must be assumed to have taken place. In the rocks supposed to be hypabyssal, the grain size both in the marginal parts and in the center of the intrusion is the same, which may indicate that the intrusion took place into a ready heated environment. It should be remembered, however, that the recrystallization may have partly dissipated the primary features.

With respect to the infracrustal rocks, the fabric of anatectic charnockites remains unchanged up to the extreme margins of the contact. In the composition, however, certain changes may still be observed some meters away from the contact. Thus, for instance, if, verging on the lutogenite, there appears some garnet in the charnockite, either besides or instead of the hypersthene, and if it borders upon calcareous sediments, all the pyroxene is monoclinic. As will be evident from diagram B of Fig. 10, to be given later on, the occurrence of the MgFe-phases very sensitively depends upon the changes in the Ca/Al ratio in the bulk composition. Therefore, even small assimilations of these elements may be sufficient to explain the differences in the mineral associations of the contact zones. In the country rocks, however, as, for instance, in MeiDi gneisses, the changes are to be seen also in the fabric (Fig. 9), and the change in the mineral assemblages is more thorough. There appear Pla + lamellar Di + Bi instead of Mei + + Di + Pfs + Sph. Especially the gradational alteration of meionite into plagioclase may be observed at different stages with the resulting carbonate clusters enclosed in the center of the plagioclase (cf. p. 82). Near the contact, the abundance of exolution lamellae in diopside and their rarity or absence farther away from the contact are difficult to explain without assuming a local increase of temperature. Several observations suggest that, during the emplacement, the anatectic charnockites have been in a viscose

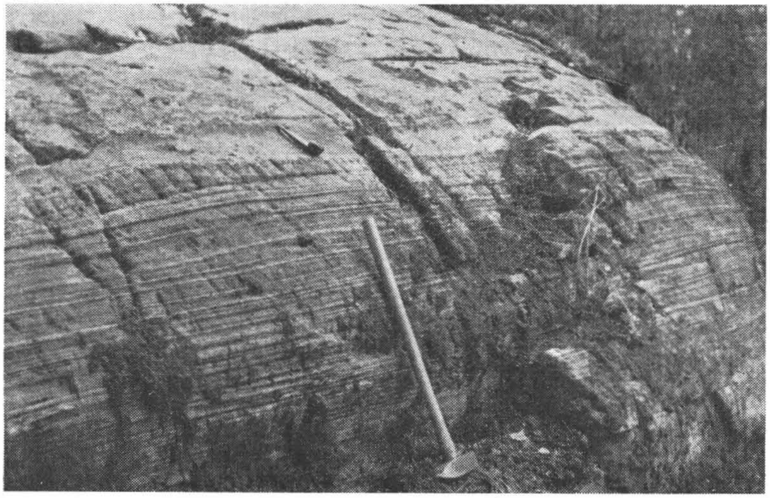


Fig. 9. Below, straight- and fine-banded meionite-diopside gneiss; above, pyroxene (diopside) granodiorite (charnockite). The contact (marked by the pipe) is a metasomatic product of the gneiss induced by the granodiorite, not a chilled margin of the latter. Small granodiorite lens 9 km NNE of the Vihti church, WUC. Photo Parras.

state and that the supracrustal rocks, into which the charnockites intruded, had at that time already attained their present appearance, but obviously were heated to a temperature close to that of the eutecticum of quartz + alkali feldspars. Furthermore, the metasomatic effect caused by the charnockites may be traced, for instance, in the calcareous sedimentary rocks, on a scale of a few centimeters or even meters. The mixed rocks formed by this effect resemble those considered as being transitional types (p. 62); in other words, at least a part of the intermediate rocks, perhaps, should be explained as being hybrid rocks (cf. p. 17). On the basis of the rocks examined by the present author, however, there seems not to exist any necessity to adopt metasomatic interpretations on the large scale (cf. Ghosh, p. 24). If, on the other hand, certain structures are explained as signs of incipient refusion or anatexis, the same structures may be seen in the paracharnockites as well.

As to the cross-cutting contacts in the highly metamorphic rocks, they hardly bring any conclusive evidence as to the age relationships of the rocks. This conclusion applies to the plastically mobilized limestone, which cuts an ophitic amphibolite dyke enclosed by the same limestone, as well as to lutogenite, which, in its conformable contact with the Px granodiorite, sends its own QuaPfs projections and veins perpendicularly to the schistosity. The same applies to the Mi granite of WUC as well. In the customary geologic language, it is "younger" than the other rocks. Such a mode of occurrence of the granite is, however, only the result of the fact that, in the sequence of processes in decreasing temperature, the granite crystallizes last or, in increasing temperature, becomes mobilized first. Expressed in the way used by Szadeczky-Kardoss (1955), the bonding potentials of the constituents of the granite are lowest among those of the crystalline phases encountered.

PETROCHEMISTRY

In chemical composition expressed in terms of the main elements, the charnockites in general are not exceptional rocks but may be interpreted as being members of the calc-alkali suite of the plutonic rocks. This applies to all charnockitic rocks of the WUC as well. Thus the author will pass over the habitual analytical comparison with the other charnockite areas, this comparison being less profitable for the present study. Reference will only be made to the complication of 88 analyses presented by Pichamuthu (1953, pp. 165—168). The chemical composition of the rocks of the WUC is summarized by using a graphical way of presentation constructed by the author. The diagram was based on one-cation percentages, calculated from the analyses, and used throughout this paper. The results of the spectroscopic trace element determinations are treated to answer two questions. On the basis of the general knowledge of their geochemical behavior, the trace elements have been examined as possible indicators for the origin of the rocks. On the other hand, a study was made to determine to what extent the geochemical character of the elements agrees with the genetical conclusions about the genesis of the rocks that may be drawn in the customary petrological way.

MAIN ELEMENTS

REMARKS

The 35 chemical rock analyses presented in this paper have been made at the laboratories of the Institute of Geology of Helsinki University and of the Geological Survey of Finland during the earlier stages of this study. They represent the original material of the present author only. Without the author's being aware of it, 19 of these analyses were published by Lokka (1950), and later on some of them have been used in other publications as well.

TABLE OF CHEMICAL ROCK ANALYSES

In Table 2 (pp. 124—127), both the weight percentages and the one-cation oxide percentages (Eskola, 1954) are indicated. In addition, there are, for the trace elements, cross references to Table 4 (pp. 131—133). Except for 7 analyses, the mineralogical compositions (modes) as averages from at least two thin sections are given in volume percentages. These determinations are made by the author with the Leitz integration stage, using intervals of 0.2—0.5 mm between the lines of measurement. The average distance measured per thin section was 51 cm. The grain size indicated is an average computed from microscopic measurements. These values are less than the grain size megascopically observable. Specific gravities were not measured.

TABLE OF CATION VALUES

In Table 3 (pp. 128—130) the values indicated are the percentages, totals, or ratios, which have been used for the construction of petrochemical diagrams (Fig. 10). Furthermore, "O in oxides" is indicated, as well as the "*qz* number" of the system of Niggli, which is taken for the sake of comparison. The values of (Na + K), (Ca + Mg), and Fe^{3+} / Fe^{2+}, on the other hand, are not reproduced in Fig. 10. The analyses are arranged according to increasing percentage of Ca.

PETROCHEMICAL DIAGRAMS

To elucidate the relationship between the composition of the rocks of the WUC and the mineral assemblages stable under constant conditions, the diagrammatic presentation of Fig. 10 was considered most appropriate. This figure gives the cation values plotted against the Ca percentages. In this diagram, the fictive points representing the extremes for each petrographic type were connected by lines. In such a way, closed fields were obtained, the positions of which illustrate the variation of the composition of the rock groups. Because the diagrams will be discussed later on in the text, the following remarks may here suffice.

The fields for the sedimentary rocks from lutogenite to MeiDi gneisses show continuous gradation. The field for the MeiDi amphibolite, however, occupies a distinctly separate position, a fact that does not support the possibility of these rocks belonging to the same sequence. The point indicating the average mixture of the Mi granites lies mostly close to the lutogenite field. The fact that the Px gneisses fall into the area occupied by Px granodiorites indicates the weakness of the basis, at least in the case of these particular rock types, of the genetic interpretations based solely on the Niggli diagrams.

A group apart is formed in Fig. 10 by the diagrams H, J, and K, representing Si and O and the Niggli value *qz*, respectively, all plotted against the Ca percentages. These diagrams are similar to each other. Consequently,

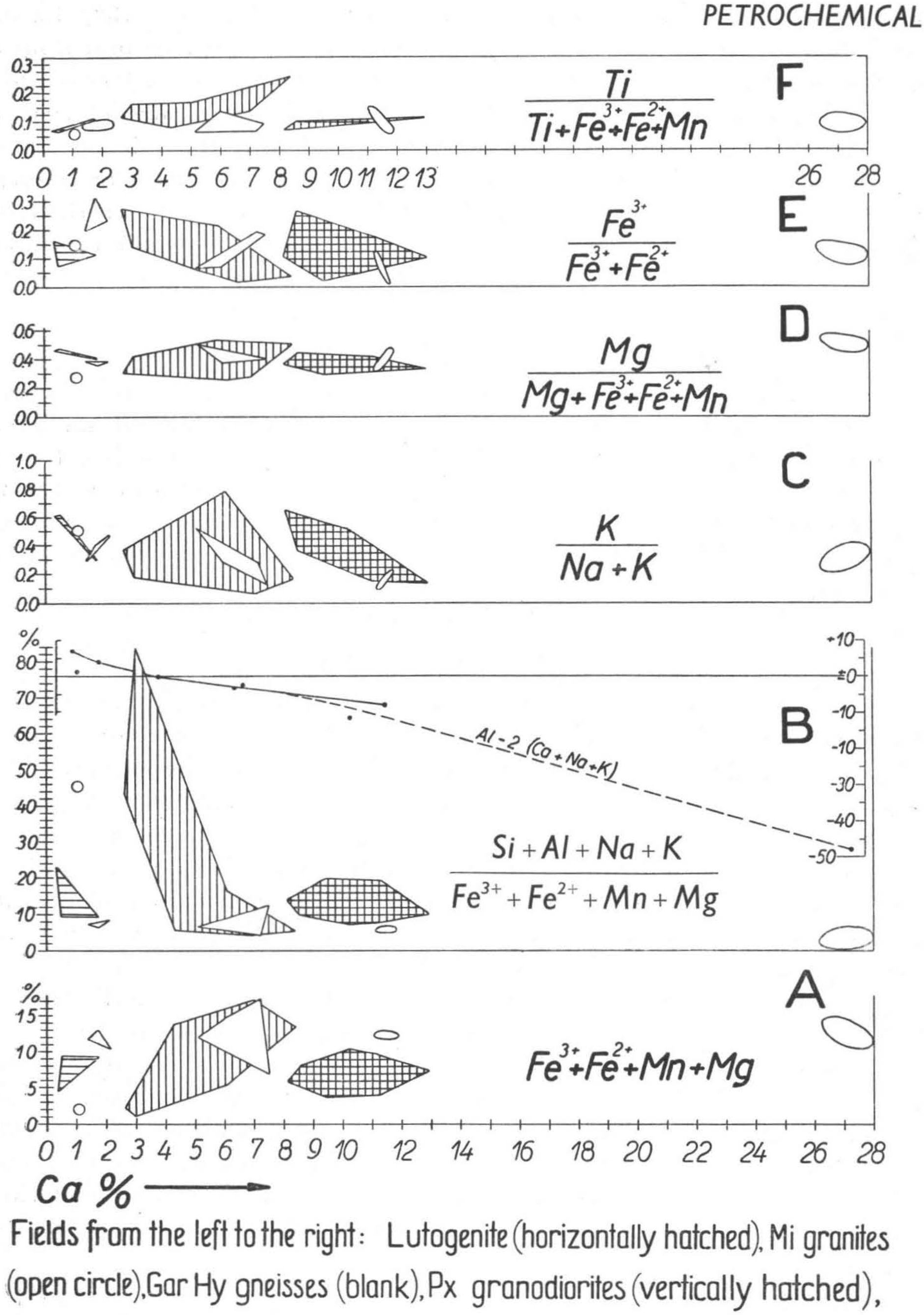
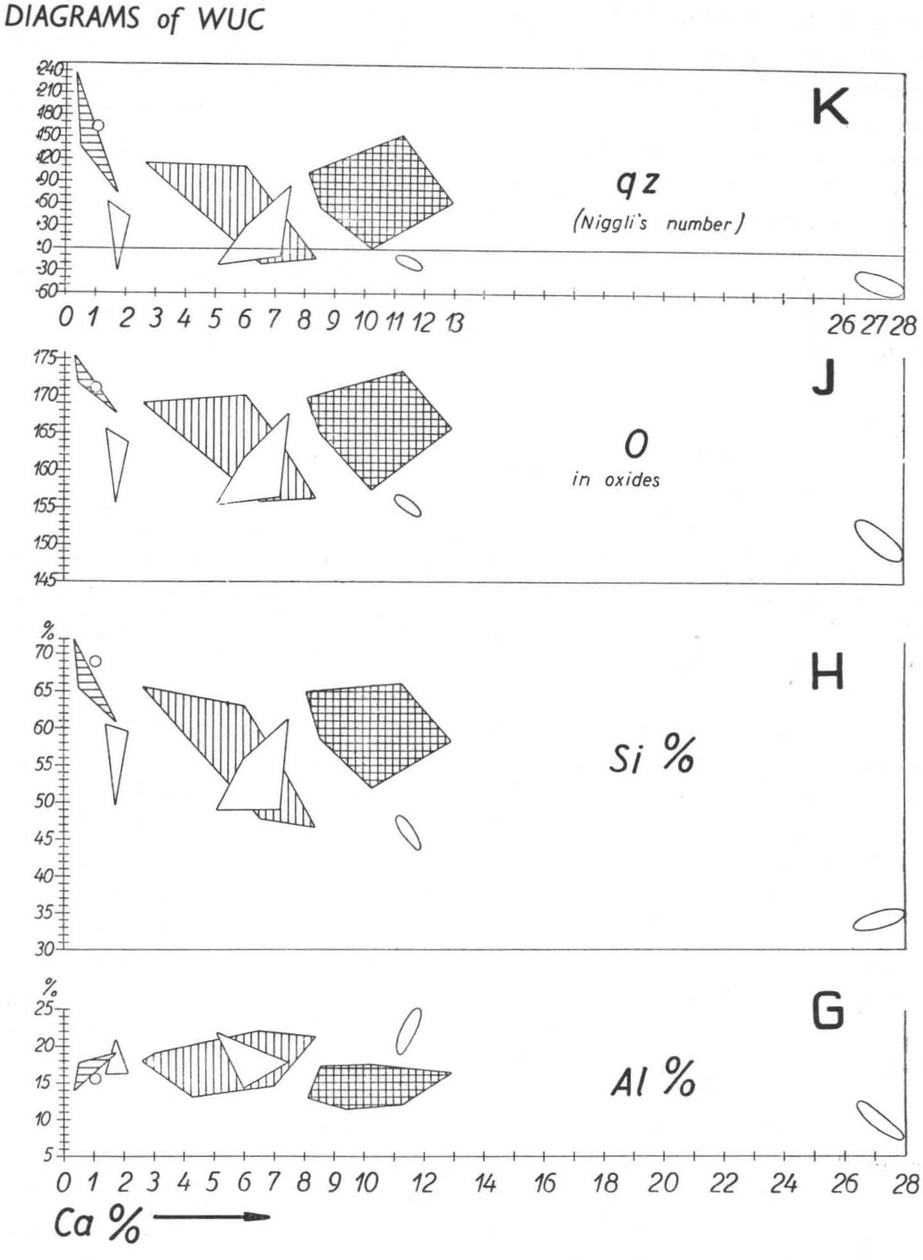


Fig. 10. For explanation see text. The fields of the rock groups are drawn on the basis of the numerical values contained in Table 3 (pp. 128—130).



Px gneisses (blank), Mei Di gneisses (cross-hatched), light Px amphibolites (oval-shaped), dark Mei Di amphibolites (outermost on the right hand).

Fig. 10 (cont.).

instead of the *qz*-value, Si ionic percentages may be used directly and in a more simple way, as well as the total of the "O in oxides". A presentation of another kind is given by including in diagram B the averages of the "excess aluminum", calculated from the analyses. Each of these averages is plotted against average Ca-percentages in the same rock groups in such a way that each rock type is represented by one point except the Px granodiorites by two (4th and 6th point from the left corresponding to the acidic or to the more basic composition, respectively). The curve obtained may be compared with the fields of the ratio of Mg/Fe (diagram D). This comparison shows that the occurrence of the dark minerals is highly dependent upon the Ca-content of the rock and not on the Mg/Fe ratio.

TRACE ELEMENTS

REMARKS

The spectroscopic determinations of trace elements have been carried out by the author at the geochemical laboratory of the Institute of Geology of the University of Helsinki, under the supervision of Prof. Th. G. Sahama. This work was done during the winter of 1944—1945 and is closely related to the regional geological study of the WUC. Because the rocks of the complex are highly metamorphic, the question arose whether or not the trace element contents could be used as indicators for the genesis of these rocks or, on the other hand, whether the trace elements have migrated from their original environment to such an extent that significant differences between trace element concentrations in different rock types cannot be found. At that time, and still at present, the investigation of Sahama (1945) dealing with the rocks of southern Finnish Lapland, was the only point of comparison available for the kind of investigation that has been carried out within the Finnish pre-Cambrian.

The specimens to be analyzed were selected in such a way that they evenly covered all the rock types throughout the WUC. Altogether 140 hand specimens were analyzed, either each separately, or after preparation of average mixtures corresponding to similar rock types. The investigations were made by using the Zeiss Spectrograph Qu24, and the Zeiss Three Prism Spectrograph. The method used was the customary one of the said laboratory, and it has been described in several publications. The determinations were made by comparing the spectra obtained with those of standard mixtures of known contents prepared for the purpose. Barium, strontium, and rubidium were determined by using internal standards and measuring intensity ratios of suitable lines with a recording densitometer. The spectroscopic techniques used have been described by the author in an unpublished

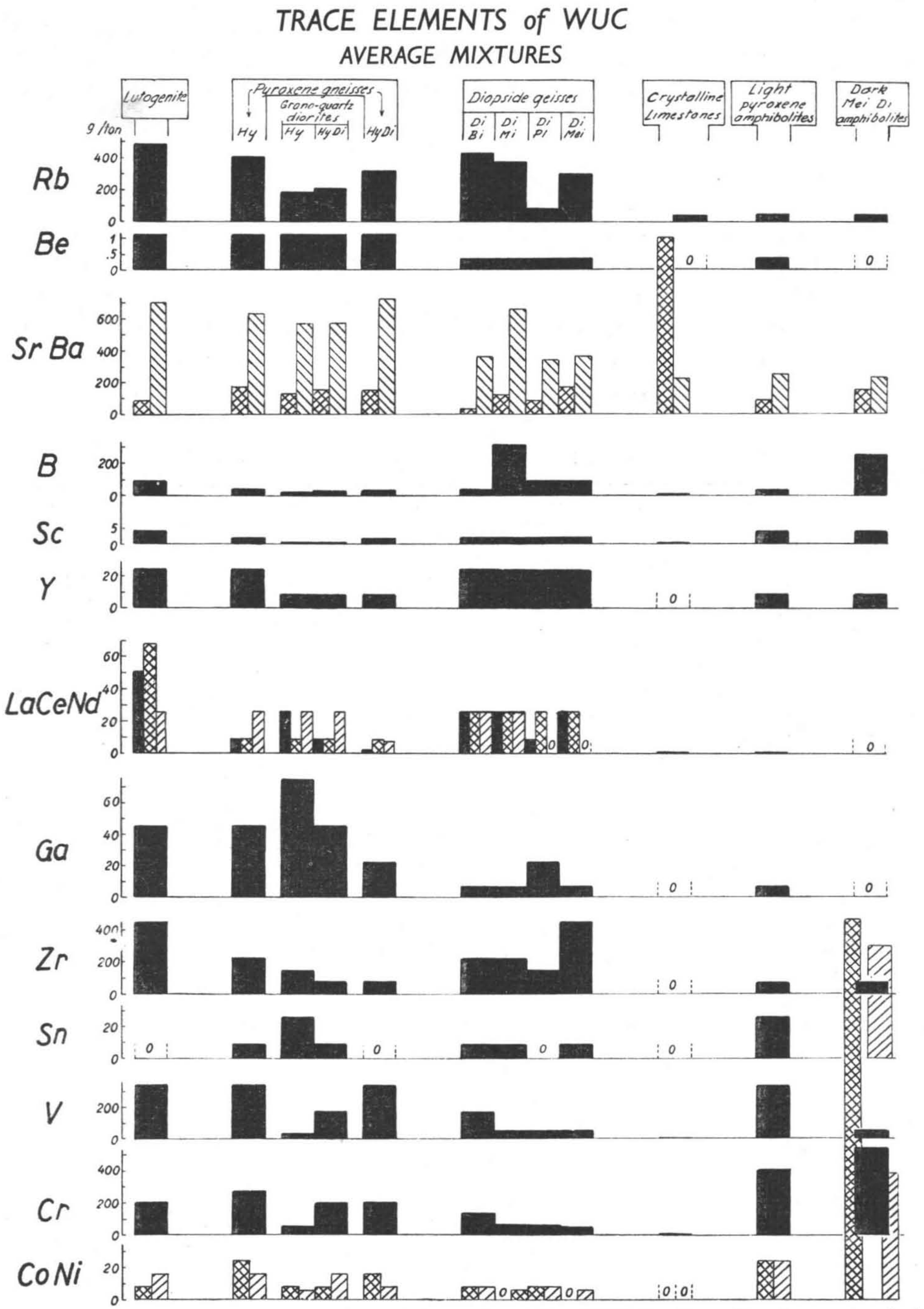


Fig. 11. Contents of 17 trace elements of the rocks of the WUC in g/ton. Based on numerical values contained in Table 5 (pp. 134—135).

manuscript only. The methods used and the accuracy of the results of the present study are comparable with those of other spectroscopic determinations of the same laboratory up to 1946, listed by Rankama (1946).

TABLES AND COLUMNAR DIAGRAM

The analyses of single samples and of average mixtures are given in Tables 4 (pp. 131—133) and 5 (pp. 134—135), respectively, arranged into petrographic groups. The original figures for weight percentages have been calculated in grams per ton. These values may be easily recalculated into weight percentages using the factors summarized in Table 6 (Rankama and Sahama, 1955, pp. 799—802).

Table 6. Gravimetric conversion factors and sensitivity

Found g/ton	Sought %	Factor × 10000	Sensitivity % oxides	Found g/ton	Sought %	Factor × 10000	Sensitivity % oxides
Ba	BaO	1.116	0.001	Ni	NiO	1.273	0.0008
Be	BeO	2.774	0.0001	Rb	Rb_2O	1.094	0.001
B	B_2O_3	3.218	0.0003	Sc	Sc_2O_3	1.532	0.0001
Ce	Ce_2O_3	1.171	0.001	Sr	SrO	1.183	0.001
Cr	Cr_2O_3	1.461	0.0001	Sn	SnO	1.135	0.001
Co	CoO	1.271	0.001	V	V_2O_5	1.785	0.0001
Ga	Ga_2O_3	1.344	0.001	Y	Y_2O_3	1.270	0.001
La	La_2O_3	1.173	0.0003	Zr	ZrO_2	1.351	0.01
Nd	Nd_2O_3	1.166	0.003				

The results of the spectroscopic trace element determinations are summarized in the columnar diagram of Fig. 11. Only the results on the average mixtures of the rock groups of the WUC have been included in this figure. For the geochemical characterization of the trace elements, further reference to the treatise by Rankama and Sahama (1955) will not be made in the following.

ELEMENTS

Rubidium

This alkali metal is one of the most common minor elements, but it does not form any minerals of its own. Because rubidium has a larger ionic radius than the metals of the lower end of its group, it is enriched into the late crystallates in the magmatic differentiation. Especially does it occur together with potassium in feldspars and in micas. In the exogenic differentiation, together with other alkalies, rubidium goes into solution. Having a lower ionic potential, it shows a stronger adsorption in clays than potassium. The columnar diagram elucidates the enrichment of rubidium into lutogenite, Px and MeiDi gneisses. Among the last-mentioned rocks, a type poor in potassium sparsely contains also rubidium. If the Px granodiorites are explained as truly igneous rocks, not related to the Px gneisses, then their Rb-contents, in relation to potassium, could be expected to be different from those of the Px gneisses. In addition, the deviation of both amphibolite groups from the rest of the supracrustal framework is noteworthy.

Beryllium

Because of its small ionic size and its low charge, this element is concentrated in magmatic differentiation into pegmatites and there forms minerals of its own. Owing to similar ionic dimensions, beryllium replaces silicon in the [SiO_4] tetrahedra. This mode of occurrence is quantitatively of more importance. During the exogenic differentiation, beryllium follows aluminum, and both elements are enriched in the hydrolyzate sediments. The picture obtained from the columnar diagram, regarding the supracrustal framework, does not contradict the geochemical character of beryllium. In their beryllium contents, the infracrustal Px rocks do not differ from the supracrustal Px gneisses. Within the WUC, no beryllium minerals have been found.

Strontium and Barium

Among the alkaline-earth metals, calcium, strontium and barium form a highly coherent group. The most important mode of occurrence of the two last-mentioned metals is the incorporation into the structures of the minerals. In igneous rocks, strontium is slightly enriched in those of intermediate composition. Barium has a tendency to be concentrated into the late differentiation products. This essentially depends upon the ionic radii of calcium (1.06 kX), strontium (1.27), potassium (1.33), and barium (1.43). Therefore, strontium mainly replaces calcium, to some extent also potassium, but barium ciefly potassium. That explains the equal distribution of strontium in the rocks of different composition.

In the exogenic differentiation, the difference is still more striking. Barium is mainly enriched in argillaceous, but strontium in the calcareous sediments. The former, having a lower ionic potential, is adsorbed in clays much more effectively than strontium, which becomes precipitated from the sea water tohether with carbonates. The behavior of strontium, if considering the marine organisms as well, is complicated. Its importance as an indicator is therefore not as yet fully understood, especially so for the organic or inorganic origin of the crystalline limestones.

In the limestones and lutogenites of the WUC, the entirely opposite behavior of strontium and barium is clearly visible, the limestone containing comparatively much strontium (1 100 g/ton). The occurrence of strontium in other rocks of the complex is likewise in agreement both with the geochemical character of this element and with the probably primary material of the rocks. Among single samples, an ultrabasic rock of specimen 111 (p. 133) may be mentioned. In this rock, the contents of the elements in question are much too high to allow to this rock the character of a true peridotite. Its high strontium content can be more easily understood if this ultrabasic rock is taken as having a volcanic origin. The impoverishment in barium, in different type groups, together with a simultaneous increase of the calcium content, is rather clear. On the other hand, among the MeiDi gneisses, the exceptionally microcline-rich types are richest in barium as well. It is noteworthy that also in this respect, the infracrustal Px granodiorites become merged in the supracrustal parent rocks.

Boron

Owing to the high mobility of this element, its geochemistry is somewhat complicated. In suitable cases, however, the sensitively indicative character of the boron may be used in petrogenetic interpretations. Boron tends to accumulate in the last products of magmatic differentiation, being trapped into the hydroxyl-bearing minerals. In addition to the accumulation of boron in sea water, this element, because of its ionic properties, occurs enriched in the hydrolyzates as well. The concentration in the residual sediments, on the other hand, depends upon the persistency of tourmaline against the chemical and mechanical disintegration.

In the rocks of the WUC, the boron content of the lutogenites is rather at the lower limit found in the argillaceous sediments. This could hardly be expected if the ample granitic material of these rocks would have derived from the juvenile residual melts, and that the whole rock type would be principally the product of granitization (metasomatism). Concerning the boron content, the infracrustal types of the pyroxenic rocks are similar to the supracrustal ones. The MeiDi gneisses, however, form a group apart, the Mi-rich type being distinguishable more clearly than the others from the rest. Compared with the hydrolyzates, the concentration in the calcareous sediments as well may be due to the thalassophile character of boron. Taking, however, into account the possibility of accumulation through tourmaline, this manner of enrichment may, perhaps, be even more probable, because, if concluded on a petrological basis, the residual component (=sand) is strongly represented in the primary material of the MeiDi gneisses (cf. zirconium, p. 76).

The boron content being at its minimum in the limestones, it approaches the maximum in the MeiDi amphibolites. This kind of concentration, together with other facts of the same character, indicates the volcanic origin of these rocks. Notwithstanding the concentration of boron in certain rock types, neither tourmaline nor other boron minerals have so far been detected in the rocks of the WUC. The minerals of this complex being poor in water (Fig. 23, p. 110), the concealing of boron in hydroxyl-bearing minerals is not to be here expected, either.

Scandium, Yttrium, Lanthanum, Cerium, and Neodymium

Among the rare-earth metals, the yttrium and the lanthanides form a coherent group. They have a tendency to concentration opposite to that of scandium, which, in the magmatic differentiation, is enriched in the early crystallates replacing Mg^{2+} and Fe^{2+} in the structures of the mafic minerals. Among the lanthanides, the cerium earths, on the contrary, will be enriched into the alkalic rocks. The yttrium earths, on the other hand, form independent minerals with the late crystallates of the calc-alkalic suite. The other quantitatively important kind of occurrence is particularly the substitution of calcium by the yttrium earths, though not, however, in anorthite. In the exogenic differentiation, scandium likewise follows iron (iron-bearing hydrolyzates), but avoids the carbonate sediments. Yttrium and lanthanides, on the other hand, except in the hydrolyzates, have been observed concentrated in the limestones as well. ,

In the WUC, in accordance with its geochemistry, scandium has been slightly concentrated both in the lutogenite (almandite-pyrope) and in both amphibolite groups (pyroxenes and hornblende). In addition, it seems to be present in the representatives of the carbonate sediments and in the limestone itself. In these rocks, however, the scandium contents are so low that they approach the limits of sensitivity of the analytical methods used. Similar suspense is valid in regard to yttrium as well. With respect to this elements, as well as to cerium and to neodymium, at least the limestones are distinctly impoverished. The cerium earths show a repugnance toward the intermediate and still more toward the more basic rock types. A considerable concentration of these elements into lutogenite and into MeiDi gneisses, except purely chemically, may also be explained by the accumulation of accessory minerals (monazite) in the residual component of the primary material of these rocks.

Gallium

If occurring as oxyphile, and owing to the similar size of the ions, the replacement of Al^{3+} by Ga^{3+} is the only mode of occurrence of gallium, which tends to be concentrated into the late crystallates of the differentiation. During weathering, gallium follows aluminum, together with which it is enriched in the hydrolyzates in the same way as are other trivalent ions. The carbonate sediments, on the other hand, seem to be poor in gallium.

The occurrence of gallium within the WUC is in accordance with the general geochemistry of this element. There is a difference of opinion as to whether the abundance ratio of Ga/Al is constant or not. Remembering that the rocks indicated in Table 7 vary in mode of origin, the figures of this table tend to indicate that this ratio is not constant.

Table 7. Abundance ratio of Ga/Al

Rock	Ga g/ton	Al cat. % [1]	Feldspars volume % [1]
Px granodiorites, type: HyBi	74	19	70
Px gneisses, » HyDiBi	22	17	55
Px amphibolites, » HyDiHo	7	22	65
MeiDi » » HoDi	0	10	21 (Mei + Pla)

Consequently, despite the fact that gallium is closely associated with aluminum, the averages mentioned above as well as the results of single determinations (Table 4) seem to support the view that the geochemical coherency of these elements is rather weak.

Zirconium

In igneous rocks, zirconium shows a tendency to become enriched in the last crystallates as zircon. This mineral plays an overwhelmingly important role in the exogenic cycle of the element. Owing to its persistency against all kinds of mechanical and chemical weathering, zircon is accumulated into resistates. The zirconium may appear in solutions in the form of zirconates, which are precipitated by adsorption of the hydrolyzates. Compared with the mechanical process, the chemical one is quantitatively of much less importance.

At first glance, the behavior of zirconium in lutogenites and in MeiDi gneisses of the WUC is surprising. Considering lutogenite a representative of plain hydrolyzates, the Zr-content would be tenfold to the available averages of the general Zr-content figures for hydrolyzates. In the calcareous

---

[1] The averages of the respective analyses.

sedimentary rocks, an unusual enrichment of zirconium is also to be observed. Considering, however, what the author has written in several connections about the presence of the residual component in both these rock types, the Zr-contents as given above are in full agreement with it. The enrichment of zirconium into the lutogenite, on the other hand, could also be explained by assuming, the granitic material to have originally been truly igneous. For the MeiDi gneisses, such an explanation would not be fruitful. In addition, such an assumption would neglect the fact that, in both rock types, the zircon occurs also in the form of rounded grains (p. 111; cf. boron, p. 74). In the intermediate Px gneisses and in their anatectic derivatives, the Zr-content is low, a tendency which is still more distinct in both amphibolite groups. The limestones have been most impoverished in this element.

Tin

This element has both a sulfophile and an oxyphile character. Thus the tin is enriched, during the magmatic differentiation, predominantly into the granites, thereby partly replacing Fe^{2+}, Ca^{2+}, and Ti^{4+}, but chiefly occurring as cassiterite. This mineral is highly persistent against disintegration, being concentrated into resistates. The dissolved tin is adsorbed by the hydrolyzates.

Notwithstanding the similarity to zirconium, both in the exogenic and endogenic cycle, within the WUC, the behavior of tin is surprising at least in two ways: It is lacking in lutogenites (see sensitivity, Table 6, p. 72), and is most abundant in the MeiDi amphibolites. The former fact does not support the idea about the residual component too well, but still less does it support the view that the granitic material of the lutogenite would be of true igneous character. The lacking of tin simply indicates the scarcity of this element in those rocks, the denudation products of which, to some extent, are represented by the lutogenite. Therefore, also the anatectic derivaties of this same material are poor in tin. In other rock types of the WUC the tin content is less illustrative, but shows a culmination in the MeiDi amphibolites. This peculiarity, together with some other features of similar character, may again be interpreted as indicating that this rock type is of volcanic origin. This interpretation is valid for the representative of the ultrabasic rocks as well (Table 4, No. 111).

Vanadium

The mode of occurrence corresponding to different stages of oxydation and, hence, to the redox potential of the environment is essential for the geochemistry of this element. The enrichment of vanadium in the rocks of gabbroic composition during the differentiation by crystallization and its adsorption in the hydrolyzates will only be mentioned.

The carbon arc cathode layer method, which was used for the determination of vanadium, is sensitive but not especially accurate. Therefore, the values obtained must be considered with reservation. Compared with chromium, the absolute contents and their variations are, however, surprisingly similar.

Chromium

This metal is concentrated into the earliest crystallates, there forming minerals of its own. The quantitatively next important mode of occurrence of chromium is that of incorporation as a trivalent positive cation, in the silicate structures. There it mainly replaces Fe^{3+} and Al^{3+}. Together with these elements chromium is enriched, in the exogenic differentiation, into the hydrolyzates and weathering residues. This apparent discrepancy explains itself by the chromiferous oxides being very resistant to disintegration.

For that reason, in comparison with the MeiDi gneisses, the scarcity of chromium in the lutogenite is less to be expected, as it also was in the case of tin (p. 77). The high Cr-contents of both amphibolite groups are distinctly different from those of the other supracrustal rocks. The low Cr-content of the acid types of the infracrustal Px rocks may indicate that the chromium is reluctant to be mobilized in the palingenetic processes by refusion of the basement rocks.

Cobalt and Nickel

In silicate rocks, both elements become exceedingly enriched in the basic ingeous rocks, if the absolute amounts are considered. As to their relative amounts, nickel prefers the ultrabasic rocks and cobalt the acidic ones. Such a distribution depends upon the fact that Ni^{2+} follows Mg^{2+}, but Co^{2+} follows Fe^{2+}. In the exogenic cycle, both elements are enriched in the hydrolyzates, nickel more intensely than cobalt.

In the rocks of the WUC, the absolute Ni- and Co-contents are mainly in agreement with the known geochemical character of these metals, the abundance ratios, however, being less clear. The enrichment of both elements in the MeiDi amphibolites may sufficiently well indicate that the primary material of these rock types is clearly different from the sedimentary rocks.

Cesium, Molybdenum, Tungsten, Zinc Germanium, and Lead

Apart from lead, none of these elements showed any lines in the spectra photographed of the rocks of the WUC. This would mean that there is less than 0.001 weight per cent Cs_2O and GeO_2. The extreme scarcity of molybdenum, tungsten, zinc and other heavy metals within the WUC appears also in the fact that within the complex there is no single ore deposit, the lack of ores being very striking. Lead has been found in five single samples only (Nos. 26, 47, 49, and 111). Consequently, also this element is obviously present in amounts less than 0.001 weight per cent of PbO. Samples 47 and 49 are MeiDi amphibolites, and No. 111 is an ultrabasic rock. Thus, once more these rock types display their peculiarity (see chalcopyrite, p. 110), and the only signs of enrichment of lead appear — rather than in acidic rocks (Pb^{2+} pro K^{+}) — in the most basic ones (Pb^{2+} pro Ca^{2+}; cf. strontium, p. 74).

DISCUSSION OF RESULTS

The reader familiar with the geochemistry of trace elements may have observed that the values for different elements remain within the limits well known for such rocks. Between the rock groups of the WUC, differences in trace element contents are found that, though not very striking, yet are in accordance with the general geochemical character of the elements and, on the other hand, with the assumed genesis of the rocks. A partial migration of the trace elements away from their original environment during the metamorphism, or, for the sedimentary rocks, an incomplete sorting during the exogenic differentiation may have lessened those originally valid differences. If the interpretation of the origin of the rocks, as made on a petrological basis, is assumed to be correct, then also the tendency of the trace elements to be distributed between the rather heterogeneous rocks of the complex seems to be in agreement with the geochemical character of the respective elements. Thus it may be concluded that these elements, despite the high metamorphic grade of the rocks, have been rather reluctant to migrate into a new environment (e. g. MeiDi amphibolites). This may, perhaps, indicate also that, within the WUC, no large-scale metasomatic migrations of the main elements have taken place. On the other hand, with respect to the trace element contents, the infracrustal Px rocks (charnockites) should differ much more from the corresponding gneisses (paracharnockites) than if they were true igneous rocks without any material connection with the supracrustal framework. Instead, it is much easier to understand the weak tendency of the accessories to be enriched or impoverished by anatectic processes within a limited field of the PT-conditions.

The general geochemistry of the said trace elements is mainly known, and for some elements rather thoroughly. As a piece of evidence for the genetical interpretation of the rocks, the trace element contents must, however, be considered with reservation. This is particularly valid for rocks like those of the Finnish pre-Cambrian, because regional geochemical investigations dealing with such rocks are few. Considering such a reservation, the author is inclined to believe that the use of the trace elements as indicators of the origin of the highly metamorphic rocks, too, has proved to be possible.

MINERALOGY

The separate species of the mineral assemblages discussed in the foregoing (p. 54) will be described in the following, especially the mode of occurrence and some paragenetic problems of these minerals.

Taking the total amount of thin sections examined into account, the microscopic observations made of the minerals may be used statistically as well. Special investigations, e. g. the determinations of the refractive indices by immersion and prism methods and the measurements of the axial angles with the Universal Stage, have been carried out and checked, not only by the present author but by three other persons. The separation of minerals for the optical determinations has been performed by the author using Clerici's solution, but the final purification was made, grain by grain, by picking under a binocular microscope. In addition to the chemical analyses of minerals, the loss on ignition for hornblende and for biotite was separately determined by Mr. Pentti Ojanperä at the chemical laboratory of the Geological Survey of Finland in 1954. Thereby precautions were considered to avoid the oxidation of iron. The specific gravities have been neglected. In Table 2, the amounts of minerals as well as the grain sizes in different rock types are indicated. The chemical and physical properties are mentioned in connection with the descriptions of the respective minerals.

CONSTITUENTS

QUARTZ

The color of this mineral is not exceptional in either the charnockitic or other rocks. Under the microscope, the fresh structure of the rock is stressed by the absence of granulation and by the weakness of the undulatory extinction of the quartz. There are two kinds of inclusions: 1) Liquid or gaseous bubbles, usually arranged in definite crystallographic directions; 2) more evenly distributed dusty material, having a lower index of refraction than quartz. The primary nature of this matter may be doubted because there may occasionally occur, along the margins and fissures of the crystals (also of feldspar), zones some 0.5 mm broad having a lower index of refraction than the rest of the crystal. In the zones of low refractivity, however, no inclusions are seen. Therefore the author is tempted to assume that these "inclusions", too, have been actually caused by the technique of the slide making.

Paragenetically, the occurrence of quartz together with calcite without wollastonite and its absence from the company of hornblende is important and will be discussed in a later connection.

CALCITE AND WOLLASTONITE

Calcite occurs interstitially but has been met with as inclusions in quartz as well. Also in the latter case, the grains are distinctly bounded and there is no trace of reaction rims. The association quartz + calcite is common, but the presence of wollastonite is a great rarity. In such microscopically or megascopically observed cases (MeiDi gneisses), wollastonite forms the matrix enclosing all the other minerals and appears as if forming the last phase. The formation of wollastonite seems to have taken place only when favored by mechanical movements, under decreased partial pressure of CO_2. This explanation is supported by the mode of occurrence of wollastonite in crystalline limestones of the area in which, if present, it occurs in abundance in tectonically deformed zones. The paragenesis of carbonate + quartz will be discussed again in connection with meionite (p. 85).

PLAGIOCLASE

This is the most abundant mineral, which in the charnockitic rocks has a characteristic dark color (pp. 10, 12, 14), varying within the WUC, from dark grey to brownish yellow. The color probably derives from ferric iron pigment (Rosenqvist, 1951), possibly also from extremly fine sericite (cf. below). Notwithstanding the dark color, the plagioclase is clear under the microscope and, in addition to the albite and pericline laws, other twinning laws also are involved. The author is well aware of the efforts in statistical investigations to apply the twinning laws as indicators for the mineral facies. Deviating from his original plan, however, the author did not find it possible to undertake the extended Universal Stage work needed.

The composition of the plagioclase is homogeneous, in rare cases exhibiting a tendency to form inverse zoning, whereupon the center contains at most 10 per cent more of the albite component than the margin. The variations in the composition of the plagioclase within the complex are shown in Tables 1 and 2. If the bulk composition of a rock contains more than 7 cat. per cent Ca, then the anorthite content of the plagioclase regularly exceeds 40 per cent, entirely independent of the petrographic type of rock. Sericitization, in the common sense of the term, is incidental and occurs together with other kinds of secondary alteration. The presence of minute sericitic scales in the plagioclase surrounded by entirely unaltered rock, however, is more difficult to explain in the same way. This case may be more conveniently explained by an unmixing in the solid state, similar to the formation of antiperthite (cf. biotite). The short-prismatic antiperthite and hair-perthite, as well as myrmekite, are typical of the more mobilized rock types to such an extent that the presence or absence of both may almost be used as a criterion to distinguish microscopically between charnockites and paracharnockites, even if these features are not very abundant.

As for the origin of myrmekite, the well-known theory of Becke is in lesser agreement with the energetic viewpoints if no additional assumptions are accepted. During the solidification of the rocks, the phase of a higher bonding potential, plagioclase, should form after the crystallization of the less stable form, which is the potash feldspar. Second, the explanation opposite to the foregoing is that the potash metasomatism causes the formation of myrmekite. This phenomenon can get no support from the rocks studied by the author. Furthermore, metasomatism should then be restricted to the mobilized types only. The author is inclined to explain the myrmekite as well as some other phenomena on the basis of the exsolution which takes place in the solid state. Thus the formation of myrmekite within the rocks of WUC is in some way bound to the abnormal composition of the feldspars (cf. Spencer, 1945).

MEIONITE (MIZZONITE)

Scapolite occurs in the calcite-bearing MeiDi gneisses and in the respective amphibolites. In these rocks it is only microscopically detectable. It forms isometric, well bounded, clear, fresh grains, sometimes altered in a manner typical of the primary minerals. This alteration begins from boundaries and fissures of the grain. In the order of crystallization it may be comparable with plagioclase, but the latter mainly tends either to be interstitial or to enclose the scapolite. In such cases the plagioclase is more heterogeneous than usually and becomes enriched in the albitic component away from its boundary with scapolite (Fig. 12). Meionite is optically negative, but, peculiarly enough, in most cases distinctly biaxial, the axial angle ranging up to a few degrees. The phenomenon, however, is irregular and varies from crystal to crystal (cf. biotite).

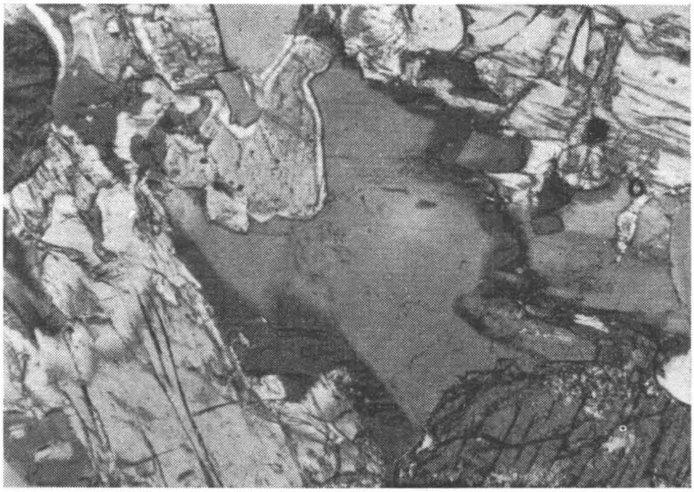


Fig. 12. Heterogeneous plagioclase grain (middle) showing dark anorthite-rich zones in the margins towards the scapolite (upper right and lower left). The core of the plagioclase grain is more albitic. Meionite-diopside gneiss. No. 159. Nic. +. Magn. 100 ×.
Photo E. Halme.

Table 8 gives the chemical and optical data for the scapolite of the WUC. Owing to the difficulties encountered in separation, the material chemically analyzed was not perfectly pure. The chlorine and fluorine have been

Table 8. Properties of scapolites (WUC)
(Specimen Nos., see Table 1, pp. 116—123)

	Chemical composition			Optic properties				
	No. 39			± 0.002				
	Weight	Cation	O in oxides	No.	ω	ε	$\omega-\varepsilon$	
	%							
SiO_2	45.18	41.41	82.82	33	1.586	1.552	0.034	Uniaxial or slightly biaxial negative
$AlO_{3/2}$	26.23	28.33	42.50	48	1.588	1.553	0.035	
$FeO_{3/2}$	0.30	0.20	0.30	90	1.588	1.553	0.035	
FeO	0.72	0.55	0.55	50	1.589	1.554	0.035	
MnO	0.01	0.01	0.01	38	1.590	1.554	0.036	
MgO	0.38	0.52	0.52	37	1.592	1.557	0.035	
CaO	18.12	17.79	17.79	35	1.593	1.558	0.035	
$NaO_{1/2}$	2.74	4.87	2.44	39[1]	1.593	1.556	0.037	
$KO_{1/2}$	0.43	0.50	0.25					
TiO_2	0.03	0.02	0.04	47	1.593	1.557	0.036	
H_2O+	1.20	(3.67)	—	36	1.595	1.558	0.037	
H_2O-	0.08	—	—	93	1.595	1.557	0.038	
CO_2	4.64	5.80	11.60	34	1.596	1.560	0.036	
Cl	0.06	—	—					
Total	100.12	100.00	158.82					

[1] Chem. anal.: 75 mol. % meionite
Refractive indices: 70—85 » » } Mizzonite
(Winchell, 1951, Pt. II, p. 353)

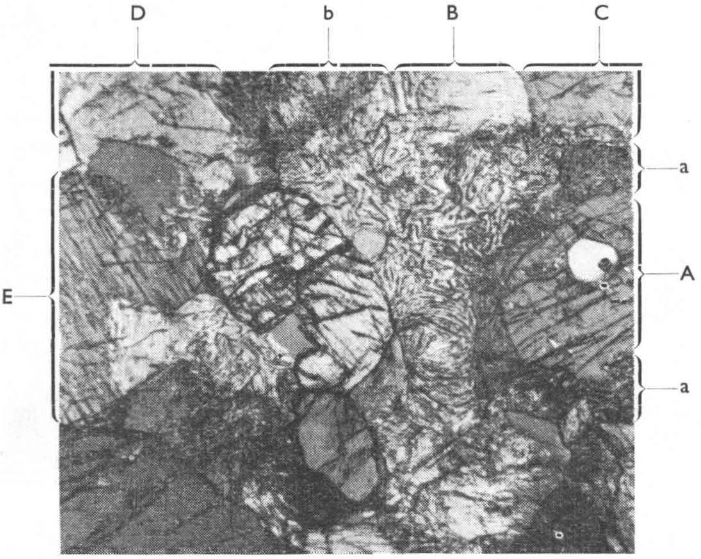


Fig. 13. Meionite and quartz + scapolite symplektite.
A and B = meionite grains, symplektite in the margin.
a and b = symplektite with scapolite worms extinguishing parallel to the host grains A and B, respectively.
C, D, and E = meionite grains without visible symplektitic structure.
Diopside-hedenbergite grain (oval) between A and E.
Meionite-diopside gneiss. No. 39. Nic. +. Magn. 40 ×. Photo E. Halme.

determined in the respective rock as well and found to be present in traces. The values presented are in good agreement with the data given by Winchell (1951, Pt. II, p. 353), corresponding to a content of 70 to 85 mol. per cent meionite. Thus this scapolite is actually a mizzonite.

In addition to the mode of occurrence as homogeneous scapolite crystals, grains with a symplektitic structure resembling myrmekite are comparatively common as well. This structure is mainly represented by a wormlike intergrowth of quartz and scapolite (Fig. 13). Further, intergrowths of scapolite with plagioclase and calcite are found, but also those of plagioclase and calcite only. Such intergrowths have been observed exclusively in the MeiDi gneisses — in some cases all the kinds of intergrowths in the same thin section, in others only one of them. Homogeneous meionite crystals either form the center of symplektitic grains or adjoin them, or, then, they occur separated from such grains. The scapolite worms and the homogeneous part of the crystal extinguish simultaneously. The quartz worms, on the other hand, have a tendency to cross the boundary of the symplektite and to expand into small separate quartz grains outside the intergrown crystal. These quartz grains extinguish simultaneously with a part of the symplektitic quartz worms only. Thus the quartz component does not always belong to the same crystal. On the other hand, however, the presence of quartz immediately outside the intergrown crystal does not seem to be a necessary condition for the formation of symplektite. Neither does the proximity of plagioclase seem to be necessary there, even though there are instances of fading boundary lines between neighboring plagioclase and meionite grains, as well as cases of a marginal zone composed of plagioclase surrounded by meionite. These intergrowth structures were earlier interpreted by the author as being connected with the scapolitization. Therefore, at that time, the origin of the meionite of the WUC was explained as being of metasomatic character. To illustrate the view according to which plagioclase + meionite belongs to the mineral assemblage of the rock together with other primary crystalline phases, the following series of reaction equations may be presented:

(1) . . . . quartz + calcite $\rightleftarrows$ wollastonite + CO_2
(2) . . . . 6 quartz + 3 calcite + biotite $\rightleftarrows$ microcline + 3 diopside + 3 CO_2 + (H_2O)
(3) . . . . quartz + 2 calcite + anorthite $\rightleftarrows$ grossularite + 2 CO_2
(4) . . . . calcite + 3 anorthite $\rightleftarrows$ meionite

As is generally known, with increasing temperature, the reactions (1), (2), and (3) proced from left to right, depending on the partial pressure of CO_2. This again depends on the permeability of the rock to CO_2. The direction of the reaction (4) is not clear. Knowledge of the plagioclase-scapolite system in general is still deficient.

In the diagram of the MeiDi gneisses (Fig. 14), the rock analyses with the mineral compositions have been arranged according to an increasing ratio of $\frac{Ca}{Ca + Al + Na + K}$, from left to right. If this diagram is discussed from the point of view of the equations mentioned, it may be deduced that the diopside is stable throughout the whole series. Notwithstanding its apparently suitable chemistry, biotite disappears from the stage when the calcite content exceeds 0.5 per cent or, more exactly, by the value of abscissa exceeding 0.28. This fact is in agreement with the equation (2) if the equilibrium is on the right side. In other words, the partial pressure of CO_2 has not prevented the reaction in the members of this series containing free calcite. At the same time, the potassium and aluminum content of biotite is available for the formation of microcline. In this case, sphene is stable, too. After the value of 0.39 has been passed, there appears a new phase, meionite, which decisively takes over the quantitatively predominant position of the plagioclase (the scarcity of microcline in Anal. 33 is acci-

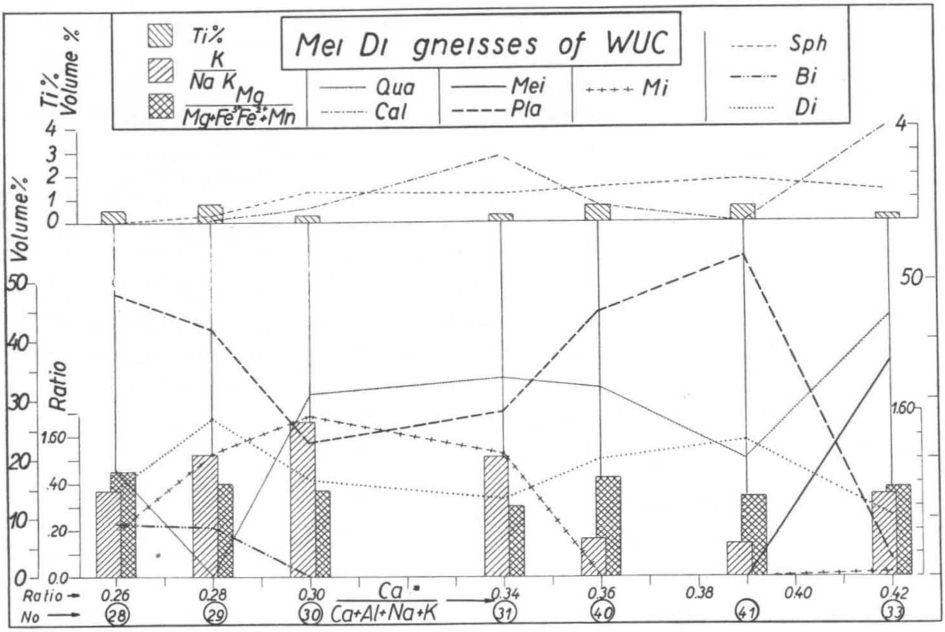


Fig. 14. Modes of the meionite-diopside gneisses of calcareous bulk composition plotted against $\frac{Ca}{Ca + Al + Na + K}$.

Chemical data, see Tables 2 and 3 (pp. 124, 128). Mineralogical data, see Table 2. Anal. Nos. 28, 29, 30, 31, 33, 40, and 41.

dental). Therefore it seems that, in addition to a temperature necessary for the diopside reaction, the other essential condition for the formation of meionite in this system is a certain value of the ratio $\frac{Ca}{Ca + Al + Na + K}$ in the bulk composition. This may also be understood as a deficiency of aluminum + alkalies with respect to calcium.

The conditions of metamorphism of the WUC, as a whole, being high-grade, it would be expected that the reactions (1) and (3) would have proceeded from left to right as well. Actually, however, wollastonite has been observed accidentally only, and grossularite does not occur at all (pp. 57, 81). As an exception proving the rule, grossularite has been found only in very few thin sections of MeiDi gneisses. In these cases, the texture of the rock indicates an exceptionally strong mechanical deformation accompanied by secondary phenomena in different minerals. The alteration is most distinct in the meionite. It begins with the mineral getting turbid and may be continued until an entangled mixture of calcite + plagioclase + sericite results, or until there are more distinct aggregates containing

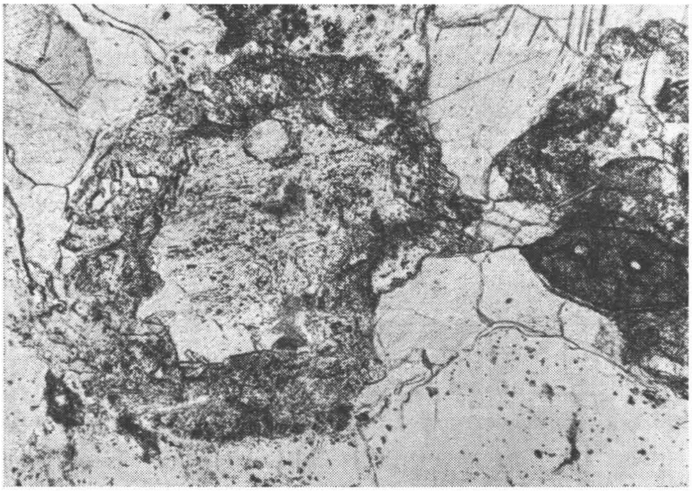


Fig. 15. Grossularite-vesuvianite reaction rim around plagioclase. Grossularite-vesuvianite gneiss. No. 183. Nic. ||. Magn. 100 ×. Photo E. Halme.

epidote, plagioclase, and vesuvianite in the center, enveloped by a narrow rim of grossularite. In some cases, the grossularite + vesuvianite rim envelops the plagioclase (Fig. 15). The occurrence of the grossularite clearly bears the character of the reaction rims. Such a rim is not uncommon at the microcline-calcite contacts either. In the same association, wollastonite occurs as well. It forms large crystals, poikiloblastically enclosing all the other minerals. Together with grossularite, wollastonite corresponds there to the very last and wholly exceptional phases of the final stages of the metamorphism. It would seem that the partial pressure of CO_2 has been high enough, in regard to wollastonite and grossularite, to prevent the formation of these minerals during the "main stages" of recrystallization. After the rocky mass had attained its nearly final consolidated state, the temperature still remaining sufficiently high, this partial pressure was reduced in the zone of the mechanical deformations. Under such conditions, the reactions (1) and (3) could start to work left to right. Because both quartz and calcite still remained there, the reaction must have been stopped, and this was probably caused by the re-elevation of the partial pressure of CO_2, and by a contemporaneous dropping of the temperature. This new factor has, consequently, to be considered as the third one, which is essential for the paragenesis here under consideration. Hence, the formation of meionite within the WUC has taken place in the following way:

Starting from the culmination point of the physical conditions of the recrystallization, a temperature is required at least corresponding to the demand of the diopside reaction, and the presence of high CO_2 pressure (cf. also monoclinic pyroxene, p. 106). Under such conditions, and if, in the chemistry of the material to be reconstructed, an optimal $\frac{Ca}{Ca + Al + Na + K}$ ratio (0.40 or more) occurs, the plagioclase is unstable. Instead of it, the primary meionite will be formed (reaction 4) as far as the aforementioned cation ratio and the physical conditions are favorable for the stability of this structure. The partial pressure of CO_2 does not seem to be able to make unstable the calcic plagioclase alone. As soon as the surplus of the salic calcium with respect to Al + Na + K becomes insufficient, the natural result of the progress of recrystallization is the formation of plagioclase immediately around the meionite. In general, it becomes stable after the meionite, and displays in its composition neither homogeneity nor regularity (Fig. 12). Remaining now on the physico-chemical marginal field between the stability areas of meionite and anorthite, and the bulk composition being silica-saturated, all kinds of abnormal cation ratios are there possible, and the afore-described phenomena of intergrowths can be understood. Consequently, the explanation of symplektites is to be sought from the exsolution phenomena, analogically to the explanation of myrmekite (p. 82). The possibility should, however, be kept in mind that the parageneses here considered may include reactions running in both directions. This makes, of course, the whole process much more complicated than it schematically appears.

The paragenesis of meionite, as here described, represents a limited field of the bulk composition only. The exclusive MgFe-phase of this field is diopside-hedenbergite (Fig. 14). If the MeiDi amphibolites (Nos. 47 and 49) are compared in respect to composition, they have the same value (0.70) of the ratio mentioned numerous times in the foregoing, as well as an equal CO_2-content. Therefore, the lack of meionite in No. 49 may result, at least to some extent, from the fact that both calcium and aluminum have been amply incorporated into the structure of amphibole.

The opinion that all the scapolites of the metamorphic rocks are exclusively of metasomatic-pneumatolytic origin has been tenaciously held, and still there are many investigations (Sundius, 1915; and others) which have proved that the volatile components do not necessarily have to be derived from any external sources. They belong to the rock itself, as primary constituents of the original material. As to CO_2, Korjinsky has stressed its conclusive importance for the stability of the crystalline phases in extremly high pressure conditions (cf. pp. 19, 23); lime scapolite is classed by him with his Aldan facies including parageneses not containing wollastonite, vesuvianite, or grossularite. Turner and Verhoogen (1951, pp. 474—475) have generally accepted scapolite as belonging to the minerals of the granulite facies. In the following, the author will epitomize his ideas on this question (cf. p. 34). In addition, he would like to express his hope that the experimental examination of the scapolite system would draw more attention in the future than it does at present.

1) The meionite scapolite (mizzonite) of the WUC has originated exclusively from the primary material of the rocks and entirely under conditions of regional metamorphism.

2) It occurs in lieu of calcic plagioclase and, in regard to its mode of formation, it is primary as compared with plagioclase.

3) The mineral assemblages: quartz + calcite + potash feldspar + meionite + monoclinic pyroxene (without wollastonite and grossularite), and calcite + meionite + monoclinic pyroxene + brown hornblende, represent in calcareous bulk composition the PT-conditions corresponding to those of charnockites.

4) Among the minerals listed in the foregoing paragraph, meionite has, from the point of view of mineral facies, the same position as almandite-pyrope and orthorhombic pyroxene within the fields of the chemical composition corresponding to the last-mentioned constituents.

POTASH FELDSPAR

Potash feldspar is microscopically always clear and fresh; it occurs either untwinned or cross-hatched. In the charnockitic rocks, the untwinned form overwhelmingly predominates. It is common in the lutogenite and in the granitic component of this rock, too. The cross-hatched potash feldspar, on the other hand, is more characteristic, but not exclusive among the MeiDi gneisses. Both modifications may occur together in the same thin section, and behave, in respect to the fabric, in a similar way. In addition, if the potash feldspar of the charnockites is involved, an indistinct quadrille structure may sometimes be observed in the marginal parts of the grains. The untwinned grains have usually a straight extinction in sections perpendicular to (010), but extinction angles indicating a triclinic symmetry occur as well. Consequently, at least the occurrence of the untwinned microcline in these rocks is certain. The presence of a monoclinic symmetry, however, cannot be sufficiently established microscopically (cf. p. 14). Unfortunately, the author has not tested the potash feldspar by X-ray methods and, therefore, the term "orthoclase" is avoided in this paper (see abbreviations on p. 48). Thus, further discussions concerning the symmetry of the potash feldspar will not be taken up here.

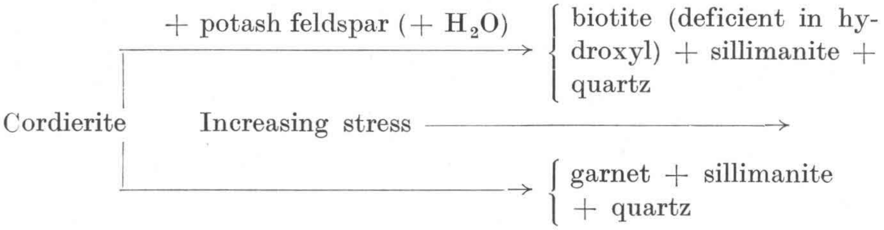
Perhite has been taken as an indicator of the mineral facies (p. 14). In the rocks here to be described (and also in the Mi granite), it occurs exclusively in the form of hair-perthite, just as this microstructure has been described by Eskola (1952, p. 149). Among the details observed within the WUC, it may be mentioned that the marginal zone of the host grains is usually hairless (this applies to the antiperthite as well). If the triclinic, cross-hatched phase predominates, the perthite is often lacking.

SILLIMANITE

This is a constituent found exclusively in lutogenite. Quantitatively, it is of much more importance than would be expected from the microscopy or from chemical analyses, because the coarse, megascopically visible prismatic type may be enriched into separate stripes. The fibrolitic sillimanite (mullite?) of the microscopic scale is much more evenly distributed. It occurs commonly as inclusions in the cordierite grains. Sometimes it is enclosed by plagioclase, rarely by biotite or garnet. It seems especially to prefer sheared zones of the rock, in which it occurs together with ample biotite or garnet. Obviously there are several generations of sillimanite. One of them is dependent upon shearing stress (see cordierite and garnet), and thus it is secondary when compared with the sillimanite occurring in a ''normal'' way. The enclosures of the fibrolitic type of sillimanite are probably to be classed with the exsolution phenomena.

CORDIERITE

Unfortunately, the author had to refrain from a more detailed study of cordierite, which is characteristic of lutogenite. The general observations are restricted to the following: Compared with the pale constituents, the dark blue cordierite has a tendency to form more regular, elongated (appr. 1 cm) grains conformable with the foliation of the rock. In the pegmatitic portions, it may attain even crystal form. Under the microscope, the mineral is either entirely clear, except for minute sillimanite (mullite?) needles and the customary pleochroic halos, the polysynthetic lamellar twinning appearing in the isometric grains only; or it is entirely pinitized, and does not contain any fibrolitic sillimanite. This difference may appear in grains situated side-by-side, where the environment has no signs of alteration. Apart from the pinitization, another entirely different kind of alteration may occur. It begins with the formation of thin needles of sillimanite and flakes of biotite, which form a narrow rim enveloping the cordierite. In the sheared portions of the rock, this rim grades into a mass composed of biotite, coarse prismatic sillimanite and secondary quartz. The biotite looks quite usual, but contains exceptionally many pleochroic halos. If rolled garnet occurs in the rock as well, clear cordierite will have crystallized on both its sides and in the direction of the schistosity. This is obviously a product of re-deposition into pressure minima offered by garnet. As another extreme result of such alteration, a formation of garnet may be considered together with sillimanite, but without biotite, embedded in a quartz matrix (see garnet, p. 92). Consequently:



These phenomena may be explained on the basis of the anti-stress character of cordierite, without assuming any significant metasomatic changes in the material of the rock itself. If the composition is suitable for the lower reaction in the scheme (khondalites and schistose granulites with platy quartz), then it indicates at the same time the important role of stress in the formation of almandite-pyrope.

A noteworthy special feature, the optically positive character, is rather common among the cordierites of the WUC. The optic axial angle varies widely, however, and two nearby grains may have an opposite sign of optical character. In the unfortunate absence of sufficient data, the author will leave the question about this peculiarity referring to the detailed investigations carried out by, among others, Pehrman (1932 and 1936) and Folinsbee (1941b).

Taking into account the microscopically observed irregularities as well as the possibility of the presence of several generations of cordierite, it is rather improbable that even in adjoining grains of this mineral the chemical composition would be similar. And vice versa, precisely the difference in composition, and hence the difference in stability, may explain the capricious occurrence of pinitization and fibrolitic sillimanite. The cordierite of the WUC has derived, principally, from the original argillitic composition, in which even a small increase in the Ca-content — not the unsuitable Mg/Fe ratio — results in the reduction of the excess aluminum and thus chemically hampers the occurrence of this phase (cf. Fig. 10). From the physical point of view, cordierite does not become unstable until subjected to high stress.

GARNET (ALMANDITE-PYROPE)

The data here presented relate to the garnet occurring in lutogenite and in Mi granite. The garnet occurring together with orthorhombic pyroxene may belong to the same series (cf. Fig. 3, p. 55). The coarse (0.5 to 3.0 cm) garnet of lutogenite is, if microscopically inspected, only seldom pure; but it contains inclusions mainly composed of quartz, which may also form the matrix (p. 91). The biotite flakes are less essential, and these two dark minerals avoid each other in other respects as well. The paragenetic picture may be completed by saying that the garnet may contain remnants of cordierite (never vice versa), and may be accompanied by sillimanite.

Table 9 gives chemical and physical data for the garnet of the WUC. Some components of the chemical analyses of the table are represented as averages in Fig. 23 (p. 110) as well. The refractive indices, on the other hand, are diagrammatically reproduced in Fig. 24 (p. 111).

Table 9. Properties of garnets (WUC)

(Specimen Nos., see Table 1, pp. 116—123)

	Chemical composition								
	No. 53			No. 63			No. 99		
	Weight %	Cation %	O in oxides	Weight %	Cation %	O in oxides	Weight %	Cation %	O in oxides
SiO_2	37.76	37.24	74.48	37.98	37.64	75.28	37.72	37.64	75.28
$AlO_{3/2}$	22.12	25.70	38.55	20.30	23.70	35.55	19.86	23.35	35.03
$FeO_{3/2}$	2.36	1.75	2.63	4.60	3.43	5.15	2.80	2.10	3.15
FeO	30.42	25.08	25.08	29.28	24.25	24.25	31.61	26.38	26.38
MnO	0.40	0.33	0.33	0.93	0.78	0.78	0.67	0.56	0.56
MgO	6.19	9.09	9.09	6.34	9.35	9.35	6.05	8.99	8.99
CaO	0.62	0.66	0.66	0.80	0.85	0.85	0.92	0.98	0.98
TiO_2	0.20	0.15	0.30	trace	—	—	trace	—	—
H_2O	n. d.	—	—	0.15	—	—	0.17	—	—
Total	100.07	100.00	151.12	100.38	100.00	151.21	99.80	100.00	150.37
	$100 \cdot \frac{Mg}{Mg + Fe + Mn + Ca} =$			$100 \cdot \frac{Mg}{Mg+Fe+Mn+Ca} =$			$100 \cdot \frac{Mg}{Mg+Fe+Mn+Ca} =$		
	$100 \cdot \frac{9.09}{35.16} = 25.85\ \%$ Mg			$100 \cdot \frac{9.35}{35.23} = 26.55\ \%$ Mg			$100 \cdot \frac{8.99}{36.91} = 24.36\ \%$ Mg		
	25.85 mol. % pyrope			26.55 mol. % pyrope			24.36 mol. % pyrope		

Refringence	
No.	n_{Na}
86	1.7822
59	1.7934
88	1.7939
(1) 63	1.7940
66	1.7947
87	1.7949
70	1.7956
92	1.7958
91	1.7968
(1) 53	1.7970
98	1.7971
101	1.7981
103	1.7987
55	1.7990
97	1.7992
(1) 99	1.7992
95	1.7996
58	1.8000
76	1.8000
64	1.8010
89	1.8014
56	1.8015
100	1.8019
84	1.8021
60	1.8041
62	1.8047
96	1.8074
85	1.8096
65	1.8150
57	1.8205

(1) Chem. anal.

The analyses and respective indices of refraction are in good agreement with the values given by Winchell (1951, Pt. II, p. 487), according to which the garnet of the lutogenite and of its granitic component contains 8 to 38 mol. per cent pyrope. In the granulites of Finnish Lapland, the respective pyrope content may increase up to 55 per cent (Eskola, 1952, pp. 150, 153; 1957, p. 105). Because, according to Eskola, the isomorphism between almandite and pyrope is extended simultaneously with an elevation of the PT-conditions, the garnet of the lutogenite would thus represent a facies lower than that of granulites. Judged by its refringence, the garnet of the WUC, if occurring in rocks of Mi granitic composition, is poorer in pyrope than is the garnet of lutogenite (cf. Tables 1 and 9). The representatives of the latter have been, however, collected erroneously, because they have been taken from the QuaFsp veins, which contain more homogeneous garnet material. Thus most of the given values represent the phase rather of "granitic" than argillitic composition. The Mg/Fe ratio of the former is 0.28, that of the latter 0.45 (Fig. 10, diagram D, p. 68). Consequently, if the ratio pyrope to almandite is used as a mineral facies indicator, the limitation set by the Mg/Fe ratio of the composition of the host rock is to be considered. On the other hand, in spite of the fact that the arithmetical mean of the Mg/Fe ratio in the analyses of garnet is 0.25 (Fig. 23, p. 110), which corresponds closely to the maximum value of Folinsbee (1941a) for the association garnet + biotite + cordierite, a wider range of isomorphism is obvious among the lutogenitic garnets. The petrochemical diagrams elucidate the dependence of the occurrence of garnet on the chemical bulk composition. Within the WUC, it is calcium that controls the boundary between the parageneses garnet + cordierite and pyroxenes + plagioclase. From the physical point of view, stress seems to expand the field of its occurrence at the expense of cordierite.

BIOTITE

This constituent is most abundant in the charnockitic rocks. In the lutogenitic composition, it is of less importance. In general, it occurs independently as a stable phase, and it has a tendency to avoid the company of other MgFe-minerals. On the other hand, it may co-occur with them, especially with pyroxenes and then also in the form of specks indicating the prism surfaces. These specks are concentrated in the inner parts of the host mineral. When occurring near the margins, the biotite seems to have grown outwards from the center of the host and not vice versa. In the same connections, very minute amounts of secondary quartz occur (Fig. 16; see also Fig. 21, p. 102). Independent of the mode of occurrence or of the mineral association, the biotite is strongly pleochroic under the microscope: α = pale

Fig. 16. Biotite and ilmenite-magnetite (three black grains to the right from the center) as inclusions in pyroxene grains, partly filling their shapes.
Pyroxene gneiss (paracharnockite). No. 25. Nic. ||. Magn. 40 ×.
Photo E. Halme.

yellowish brown; β and γ = pure brown to reddish or dark brown. In general, the color is strengthened together with increasing refringence. Both these properties, and the freshness of the biotite, as well as the deficiency in the volatiles (OH), are peculiarities characteristic of the biotite of charnockites (p. 13), being typical of the micas of the WUC as well. Among biotites of the WUC, a distinctly ascertainable negative axial angle is at least as common as is the uniaxial form. Both types may occur side by side in the nearby lamellae (cf. meionite and cordierite). An increase of the axial angle parallel to the increasing refringence seems to be obvious. The pleochroic halos appear to be most abundant and of largest size in the biotite of lutogenite.

The values given in Table 10 are reproduced in Figures 23 (p. 110) and 24 (p. 111) as well.

A mica of a typical Px granodiorite or charnockite is represented by Anal. 3. There the Mg/Fe ratio corresponds to the average of the orthorhombic pyroxene (Fig. 23). A low content of aluminum and ferric iron, but a high content of titanium, on the other hand, supports the view that there does not occur any Si^{4+} — Ti^{4+} diadochy, but that Ti^{3+} replaces both Al^{3+} and Fe^{3+} (Rankama and Sahama, 1955, p. 561). The inclination of titanium to be camouflaged in the structure of biotite is in agreement with the observation that the association biotite + sphene is, practi-

Table 10. Properties of biotites (WUC)

(Specimen Nos., see Table 1, pp. 116—123)

Chemical composition	No. 3		
	Weight %	Cation %	O in oxides
SiO_2	35.98	35.49	70.98
$AlO_{3/2}$	13.93	16.19	24.29
$FeO_{3/2}$	3.08	2.29	3.43
FeO	19.32	15.93	15.93
MnO	0.07	0.06	0.06
MgO	9.37	13.76	13.76
CaO	0.74	0.78	0.78
$NaO_{1/2}$	0.35	0.67	0.34
$KO_{1/2}$	8.84	11.12	5.56
TiO_2	5.00	3.71	7.42
H_2O+	2.70	(8.88)	—
H_2O-	0.18	—	—
Total	99.71	100.00	142.55

$$\frac{Mg}{Mg + Fe^{3+} + Fe^{2+} + Mn} = 0.429$$

$$\frac{Fe^{3+}}{Fe^{3+} + Fe^{2+}} = 0.126$$

$$\frac{K}{Na + K} = 0.94$$

Optic properties No.	β	(—) 2V (Max.)	Loss on ignition Weight %
53	1.644	0°	1.60
62	1.647	4°	1.79
10	1.648	6°	2.53
14	1.648	6°	2.11
20	1.648	6°	
13	1.651	4°	
63	1.651	4°	1.98
66	1.651	0°	
55	1.653	0°	
19	1.654	4°	1.74
22	1.656	6°	
7	1.660	0°	1.87
65	1.661	0°	1.73
77	1.662	0°	
1	1.662	10°	2.32
12	1.663	10°	
8	1.664	6°	
17	1.664	10°	1.53
24	1.664	12°	
44	1.664	8°	1.46
43	1.665	4°	
28	1.665	12°	1.36
94	1.666	14°	1.35
41	1.667	8°	
3 [1]	1.673	18°	2.00
23	1.673	14°	1.65
5	1.676	12°	1.08
[1] Chem. anal.			1.76 (Average)

Pleochroism (No. 3): α = pale yellowish brown
$\beta \sim \gamma$ = reddish brown

cally taken, lacking and this is valid for the charnockites in general (p. 14). The water content with the Penfield method (2.70 %) and the determination of loss on ignition of the same material (2.00 %) justifies considering the arithmetical mean of 16 determinations of the loss on ignition (1.76 %) as approaching in its order of magnitude the actual average content (see hornblende, p. 108).

The occurrence of biotite as inclusions in other dark constituents does not mean a reverse order of crystallization or any secondary alteration of the host; but it is a result of an exsolution in the solid phases. If, under high PT-conditions, potassium and aluminum as well as titanium, in small amounts, are forced to enter pyroxenes during the formation of the host, they tend later on to form a more suitable phyllosilicate structure deficient in hydroxyl, because the structure of pyroxene does not suit them. In this process, the elements mentioned combine with available iron and magnesium, the excess silica being thereby liberated as secondary quartz. The fact that the mica inclusions remain inside the host indicates that there is just an unmixing in progress and that the phenomenon is not caused by any external factor.

Regarding the occurrence of the strongly brown biotite as a constituent of charnockites, some points of view have been expressed in Part I. Taking into account the limitation of stability in the calcareous rocks (see meionite), the biotite of the WUC with the afore-mentioned properties has to be considered typomorphic and the paragenesis of it is of equal value with the other MgFe-phases belonging to the granulite facies.

ORTHORHOMBIC PYROXENE (FERROHYPERSTHENE)

This is the most important MgFe-phase of the charnockitic rocks. It may occur independent of the acidity of the rocks, in the strongly foliated gneisses as well as in the massive pegmatitic segregation veins. It occurs independent of the mode of origin of the rocks, thus representing, within the WUC, the whole petrographic milieu well known from different descriptions of charnockites. It is of dark brown color. Microscopically it is clear and fresh; and in respect to its optic properties, it displays all the peculiarities of the hypersthene of charnockites (p. 13). Depending upon the rock texture, the following grain shapes are to be distinguished: 1) Hypidiomorphic is always coarse-grained and occurs in the segregation veins; 2) homogeneous, but corroded crystals, occurring in the gneissose Px granodiorites (charnockites); 3) poikiloblastic grains that form apparently separate patches or more coherent spongy crystals. These are typical of all other charnockitic rocks of the WUC. The author wishes to emphasize that if orthopyroxene occurs on the margin of a coarse-grained aplitic segregation, the individual crystals are coarse and homogeneous on the side towards the segregation, whereas the part belonging to the finer-grained rock is of a spongy type (cf. texture as the criterion of charnockites, pp. 29—30).

Table 11 presents chemical and optical data for orthorhombic pyroxenes of the WUC. Some of the values of the chemical components are also included as averages in Fig. 23 (p. 110) and the optic properties in Fig. 17. The values indicating the refringence are included in Fig. 24 (p. 111) as well.

Table 11. Properties of orthorhombic pyroxenes (WUC)

(Specimen Nos., see Table 1, pp. 116—123)

Chemical composition	No. 7			No. 18		
	Weight	Cation	O in oxides	Weight	Cation	O in oxides
	%	%		%	%	
SiO_2	49.84	49.30	98.60	48.52	49.13	98.26
$AlO_{3/2}$	0.00	—	—	0.00	—	—
$FeO_{3/2}$	1.29	0.96	1.44	0.81	0.61	0.92
FeO	29.45	24.39	24.39	35.56	30.10	30.10
MnO	0.62	0.51	0.51	0.99	0.85	0.85
MgO	15.23	22.47	22.47	11.56	17.43	17.43
CaO	1.05	1.11	1.11	1.12	1.22	1.22
$NaO_{1/2}$	0.46	0.88	0.44	0.13	0.26	0.13
$KO_{1/2}$	0.12	0.14	0.07	0.08	0.10	0.05
TiO_2	0.33	0.24	0.48	0.40	0.30	0.60
H_2O	1.80	—	—	0.63	—	—
Total	100.19	100.00	149.51	99.80	100.00	149.56

No. 7:

$$\frac{100\ \mathrm{Mg}}{\mathrm{Mg} + \mathrm{Fe}^{3+} + \mathrm{Fe}^{2+} + \mathrm{Mn}} = 46.50$$

53.50 mol. % hypersthene

No. 18:

$$\frac{100\ \mathrm{Mg}}{\mathrm{Mg} + \mathrm{Fe}^{3+} + \mathrm{Fe}^{2+} + \mathrm{Mn}} = 35.60$$

64.40 mol. % hypersthene

Optic properties							Exsolution lamellae	Mineral assembages
No.	α	β	γ	$\gamma—\alpha$	(—) 2V	Pleochroism		
20	1.703	n. d.	1.720	0.017	45°—51°	Weak	Rare	PlaHyBiQua
43	1.705	1.716	1.722	0.017	48°—55°	Strong	(Not visible)	PlaDiHoHyBi
17	1.711	1.723	1.728	0.017	42°—48°	Very weak	Rare	PlaQuaBiHy
22	1.712	1.724	1.729	0.017	43°—45°	Not appreciable	Rare	PlaQuaHyBi
13	1.713	1.724	1.729	0.016	42°—45°	Distinct	None	PlaQuaBiHy
10	1.714	1.725	1.730	0.016	44°—47°	Not appreciable	None	PlaHyQuaBi
46	1.713	n. d.	1.731	0.018	41°—46°	Strong	Numerous	PlaHyHoDi
7 [1]	1.717	1.729	1.733	0.016	43°—47°	Not appreciable	None	PlaQuaHyBiPfs
3	1.717	n. d.	1.735	0.018	47°—51°	Moderate	Numerous	PlaQuaHyBi
19	1.717	n. d.	1.735	0.018	44°—51°	Moderate	Numerous	PlaBiQuaHy
94	1.718	n. d.	1.736	0.018	48°—52°	Moderate	Numerous	PlaHyPfsQua
12	1.720	1.733	1.737	0.017	42°—52°	Weak	Rare	PlaQuaHyBiDi
44	1.720	n. d.	1.737	0.017	44°—51°	Distinct	Numerous	PlaHoDiHyBi
77	1.720	n. d.	1.737	0.017	42°—51°	Not appreciable	None	PlaHyQuaBiPfs
1	1.720	n. d.	1.738	0.018	49°—52°	Weak	None	PlaPfsQuaBiHy
24	1.720	1.735	1.740	0.020	50°—53°	Not appreciable	None	PlaQuaBiHyDi
8	1.724	n. d.	1.741	0.017	50°—55°	Distinct	(Not visible)	PlaQuaHyBiPfs
5	1.722	n. d.	1.742	0.020	54°—56°	Strong	Numerous	PlaHyBiMiHo
23	1.727	1.739	1.744	0.017	51°—58°	Moderate	(Not visible)	PlaQuaHoBiHy
18 [1]	1.729	1.741	1.747	0.018	55°—62°	Strong	Numerous	PlaQuaHyBi
9	1.731	n. d.	1.748	0.017	54°—58°	Distinct	Numerous	PlaHyQua

[1] Chem. anal.

Analysis No. 7 represents a typical charnockite specimen from the WUC, No. 18 a representative of a paracharnockite. Both are aluminum-free, which is against the generalized observation (p. 13) concerning the extended Si—Al diadochy as a result of high PT-conditions (e. g. Eskola, 1952, p. 154; 1957, pp. 105—106). Not to cast doubts on the results of other investigators, the present author will only stress the considerable difficulties encountered in the purifying of the material analyzed (cf. diopside, p. 106).

Using some of the curves by Hess (1952, Fig. 2) as a background, the diagram (Fig. 17) indicating the relationship of the optic properties with the chemical composition may be constructed. This diagram reveals that the mol. percentages corresponding to the γ-values deviate only by 1 ½ units from the respective values of the Bushveld type. The high birefringence, however, does not agree at all with the lower interference colors verified through measurements with a Bereck compensator. This is due to the heterogeneity of the material, appearing through the determination of the highest and lowest refringence by the immersion method. According to repeated measurements, the optic axial angles are unusually variable, even within the same thin section. Therefore the values indicated for the axial angles are limit values of several determinations only. These, however, are in clear agreement with the curves of Hess.

Furthermore, the diopsidic exsolution lamellae parallel to (100) are characteristic of the hypersthene of the WUC. These are most distinctly visible in sections perpendicular to the acute bisectrix in such a way that, if the host-hypersthene is extinguished, the lamellae are light and vice versa (Figs. 18 and 19). The lamellarity occurs in all shape-types of the orthorhombic pyroxene, and, consequently, independently of the mode of crystallization. In addition to the lamellae, the diopsidic pyroxene may form minute blebs within the orthopyroxene. Also these blebs probably originate as products of unmixing (Fig. 21, p. 102). Furthermore, there are reasons to assume an occurrence of submicroscopic lamellae as well. The presence of such lamellae would explain, at least to a certain extent, the incomplete extinction of the host. On the other hand, the absence of the products of exsolution, at least of lamellae, is not rare, despite the fact that, according to the chemical analyses, the calcium content of the pyroxene without lamellae (No. 7) is the same as that of the pyroxene containing ample lamellae (No. 18). Because these lamellae are very much similar to those described by Hess and Phillips (1940), by Poldervaart and Hess (1951), and by Hess (1952), the author will not here go further into these details, but will stress the regularity occurring between the pleochroism and the lamellarity. Statistically, the simultaneous co-occurrence or absence of pleochroism and lamellarity, as observed in different grains of the same thin section, is

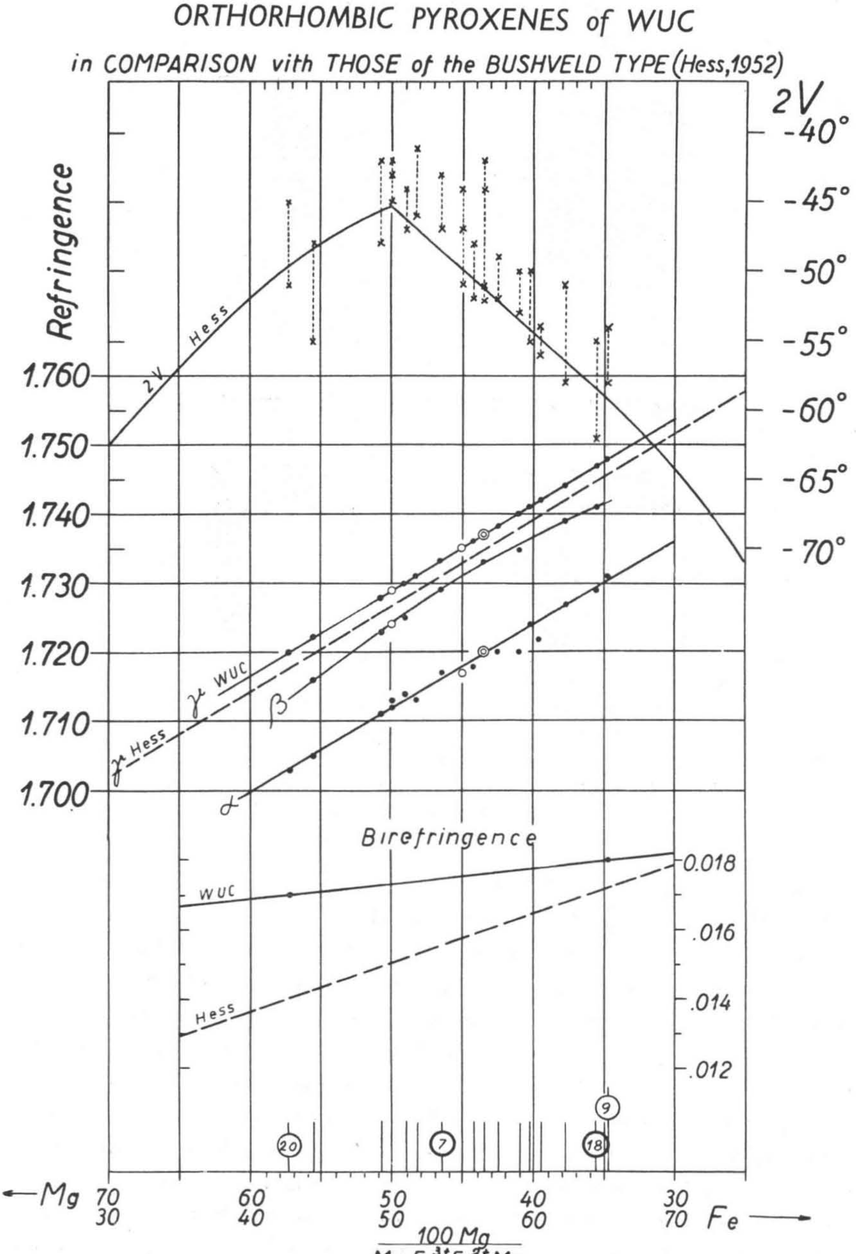


Fig. 17. Optic properties of orthorhombic pyroxenes of rocks of WUC plotted against chemical composition.

Black dots = single values.
Open circles = two equal values obtained with different specimens.
Double circles = three or more equal values obtained with different specimens.
Chemical and mineralogical data, see Table 11 (p. 97).

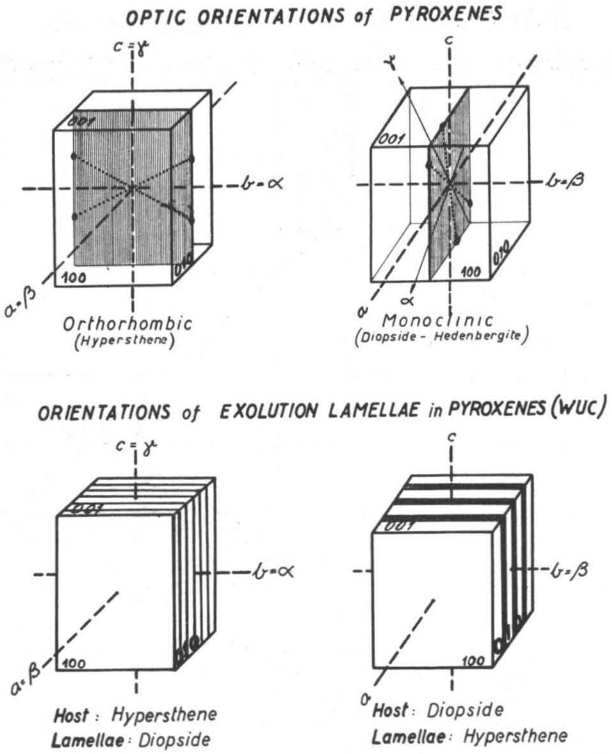


Fig. 18. Optic orientation and lamellar structure of the pyroxenes.

noticed in 90 per cent of the cases examined. The intensity of the hue is directly proportional to the abundance of the lamellae. Thus the colorless pyroxene, in the sections parallel to (010), does not contain lamellae. By the unmixing of the diopside component and of the ferric iron, the latter, possibly in the form of an oxide, has been concentrated on the surfaces of the growing lamellae. Thus get, in the host-pyroxene, the particles the general orientation parallel to (100). The intensity of the pleochroism would thus depend upon the stage of the exsolution of both components and simultaneously of the orientation. This is a tentative explanation of the problem, so far considered as being unsolved (p. 13; Eskola, 1957, p. 106).

Another property of the orthorhombic pyroxene of the charnockites, which has also drawn much attention, is its oblique extinction (p. 13; Sen Gupta, 1916; Washington, 1916; Groves, 1935; Johannsen, 1937; Naidu, 1943; Ray and Roy, 1944; Rama Rao, 1945; and Quensel, 1951. See Part I, Bibliography). The explanations of this phenomenon have so

Fig. 19. Clinopyroxene exsolution lamellae (light) in hypersthene. Leucocratic segregation vein in pyroxene granodiorite (charnockite). No. 94. Nic. +. Magn. 100 ×. Photo E. Halme.

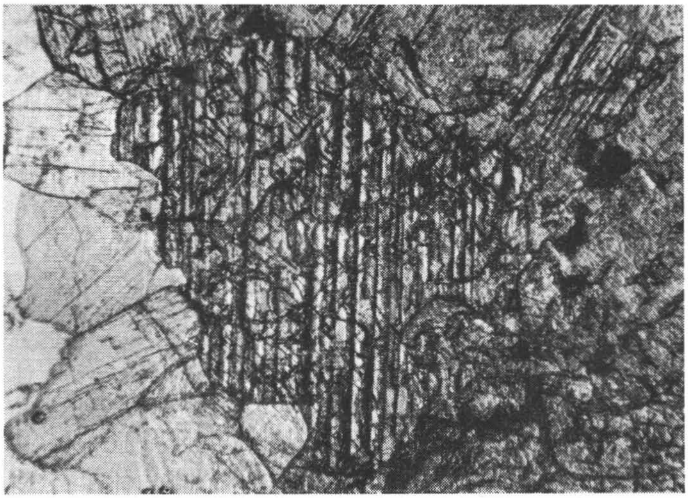


Fig. 20. Orthopyroxene exsolution lamellae in clinopyroxene. Meionite-diopside amphibolite. No. 48. Nic. +. Magn. 40 ×. Photo E. Halme.

far been mainly based on the occurrence of a primary or relictic (hypersthenization) cleavage, other than that parallel to (110). Despite the fact that within the WUC the straight extinction of the hypersthene is rather rare, the most important cause of this phenomenon is the rarity of the sec-

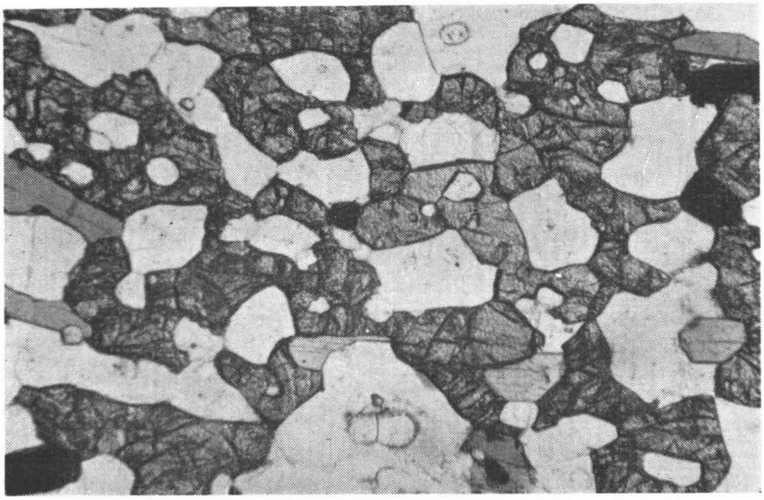


Fig. 21. Hypersthene (dark), with diopside (in center) and biotite, forming spongy grain.
Pyroxene gneiss (paracharnockite). No. 26. Nic. ||. Magn. 10 ×.
Photo E. Halme.

tions parallel to the c-axis, compared with otherwise orientated sections. Measured by the traces of prismatic cleavages, the latter ones show, of course, a more or less inclined extinction (cf. Johannsen, op. cit., pp. 212—213). After all, this ballast of descriptions of hypersthene is, in many cases, useless. On the other hand, the traces of former amphibole cleavages, perhaps, may not always be absent in the orthorhombic pyroxenes of the WUC either.

The composition of the orthorhombic pyroxene, as expressed in terms of atomic percentages, is mainly between $Mg_{50}Fe_{50}$ and $Mg_{35}Fe_{65}$. Thus it represents ferrohypersthene. As is revealed by the comparison of respective rock analyses, there does not appear any connection with the acidity of the rock, not even in the igneous-looking rocks. Instead, the γ -values, if compared with the Mg/Fe ratio in the rock composition, attain their maximum (approx. 1.745) when Mg/Fe of the bulk chemistry of the rock is 0.37 (Fig. 10, diagram D). If the iron content of the bulk composition increases, the γ-values decrease (except in the case of Anal. No. 9). On the other hand, the ratio of 0.37 is close to that of the pyroxene richest in iron ($Mg_{35}Fe_{65}$). Thus the orthorhombic pyroxene of the WUC seems to remain stable to a certain Fe-content only (65 mol. per cent hypersthene). The excess iron of the bulk composition of the rock then becomes distributed between other phases, not least into anhydrous biotite; or, then, it occurs outright as magnetite (No. 9). The same comparison gives hints about the maximum limit of the Mg-component as well. The excess magnesium is thereby mainly bound into diopsidic pyroxene. Optically positive orthopyroxene has not been met with.

The replacement of Si^{4+} by Al^{3+}, characteristic of the granulite facies, seems to be lacking. Instead of this diadochy an extended isomorphism, represented by the diopsidic pyroxene as a solid solution in the orthorhombic pyroxene, occurs on a large scale. This feature is not in agreement with the observations of other authors, who state that extended diopside-orthopyroxene solid solutions are rare rather than common in the charnockitic environment (Hess and Phillips, op. cit., pp. 283—284) or that such solid solutions do not belong to the granulite facies at all (Naidu, 1955, cited by Eskola, 1957, p. 106). In view of the fact, however, that this feature has exact bearings on the interpretation of the physical conditions, the present author takes it amply into consideration in interpretations of the petrogenesis of the WUC.

MONOCLINIC PYROXENE (SALITE-FERROSALITE)

In silicic charnockitic rocks, the occurrence of clinopyroxene is more restricted than that of the orthorhombic. The first-mentioned pyroxene is more common in the intermediate and basic rock types. Microscopically, clinopyroxene is clear and fresh and the grain-shape corresponds to the main types (2) and (3) to the hypersthene type (p. 96) in all other rocks except the MeiDi gneisses and the corresponding amphibolites. In the last-mentioned rocks, the grains are isometric, and sometimes they tend to develop crystal faces. In addition to the independent crystals of the clinopyroxene, this mineral also may occur in the spongy crystals of the hypersthene, in which it forms either narrow bridges between islets, or forms the continuation of the projections. In general, it acts as if to patch up the ragged framework of the host mineral (Fig. 21). This mode of occurrence is also probably connected with the exsolution.

The monoclinic pyroxene contains exsolution lamellae parallel to (100) as well, but these are coarser than they are in the hypersthene and are made of orthorhombic pyroxene (Fig. 20). In addition to the orientation shown in Fig. 18, the author has noticed other types as well (cf. Poldervaart and Hess), which, however, will not be here described. The possible relationships between pleochroism and the lamellae of the monoclinic pyroxene will not to be discussed here, either.

Table 12 gives chemical and optical data for the monoclinic pyroxene of the WUC. The values given are reproduced in the figures containing the respective properties of the hypersthene as well.

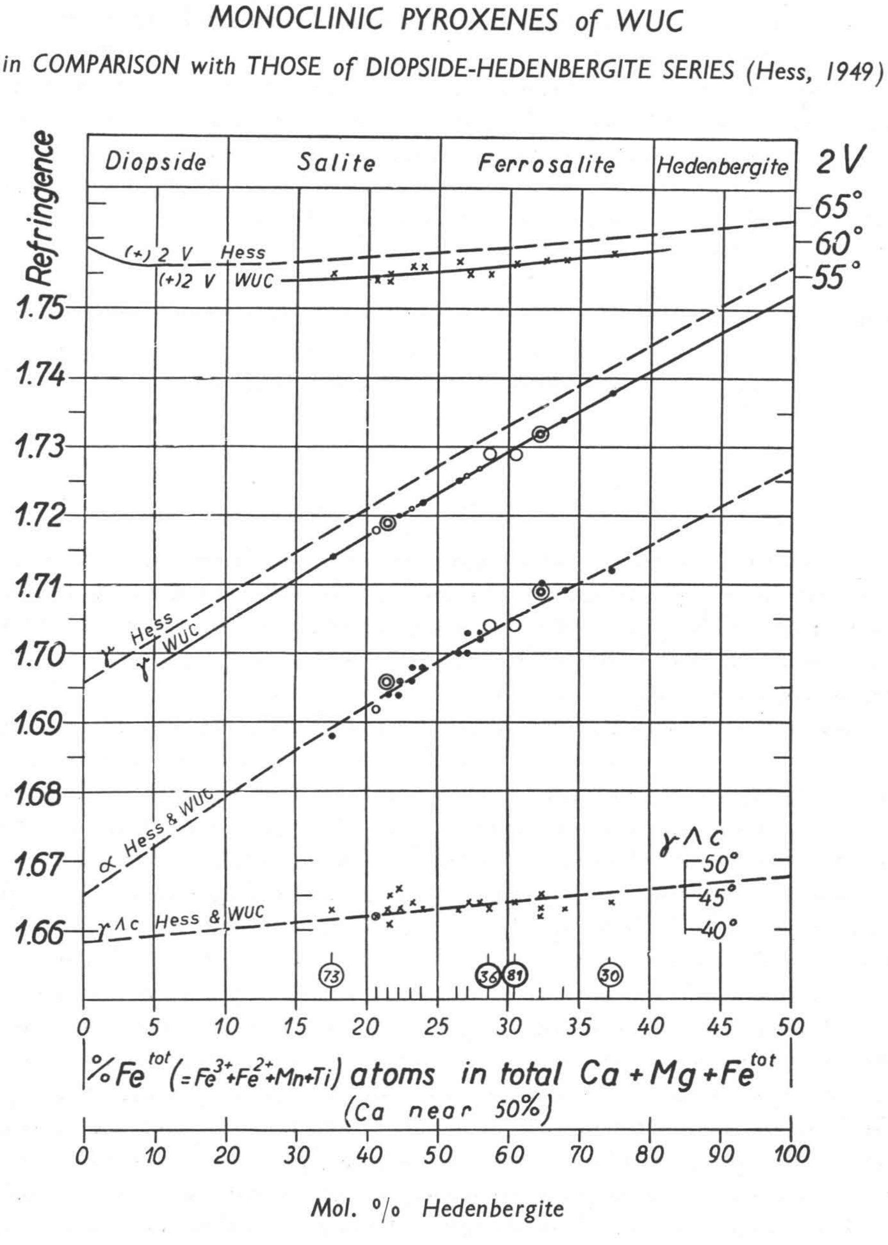
Table 12. Properties of monoclinic pyroxenes (diopside-hedenbergite) (WUC)
(Specimen Nos., see Table 1, pp. 116—123)

Chemical composition

	No. 36			No. 81		
	Weight %	Cation %	O in oxides	Weight %	Cation %	O in oxides
SiO_2	50.48	49.43	98.86	50.18	49.35	98.70
$AlO_{3/2}$	0.00	—	—	0.00	—	—
$FeO_{3/2}$	0.25	0.18	0.27	0.70	0.52	0.78
FeO	16.70	13.67	13.67	17.33	14.24	14.24
MnO	0.24	0.20	0.20	0.28	0.23	0.23
MgO	7.73	11.27	11.27	6.87	10.06	10.06
CaO	23.04	24.15	24.15	23.28	24.52	24.52
TiO_2	0.26	0.19	0.38	0.13	0.09	0.18
CO_2	0.68	0.91	1.82	0.74	0.99	1.98
H_2O+	0.07	(0.23)	—	0.09	(0.30)	—
H_2O-	0.16	—	—	0.10	—	—
Total	99.61	100.00	150.62	99.70	100.00	150.69
Cat. %	Ca 24.15 Mg 11.27 Fetot 14.24	49.66	Ca 48.63 Mg 22.70 Fetot 28.67	Cat. % Ca 24.52 Mg 10.06 Fetot 15.08	49.66	Ca 49.37 Mg 20.26 Fetot 30.37
	Total 49.66		Total 100.00	Total 49.66		Total 100.00
		Ca 48.6 Mg 22.7 Fetot 28.7			Ca 49.3 Mg 20.3 Fetot 30.4	
		56 mol. % hedenbergite			60 mol. % hedenbergite	

Optic properties							Mineral assemblages
No.	α	γ	γ—α	(+) 2V	γ ∧ c	Color in thin section	
73	1.688	1.714	0.026	55°	43°	Colorless	HoDiPla
14	1.692	1.718	0.026	n. d.	42°	Colorless	PlaBiQuaDi
28	1.692	1.718	0.026	54°	42°	Colorless	PlaQuaDiBiMi
42	1.694	1.719	0.025	n. d.	43°	Colorless	PlaDiQuaMi
46	1.696	1.719	0.023	55°	45°	Colorless	PlaHyHoDi
47	1.696	1.719	0.023	55°	n. d.	Greyish	DiCalMeiHo
48	1.696	1.719	0.023	n. d.	n. d.	Colorless	DiMeiCalHoPla
51	1.696	1.719	0.023	54°	41°	Colorless	DiHoPla
93	1.694	1.720	0.026	n. d.	43°	Greyish	QuaMeiDiCalPla
13	1.694	1.720	0.024	n. d.	46°	Colorless	PlaQuaBiHyDi
52	1.696	1.721	0.025	56°	44°	Pale greenish	HoDiPla
50	1.698	1.721	0.023	n. d.	n. d.	Pale greenish	DiMeiCalPla
12	1.698	1.722	0.024	56°	43°	Pale greenish	PlaQuaHyBiDi
44	1.700	1.725	0.025	57°	43°	Pale greenish	PlaHoDiHyBi
49	1.700	1.726	0.026	n. d.	n. d.	Greyish	HoDiPlaBi
41	1.703	1.726	0.023	55°	44°	Pale greenish	PlaDiQua
90	1.702	1.727	0.025	n. d.	n. d.	Pale greenish	QuaMeiMiDiCal
37	1.703	1.727	0.024	n. d.	44°	Greenish grey	QuaDiMeiMiPlaCal
36 [1]	1.704	1.729	0.025	55°	43°	Greenish grey	MeiDiQuaPla
81 [1]	1.704	1.729	0.025	56°	44°	Pale greenish	CalWoMiDiQua
31	1.709	1.732	0.023	n. d.	45°	Greenish	QuaPlaMiDiCal
33	1.709	1.732	0.023	57°	42°	Greenish grey	QuaMeiDiCalPla
34	1.709	1.732	0.023	n. d.	43°	Greenish	QuaDiMeiPlaCal
35	1.710	1.732	0.022	n. d.	45°	Greenish grey	QuaDiMeiMi
40	1.709	1.734	0.025	57°	43°	Green	PlaQuaDiCal
30	1.712	1.738	0.026	58°	44°	Green	QuaMiPlaDi

1) Chem. anal.


MONOCLINIC PYROXENES of WUC

in COMPARISON with THOSE of DIOPSIDE-HEDENBERGITE SERIES (Hess, 1949)

Fig. 22. Optic properties of monoclinic pyroxenes of rocks of WUC plotted against chemical composition.

Black dots = single values.
Open circles = two equal values obtained with different specimens.
Double circles = three or more equal values obtained with different specimens.

Chemical and mineralogical data, see Table 12 (p. 104).

The chemical analyses have, unfortunately, been made from pyroxenes similar to each other. They verify, however, two peculiarities of these minerals, namely, the total absence of aluminum (cf. hypersthene) and the equal content of CO_2. Regarding the latter constituent, the purity of the material is unquestionable. The following critical examination of the cation numbers, controlled by the oxygen value (without that of CO_2) shows that the cation ratio is not exceptional (within the accuracy of the analyses):

No.	$Si : (Fe^{3+} + Fe^{2+} + Mn + Mg + Ca + Ti)$	$Si : \frac{O}{6}$	$(Fe^{3+} + Fe^{2+} + Mn + Mg + Ca + Ti) : \frac{O}{6}$
36	$0.9950 \cong 1.0$	$1.992 \cong 2.0$	$2.003 \cong 2.0$
81	$0.9940 \cong 1.0$	$1.991 \cong 2.0$	$2.004 \cong 2.0$

Therefore, it seems possible that the CO_2, not belonging to the monoclinic pyroxene structure itself, occurs there in some form as an additional constituent. This suggestion is of some importance because the pyroxenes analyzed derive from the MeiDi gneisses, in which the partial pressure of CO_2 is paragenetically important.

Taking the graphical presentation of Hess (1949, p. 641) as a background, a diagram of optic properties related to the cation ratios of the analyses 36 and 81 may be constructed (Fig. 22). In this diagram, the γ-values correspond to 3 per cent less of the atoms of total iron (or 6 mol. per cent less of hedenbergite) than does the curve of Hess. The α-values are in better agreement. Thus the birefringence of the monoclinic pyroxenes of the WUC is slightly lower. This fact was verified through measurements with a Bereck compensator. Also measurements of (+)2V indicate values approximately 3° smaller with an accuracy of ±1°. Consequently, the monoclinic pyroxene does not display here any such anomalies as does the orthorhombic. As to the extinction angles, the determinations based on the cleavage fissures are without any determinative value. Having, in addition, an increasing intensity of the greenish color with an increasing ratio of Fe to Mg (Table 12), the monoclinic pyroxene of the WUC has all the properties of the diopside-hedenbergite series and shows a composition of 35 to 75 mol. per cent hedenbergite. Thus it is a salite-ferrosalite. When the monoclinic pyroxene occurs together with other dark constituents, it is richer in the Mg-component. If it occurs alone, the Fe-component predominates. In the latter cases, especially, the maximum γ-value (as in the hypersthene as well) is attained at the ratio of Mg/Fe, having the value of 0.35. Consequently, within the fields of the chemical bulk composition as indicated by Fig. 10 (p. 68), the monoclinic pyroxene of the WUC, independently of the genesis of the rock, is stable starting from the minimum of the abscissa, approx. 6 per cent Ca (cf. Table 2, pp. 124—127).

HORNBLENDE

Independently of the mode of origin of the rock, the occurrence of hornblende in the WUC is restricted to rocks with an unsaturated cafemic bulk composition. Under the microscope, the mineral is always brown or greenish brown. The single crystals tend to attain a crystal form. They never occur in the form of spongy crystals as do the pyroxenes. The idiomorphism is quite distinct when the brown hornblende occurs as minute inclusions enclosed by pyroxenes. Similarly to the inclusions of biotite, also those of hornblende may be explained as products of exsolution. Along the margins of the monoclinic pyroxene, a green hornblende may sometimes occur as a product of alteration.

Table 13 gives chemical and optical data for the hornblende of the WUC. The values of this table are indicated in the figures as well, in the same way as in the case of the properties of pyroxenes.

Table 13. Properties of hornblendes (WUC)
(Specimen Nos., see Table 1, pp. 116—123)

	Chemical composition No. 52			Optic properties						Loss on ignition
	Weight %	Cation %	O in oxides	No.	α	γ	$\gamma - \alpha$	(—) 2V	$\gamma \wedge c$ (Mean)	Weight %
SiO_2	41.10	39.21	78.42	102	1.651	1.675	0.024	80°—84°	15°	1.04
$AlO_{3/2}$	12.62	14.18	22.20	72	1.651	1.676	0.025	79°—81°	15°	1.09
$FeO_{3/2}$	3.35	2.40	3.60	46	1.661	1.684	0.023	79°—83°	14°	0.46
FeO	14.16	11.30	11.30	73	1.664	1.687	0.023	82°—85°	11°	1.18
MnO	0.21	0.17	0.17	51	1.663	1.688	0.025	78°—81°	13°	0.76
MgO	9.86	14.00	14.00	1) 52	1.674	1.698	0.024	76°—88°	13°	0.55
CaO	11.50	11.76	11.76	5	1.675	1.699	0.024	64°—68°	11°	0.22
$NaO^{1}/_{2}$	2.03	3.75	1.88	47	1.676	1.699	0.023	65°—70°	13°	0.61
$KO^{1}/_{2}$	1.07	1.30	0.65	48	1.676	1.700	0.024	68°—80°	14°	0.30
TiO_2	2.59	1.86	3.72	49	1.676	1.700	0.024	70°—80°	13°	0.64
$PO_{5/2}$	0.09	0.07	0.17	43	1.678	1.701	0.023	59°—69°	11°	0.26
H_2O+	1.76	(5.60)	—	23	1.679	1.702	0.023	64°—69°	10°	0.44
H_2O-	0.03	—	—	44	1.681	1.705	0.024	62°—64°	10°	0.42
Total	100.37	100.00	147.87	1) Chem. anal.					Average	0.61

$$\frac{Mg}{Fe^{3+} + Fe^{2+} + Mn + Mg} = 0.50$$

$$\frac{Fe^{3+}}{Fe^{3+} + Fe^{2+}} = 0.175$$

Pleochroism (No. 52):
α = brownish yellow
β = brown
γ = dark brown

Anal. 52 corresponds to the average composition of the common green hornblende, from which it deviates through its comparatively high titanium content. The relatively high total of alkalies is also noteworthy. The degree of oxidation of the iron (0.175) is rather low for a brown hornblende variety. Concerning the ratio of Fe^{3+}/Fe^{2+}, however, the possibility of an analytical error is to be taken in account. The same reservation must be made for the combined water as well, which, in the present case, is three times as high as the respective loss on ignition. This, of course, may be caused by the oxidation of iron during the determination as well (p. 80) and, consequently, the values may be smaller than the actual ones. The average loss on ignition, however, gives a more correct content in volatiles than that obtained from a single determination of H_2O. Thus the deficiency in hydroxyl is considered more likely than the normal hydroxyl content. The optic properties, on the other hand, indicate that there are some irregularities. Variations in chemical composition are probable even in the adjoining grains.

The instability of hornblende in the presence of quartz is the most essential feature of the occurrence of hornblende within the WUC. The only exceptions to this rule are the minute hornblende inclusions occurring inside the pyroxenes. The analytical material (Fig. 23, p. 110) suggests that the following reactions, from left to right, are possible:

$$\text{Hornblende} + \text{quartz} \longrightarrow \text{plagioclase} + \begin{array}{l} \nearrow \text{clinopyroxene} \\ \rightarrow \text{biotite} \\ \searrow \text{orthopyroxene} \end{array}$$

It is noteworthy that, in reaction equations mentioned, biotite is the only new MgFe-phase caused by the excess silica. This phase incorporates the titanium and potassium liberated from the hornblende. Other components liberated by the reaction increase only the amounts of the crystalline phases already present in the rock. This paragenetic rule may be followed in nature already on the scale of a few centimeters in the alternating bands characterized by the following scheme regarding the abundance of constituents:

plagioclase + hornblende + pyroxenes | plagioclase + more
diopsidic pyroxene + biotite + quartz

Because here appears a repeated banding of rocks occurring as masses of large volumes, the presence or absence of hornblende and biotite cannot be explained as a result of a rhythmic alteration of the PT-conditions; neither is it caused by the different water content alone, but rather by the bulk composition of the band. The deficiency of silica and water, assisted by the presence of titanium, has extended the stability field of the hornblende, in the scheme of the mineral facies, into the pyroxene field. This interpretation also provides an explanation for the apparently reversed order of crystallization of pyroxenes and hornblende in the charnockitic rocks in general (p. 13; see also pp. 113—114).

Neglecting some of the transitional types of the marginal parts of the WUC (Nos. 23, 68, and 105) that approach the amphibolite facies, Fig. 10 (diagram H) illustrates the petrochemical field in which hornblende is stable. This field begins with the abscissa value of 5 per cent Ca or more and has the maximum ordinate of 50 per cent Si. This diagram is valid for the charnockitic rocks. The "non-charnockitic" MeiDi amphibolites, or their bulk composition, allows the presence of calcian hornblende and diopsidic pyroxene, but not that of the hypersthene. Consequently, the difference is exclusively in the chemical and not in the physical factors. The brown hornblende of the WUC is to be considered as a stable constituent of the water-deficient, unsaturated rocks. In the scheme of the mineral facies, it is a very sensitive indicator of the lower limit of the PT-conditions corresponding to the granulite facies.

ACCESSORIES

Apatite is enriched in the most siliceous and in the most basic charnockites and paracharnockites, whilst in the intermediate compositions of these rocks it is scarce. In the MeiDi gneisses and respective amphibolites as well in the lutogenites, the apatite is scanty, too. The distribution of this minor constituent is such that it seems to seek the immediate vicinity of hypersthene and biotite. This tendency, as well as the presence or absence of crystal forms, is independent of the mode of crystallization of the rock. When it forms inclusions in the dark minerals (biotite), there are no signs of any pleochroic halos.

Graphite has been distinctly concentrated in the argillaceous (lutogenite) and in the calcareous (MeiDi gneiss) compositions, as well as in some representatives of paracharnockites. This feature also supports the point of view that these rocks are of sedimentogenic origin.

Oxidic iron ore is, within the WUC, never more than an accessory. Its distribution is more or less similar to that of apatite, being, however, most abundant in the quartz noritic vein types. The ore has been taken to be magnetite-ilmenite on the basis of the mineralogical and chemical composition of the rocks only (see sphene). No exact identification of the mineral has been made.

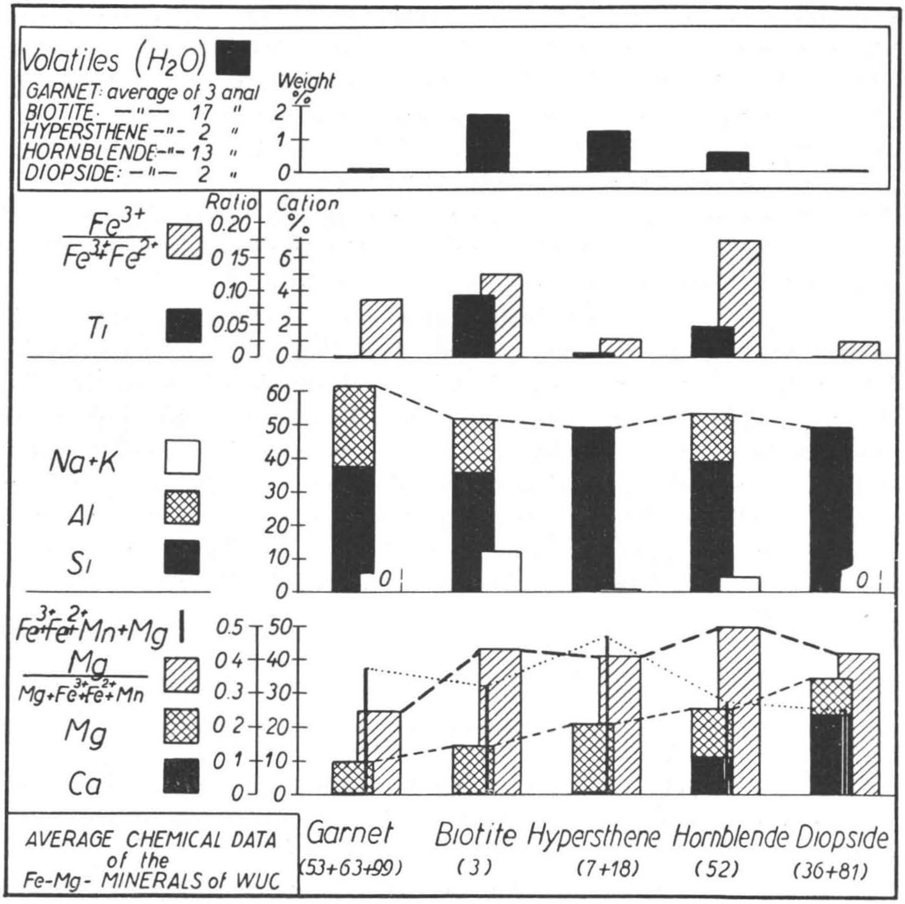


Fig. 23. For explanation see text. Based on chemical data contained in Tables 9, 10, 11, 12, and 13 (pp. 92, 95, 97, 104, and 107).

Sulfides occur in even smaller amounts than the oxidic iron ore. FeS_2 is characteristic of the lutogenites. FeS occurs in both amphibolites and quarts norites. $CuFeS_2$, in microscopic amount, is entirely restricted to the MeiDi amphibolites (cf. trace elements).

Sphene has been observed in the MeiDi gneisses and in the respective amphibolites only, particularly in the bands which do not contain hornblende. In the former it mainly forms minute rounded grains (cf. zircon). It is noteworthy that, within the WUC, sphene is unstable in rocks that contain other MgFe-minerals than diopsidic pyroxene or small amounts of hornblende together with the first-mentioned (p. 24; Fig. 3, p. 55; Fig. 14, p. 86).

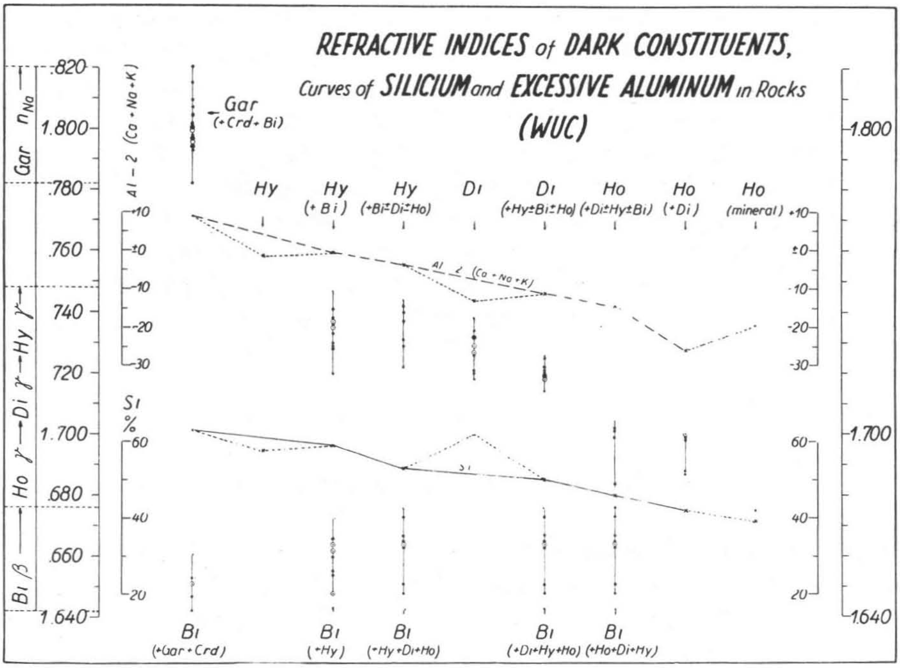


Fig. 24. For explanation see text. Curves for excess aluminum and for silicon are based on chemical and mineralogical data contained in Table 2 (pp. 124—127). Numerical values of refrigence are included in Tables 9, 10, 11, 12, and 13 (pp. 92, 95, 97, 104, and 107).

The pleochroic halos in biotite and cordierite are probably caused by zircon (cf. apatite). The zircon may also be accumulated into independent grains occurring both in the lutogenites and in the MeiDi gneisses (cf. zirconium, pp. 76—77). Especially in such cases as when zircon shows rounded forms, it is of importance for the genetical interpretation of the rocks.

SOME PROPERTIES OF MAFIC MINERALS SUMMARIZED

In Fig. 23, some chemical data mentioned earlier have been graphically epitomized. The minerals have been arranged in the order of increasing Ca + Mg, from left to right. The similarity of the Mg/Fe ratio of biotite and pyroxenes is noteworthy, as well as the total of Al + Si, which, in the biotite and the hornblende, corresponds to the amount of Si of the pyroxenes. The deviation of garnet in these respects from other minerals is here visualized as well.

In Fig. 24, the values for the refractive indices (highest index) of each mineral are grouped according to its occurrence alone or together with other constituents, the mutual abundance of the mineral being taken into account in the latter case. From the chemical analyses of the rocks representing the groups obtained, the arithmetical averages for the excess aluminum and for silicon have been calculated. These averages are represented by the curves descending from left to right. Thus in the scheme, the bulk chemistry grades from an argillageous composition (at the left) into the basic one (at the right), simultaneously elucidating the limits of variation of the refringence (Mg/Fe ratio). The "reverse order of crystallization" of the hypersthene and the hornblende appears here in a beautiful way.

MINERAL FACIES CONSIDERATIONS

Referring to the discussion of the mineral facies principle and its application to the charnockitic and associated rocks, already discussed in Part I, the author would like to add to the scrutiny of the conception of the mineral facies the following.

The idea that the dry or hydroxyl-bearing compositions of the minerals of the magmatic rocks result from differences in the water content of the magma itself is of old standing. This idea has been theoretically applied to the metamorphic rocks as well (Dunn, p. 20; Ramberg, p. 22). The same idea has been brought into the field of experimental study by Yoder (1952, 1955), and simultaneously it has become a touchstone of the mineral facies principle. Instead of the original definition (Eskola), according to which the water is ubiquitously present and therefore neglected in regard to its influence on the phase equilibria, Yoder considers the matter in precisely the opposite way. In the interpretation of his results, he draws, in regard to the principle, the following conclusions. In metamorphic rocks, the different mineral facies (critical assemblages) primarily depend upon the bulk composition, and not on different PT-conditions, as assumed by the supporters of the "classical" mineral facies conception. Furthermore (Yoder, 1952, p. 616): "It is necessary, therefore, to construct a new facies classification based on a fixed composition, or on several independent compositions, particularly sensitive to temperature and pressure." Eskola (1957, pp. 112—113), when discussing the mineral facies of charnockites, criticized the views of Yoder, by stating that in some cases the deficiency in water, in others the high temperature, results in the granulite facies, but that also the importance of high pressure in the development of this mineral facies is beyond doubt.

From the point of view of the mineral facies principle, the established fields of the bulk chemistry within the WUC are represented, independently of the genesis of the rocks, by the same mineral parageneses exclusively and by the same special properties of the different mineral species. This gives us the right to conclude that the PT-conditions governed have been constant. On the other hand, the deviations from the prevalent paragenetic rules are not accompanied by deviations in the bulk composition, particularly as regards the rocks of the marginal parts of the complex materially still belonging to the rocks of the complex (for instance, Nos. 23 and 68). In other words, the total of the observations is in agreement with the statements of the mineral facies principle. Furthermore, the lamellae of the pyroxenes (the mutual solubility of diopside and hypersthene) and the occurrence of the hair-perthite (as well as probably monoclinic symmetry) in the potash feldspar, according to the experimental findings, indicate an elevated temperature, the highest, perhaps, of the mineral facies scheme. Besides these "thermometers", there occur MgFe-phases whose bulk is represented by dry minerals. Biotite and hornblende are remarkably low in hydroxyl, too. Therefore, it seems possible that the deficiency in water is mainly a result of higher temperature and does not represent an indicator of an accidental dryness of the original supracrustal material. There is nothing surprising in the igneous-like rocks being poor in water, because the anatectic products of an already dried material must be likewise dry.

Yoder's statements seem to agree, in a limited sense, with the behavior of the hornblende and biotite of the WUC, because the stability of these minerals is mainly controlled expressly by the deficiency in water and by the silica content of the bulk composition of the rocks. In the MeiDi gneisses (Fig. 23), the presence or absence of certain crystalline phases is likewise an obvious result of the different bulk compositions. On the other hand, however, equally obvious is also the fact that (CO_2 appearing in excess) the hydrostatic pressure has been a condition necessary for the phase equilibria attained (p. 87). Because, contemporaneously, there are also hints of the direct influence of stress (p. 91), the importance of the pressure to the genesis of the rocks of the WUC must not be underestimated.

On the basis of experience, a more or less adequate picture may be obtained of the physico-chemical conditions under which the crystalline phases have become stable. This picture, however, does not yet explain the primary cause of, for instance, the reverse order of crystallization of hypersthene, hornblende, and biotite. The answer to this question possibly may be obtained from the field of crystal chemistry, or on the basis of the energetic properties of the mineral structures here under consideration. This kind of thinking may approximately be explained as follows. Certain elements incorporated in the structure energetically either strengthen or weaken it, depending upon the individual atomic properties. Thus the large Ca^{2+} ion, which does not belong to the structure of the orthorhombic pyroxene, if occurring in this structure, pushes the chains farther away from each other to decrease its bonding potential. Therefore the calcian hypersthene becomes stable at a lower temperature than a calcium-free hypersthene. Hornblende and biotite, on the other hand, by the deficiency in the OH^- anions and by an increase in cations of high E-values, get their structures strengthened. Therefore they become stable at a higher temperature than usual. Possibly, accordingly the observation could be explained that if silica is present in excess, the more stable CaMg-pyroxene will be formed, instead of hornblende. In principle, it is, consequently, worthwhile, in connection with the paragenetical discussion, to remember that differences in the stability of the same mineral species may be influenced by the accessory elements as well.

To return to Yoder's demand to establish an exact system based on fixed composition, instead of a relative facies classification, the present author would like to make the following remark. In contrast to the sterile environment of the laboratory, the natural rocks, in regard to their main and accessory components, involve us in several complications. Therefore, as far as the phase equilibria are concerned, all these components must necessarily be considered.

WEST UUSIMAA COMPLEX WITH RESPECT TO CHARNOCKITE PROBLEM

Petrographically, among the rocks of the WUC, rock types are represented that have sufficient properties in common with the charnockites to be classed together with this group. Regarding the mode of origin, some of these rock types may be interpreted as being magmatic, while others are metamorphic. Neither is a metasomatic interpretation impossible in a limited sense. Hence, all the main lines of the genetical interpretations may there be simultaneously adopted within the same lithologic environment, and the rock types here in question form part of a petrographical and petrochemical unit. Thus this is the answer of the WUC to the general title of Part I. At the same time, this is also an affirmation of the statement that the mode of origin is not suited to serve as an essential criterion for the definition of charnockite. On the other hand, if taking the mineral facies principle as a guide, both the charnockites and the non-charnockitic rocks of the WUC prove themselves to belong to the same petrographic unit, the mineral assemblages of which have attained their equilibria under the conditions of the granulite facies. Continuing on the same basis, the charnockite problem as a whole may be inserted into the same frames, including all occurrences. This simplifying procedure nowise damages the conception regarding the mode of origin of the rock itself.

Table 1. List of material (WUC)

No.	Rock	Mineralogy		Photo-micrograph	Volatiles	Chemistry				Sampling No.	Locality
		Constituents	Optic. determ.			Mineral	Rock	Trace elem.	Analyst		
1	Fine-grained Hy granite (Acid chr.)	Pla$_{\mathrm{An}_{25}}$, Pfs, Qua, Bi, Hy; Ma, Ap, Zr.	Hy, Bi		Bi		+	+	Elsa Ståhlberg, 1938 Kauko Parras, 1945	27/KP 1938	Kotkaniemi, Vihti
2	Hy granite (Acid chr.)	Pla$_{\mathrm{An}_{23}}$, Qua, Pfs, Bi, Hy; Ap, Ma, Zr.					+	+	Lauri Lokka, 1943 K. Parras, 1945	474/KP 1937	Valkinmaa, Nummi
3	Hy quartz diorite (Intermed. chr.)	Pla$_{\mathrm{An}_{30}}$, Qua, Hy, Bi; Ma, Ap, Zr.	Hy, Bi		Bi	Bi	+	+	L. Lokka, 1940 Pentti Ojanperä, 1946 K. Parras, 1945	11/KP 1936	Hyypiänmäki, Nummi
4	»	Pla$_{\mathrm{An}_{37}}$, Qua, Bi, Hy; Ap, Ma, Zr.						+	K. Parras, 1945	726/KP 1937	Vanjärvi, Vihti
5	Hy diorite (Basic chr.)	Pla$_{\mathrm{An}_{30}}$, Hy, Bi, Mi, Ho; Qua, Ma, Ap.	Hy, Ho, Bi		Ho		+	+	L. Lokka, 1943 K. Parras, 1945	59e/KP 1936	Vivola, Nummi
6	Leucocratic Hy granodiorite (Acid chr.)	Pla$_{\mathrm{An}_{30}}$, Qua, Mi, Hy, Bi; Ap, Zr.						+	K. Parras, 1945	166/KP 1937	Suittila, Lohja
7	Hy quartz diorite (Intermed. chr.)	Pla$_{\mathrm{An}_{35}}$, Qua, Hy, Bi, Pfs; Ap, Ma.	Hy, Bi		Bi	Hy			P. Ojanperä, 1938	16/KP 1938	Kotkaniemi, Vihti
8	»	Pla$_{\mathrm{An}_{33}}$, Qua, Hy, Bi, Pfs; Ap, Ma.	Hy, Bi							49/KP 1938	Suontaka, Vihti
9	Fine-grained quartz norite (Intermed. chr.)	Pla$_{\mathrm{An}_{55}}$, Hy, Qua; Ma.	Hy				+	+	L. Lokka, 1945 K. Parras, 1945	65/KP 1938	Kourla, Vihti
10	Hy quartz diorite (Intermed. chr.)	Pla$_{\mathrm{An}_{37}}$, Hy, Qua, Bi; Ap, Ma.	Hy, Bi		Bi					534/KP 1938	Vihtijärvi, Vihti
12	Px granodiorite (Intermed. chr.)	Pla$_{\mathrm{An}_{38}}$, Qua, Hy, Bi, Di; Ap, Ma.	Hy, Di, Bi				+	+	E. Ståhlberg, 1938 K. Parras, 1945	172/KP 1938	Kirvelä—Korppila, Vihti
13	Px quartz diorite (Intermed. chr.)	Pla$_{\mathrm{An}_{34}}$, Qua, Bi, Hy, Di; Ma, Ap, Zr.	Hy, Di, Bi				+	+	E. Ståhlberg, 1938 K. Parras, 1945	419/KP 1937	Papinsaari, Vihti
14	Di quartz diorite (Intermed. chr.)	Pla$_{\mathrm{An}_{28}}$, Bi, Qua, Di; Ap.	Di, Bi		Bi		+	+	E. Ståhlberg, 1938 K. Parras, 1945	206/KP 1938	Kourla, Vihti
15	Px granodiorite (Intermed. chr.)	Pla$_{\mathrm{An}_{30}}$, Mi, Qua, Di, Hy; Ap.						+	K. Parras, 1945	158a/KP 1936	Varttila, Nummi
16	Px diorite (Basic chr.)	Pla$_{\mathrm{An}_{50}}$, Hy, Di, Bi; Ma, Ap.					+	+	L. Lokka, 1943 K. Parras, 1945	259/KP 1936	Järvenpää, Nummi

No.	Rock	Mineralogy		Photo-micrograph	Volatiles	Chemistry				Sampling No.	Locality
		Constituents	Optic. determ.			Mineral	Rock	Trace elem.	Analyst		
17	Hy gneiss (Intermed. parachr.)	Pla$_{\text{An}_{40}}$, Qua, Bi, Hy; Ap, Ma, Zr.	Hy, Bi		Bi		+	+	E. Ståhlberg, 1939 K. Parras, 1945	720/KP 1937	Vanjärvi, Vihti
18	Hy gneiss (Intermed. parachr.)	Pla$_{\text{An}_{37}}$, Qua, Hy, Bi; Ma, Ap.	Hy			Hy			P. Ojanperä, 1945	236/KP 1937	Vanhakylä, Lohja
19	Hy gneiss (Intermed. parachr.)	Pla$_{\text{An}_{40}}$, Bi, Qua, Hy; Ma, Zr.	Hy, Bi		Bi			+	K. Parras, 1945	643/KP 1937	Vanjoki, Vihti
20	Hy gneiss (Intermed. parachr.)	Pla$_{\text{An}_{38}}$, Hy, Bi, Qua; Ma, Ap, Zr.	Hy, Bi					+	K. Parras, 1945	763/KP 1937	Vanhala, Vihti
22	Hy gneiss (Intermed. parachr.)	Pla$_{\text{An}_{44}}$, Qua, Hy, Bi; Ap, Ma.	Hy, Bi					+	K. Parras, 1945	51/KP 1938	Kotkanniemi, Vihti
23	Quartz-bearing HyHo gneiss (From SW boundary of WUC)	Pla$_{\text{An}_{37}}$, Qua, Ho, Bi, Hy; Ap, Ma, Zr.	Hy, Ho, Bi		Bi Ho		+	+	H. Lönnroth, 1939 K. Parras, 1945	212/EM 1936	Paikkarin torppa, Sammatti
24	Px gneiss (Intermed. parachr.)	Pla$_{\text{An}_{35}}$, Qua, Bi, Hy, Di; Ma, Ap, Zr.	Hy, Bi				+	+	E. Ståhlberg, 1939 K. Parras, 1945	715/KP 1937	Vanjärvi, Vihti
25	Px gneiss (Intermed. parachr.)	Pla$_{\text{An}_{38}}$, Qua, Hy, Di, Pfs, Bi; Ma, Ap, Zr.		+			+	+	L. Lokka, 1943 K. Parras, 1945	1e/KP 1936	Huhti, Nummi
26	Px gneiss (Basic parachr.)	Pla$_{\text{An}_{55}}$, Hy, Bi, Di; Qua, Ma.		+			+	+	P. Ojanperä, 1940 K. Parras, 1945	22/KP 1936	Tavola, Nummi
27	Px gneiss (Intermed. parachr.)	Pla$_{\text{An}_{45}}$, Bi, Pfs, Hy, Di; Ho, Qua, Ap,Zr.					+	+	L. Lokka, 1943 K. Parras, 1945	22/EM 1937	Karkalinniemi, Karjalohja
28	PlaBiDi gneiss (Paracharnockitic)	Pla$_{\text{An}_{44}}$, Qua, Di, Bi, Mi; Grf, Ap, Zr.	Di, Bi		Bi		+	+	E. Ståhlberg, 1940 K. Parras, 1945	450/KP 1937	Paksalo, Lohja
29	BiDi gneiss (Paracharnockitic)	Pla$_{\text{An}_{40}}$, Di, Mi, Bi; Sph, Cal, Grf, Ap.					+	+	L. Lokka, 1945 K. Parras, 1945	557/KP 1937	Kirkonkylä, Vihti
30	MiPlaDi gneiss (Siliceous)	Qua, Mi, Pla$_{\text{An}_{55}}$, Di; Sph, Cal, Grf, Zr.	Di				+	+	E. Ståhlberg, 1940 K. Parras, 1945	58a/KP 1938	Suontaka, Vihti
31	PlaMiDi gneiss (Siliceous)	Qua, Pla$_{\text{An}_{40}}$, Mi, Di; Cal, Sph, Ma, Zr.	Di				+	+	E. Ståhlberg, 1940 K. Parras, 1945	515/KP 1938	Vihtijärvi, Vihti
32	MiPlaDi gneiss	Mi, Pla$_{\text{An}_{33}}$, Di, Qua; Sph, Ma, Cal, Grf.						+	K. Parras, 1945	154b/KP 1937	Suittila, Lohja
33	MeiDi gneiss (Siliceous)	Qua, Mei, Di, Cal; Pla$_{\text{An}_{46}}$, Sph,Mi, Zr.	Di, Mei				+	+	E. Ståhlberg, 1940 K. Parras, 1945	782/KP 1937	Ahmo, Pyhäjärvi, U. L.
34	MeiDi gneiss (Siliceous)	Qua, Di, Mei, Pla$_{\text{An}}$?; Cal, Sph, Grf, Ap, Zr.	Di, Mei							8/KP 1936	Hyvelä, Nummi

Table 1 (cont.)

No.	Rock	Mineralogy		Photo-micrograph	Volatiles	Chemistry				Sampling No.	Locality
		Constituents	Optic. determ.			Min-eral	Rock	Trace elem.	Analyst		
35	MeiMiDi gneiss (Siliceous)	Qua, Di, Mei, Mi; Sph, Ma, Grf, Zr.	Di, Mei							108/KP 1936	Retlahti, Nummi
36	MeiDi gneiss	Mei, Di, Qua, Pla$_{An}$?; Sph, Cal, Grf.	Di, Mei			Di		+	K. Parras, 1945	182b/KP 1937	Paksalo, Lohja
37	MeiDi gneiss (Siliceous)	Qua, Di, Mei, Mi; Pla$_{An}$?, Cal, Sph, Zr.	Di, Mei							551/KP 1938	Vihtijärvi, Vihti
38	MeiDi gneiss (Siliceous)	Qua, Di, Mei, Cal; Pla$_{An}$?, Sph, Zr.	Mei							711a/KP 1938	Haavisto, Pyhäjärvi, U. L.
39	MeiDi gneiss	Di, Mei, Mi, Qua, Cal; Sph, Grf.	Mei	+						109b/KP 1938	Kourla, Vihti
40	PlaDi gneiss (Siliceous)	Pla$_{An_{50}}$, Qua, Di, Cal; Sph, Grf, Ap, Zr.	Di				+	 +	P. Ojanperä, 1940 K. Parras, 1945	189c/KP 1936	Oinola, Nummi
41	PlaDi gneiss	Pla$_{An_{63}}$, Di, Qua; Sph, Ap, Grf, Bi.	Di, Bi				+	 +	H. Lönnroth, 1938 K. Parras, 1945	340b/KP 1936	Kettula, Suomusjärvi
42	PlaDi gneiss	Pla$_{An_{34}}$, Di, Qua, Mi; Sph, Ma, Bi.	Di							204a/KP 1937	Karnainen, Lohja
43	Light Px amphibolite (Basic chr.)	Pla$_{An_{62}}$, Di, Ho, Hy; Bi, Ap, Ma.	Hy, Ho, Bi		Ho			+	K. Parras, 1945	206/KP 1936	Huhti, Nummi
44	»	Pla$_{An_{65}}$, Ho, Di, Hy; Bi, Ap, Ma.	Hy, Di, Ho, Bi		Ho Bi		+	 +	L. Lokka, 1943 K. Parras, 1945	292/KP 1936	Leikkilä, Sammatti
45	Medium-grained noritic rock (Basic chr.)	Pla$_{An_{40}}$, Di, Hy, Bi; Ho, Ap, Ma.					+	 +	L. Lokka, 1943 K. Parras, 1945	87/KP 1937	Sitarla, Nummi
46	Light Px amphibolite (Basic chr.)	Pla$_{An_{45}}$, Hy, Ho, Di; Ma.	Hy, Di, Ho		Ho			+	K. Parras, 1945	491/KP 1938	Lappajärvi, Suomusjärvi
47	MeiDi amphibolite	Di, Cal, Mei, Ho; Sph, Ma.	Di, Ho, Mei				+	 +	E. Ståhlberg, 1939 K. Parras, 1945	184/KP 1937	Salo, Nummi
48	MeiDi amohibolite	Di, Mei, Cal, Ho; Pla$_{An}$?, Sph, Ap.	Di, Ho, Mei	+	Ho			+	K. Parras, 1945	25/KP 1937	Sitarla, Nummi
49	Di amphibolite	Ho, Di, Pla$_{An_{50}}$; Bi, Ma, Sph.	Di, Ho		Ho		+	 +	L. Lokka, 1944 K. Parras, 1945	95/KP 1937	Näkkilä, Nummi
50	MeiDi rock	Di, Mei, Cal; Pla$_{An}$?, Sph, Ma.	Di, Mei					+	K. Parras, 1945	362/KP 1937	Röylä, Lohja

No.	Rock	Mineralogy		Photo-micrograph	Volatiles	Chemistry				Sampling No.	Locality
		Constituents	Optic. determ.			Mineral	Rock	Trace elem.	Analyst		
51	Di amphibolite	Di, Ho, Pla$_{An60}$; Sph, Ma, Ap.	Di, Ho		Ho			+	K. Parras, 1945	111a/EM 1936	Laidike, Suomusjärvi
52	Di amphibolite	Ho, Di; Pla$_{An65}$, Ma.	Di, Ho		Ho	Ho		 +	P. Ojanperä, 1946 K. Parras, 1945	377/KP 1937	Niemenkylä, Vihti
53	Lutogenite	Pla$_{An20}$, Crd, Qua, Mi, Gar, Bi, Sill, Grf, Ma, Zr.	Gar, Bi		Bi	Gar	 +	 +	H. Lönnroth, 1939 L. Lokka, 1943 K. Parras, 1945	3/KP 1936	Huhti, Nummi
55	»		Gar, Bi							124/KP 1936	Nummen kylä, Nummi
56	»		Gar							68/KP 1936	Yli-Immola, Nummi
57	»	Pla$_{An23}$, Crd, Qua, Gar, Bi, Mi; Sill, Zr, Grf.	Gar				+	 +	H. Lönnroth, 1939 K. Parras, 1945	207/EM 1936	Haarjärvi, Sammatti
58	»	Mi, Gar, Crd, Qua, Pla$_{An17}$, Bi; Sill, Ma, Spi, Zr, Grf.	Gar							44/KP 1937	Koski, Lohja
59	»	Pla$_{An20}$, Crd, Gar, Qua, Mi; Bi, Grf, Spi, Zr.	Gar							178a/KP 1937	Paksalo, Lohja
60	»	Pla$_{An25}$, Crd, Mi, Qua, Gar, Bi; Sill, Grf, Ma, Zr.	Gar					+	K. Parras, 1945	412/KP 1937	Haapakylä, Vihti
62	»	Pla$_{An33}$, Qua, Bi, Gar; Mi, Spi, Ma, Zr.	Gar, Bi		Bi					563/KP 1937	Vanjärvi, Vihti
63	»	Pla$_{An30}$, Qua, Gar, Bi; Crd, Grf.	Gar, Bi		Bi	Gar			P. Ojanperä, 1945	861/KP 1937	Suomela, Pusula
64	»	Qua, Gar, Pla$_{An30}$, Mi; Bi, Grf, Zr.	Gar							409/KP 1937	Haapakylä, Vihti
65	»	Pla$_{An28}$, Qua, Pfs, Gar, Crd; Bi, Zr.	Gar, Bi		Bi					447/KP 1938	Haimoo, Vihti
66	»	Pfs, Qua, Gar, Pla$_{An25}$; Ma, Zr.	Gar, Bi							457a/KP 1938	Nummenpää, Nurmijärvi
67	Crd leptite (Derivative of lutogenite)	Mi, Crd, Qua, Bi, Pla$_{An20}$; Zr.					+	 +	H. Lönnroth, 1939 K. Parras, 1945	300/EM 1937	Paavola, Lohja

Table 1 (cont.)

No.	Rock	Mineralogy		Photo-micrograph	Volatiles	Chemistry				Sampling No.	Locality
		Constituents	Optic. determ.			Mineral	Rock	Trace elem.	Analyst		
68	Ho quartz diorite (Non-charnockitic)	Pla$_{An35}$, Qua, Ho, Bi, Di; Ap.					+	+	L. Lokka, 1945 K. Parras, 1945	763/KP 1938	Haavisto, Pyhäjärvi, U. L.
70	Lutogenite		Gar							33a/KP 1936	Hyvelä, Nummi
72	Amphibolite	Ho, Pla$_{An65}$; Ma.	Ho		Ho					41a/NO 1936	
73	Di amphibolite	Ho, Di, Pla$_{An62}$; Ma.	Di, Ho							124/EM 1936	
76	Mi granite		Gar							8/KP 1937	
77	Hy quartz diorite (Intermed. chr.)	Pla$_{An30}$, Hy, Qua, Bi; Pfs, Ma, Ap, Zr.	Hy, Bi							195/KP 1937	Kutsila, Lohja
81	Calc-gneiss	Cal, Wo, Mi, Di, Qua; (Pla?), Sph, Ep.	Di			Di			P. Ojanperä, 1945	168/KP 1938	Kirvelä-Korppila, Vihti
84	Mi granite		Gar							25/EH 1938	
85	Lutogenite		Gar							79/EH 1938	
86	»		Gar							110/EH 1938	
87	»		Gar							117/EH 1938	
88	»		Gar							278/EH 1938	
89	GarCrd granite		Gar							283a/EM 1939	
90	MeiDi gneiss (Siliceous)	Qua, Mei, Mi, Di, Cal; Pla$_{An}$?, Sph, Grf, Zr.	Di, Mei							15-B$_3$/681/38, KP 1943	Haavisto, Pyhäjärvi, U. L.
91	Lutogenite		Gar							16b/548/37, KP 1943	Kirkkojärvi, Vihti
92	»		Gar							29d/65/38, KP 1943	Kirjavajärvi, Vihti
93	MeiDi gneiss (Siliceous)	Qua, Mei, Di, Cal; Pla$_{An}$?, Sph, Zr.	Di, Mei							30-C$_{10}$/680/38, KP 1943	Haavisto, Pyhäjärvi, U. L.
94	Leucocratic segregation vein in Hy granodiorite	Pla$_{An35}$, Hy, Pfs, Qua; Ap.	Hy, Bi	+	Bi					35a/113/36, KP 1943	Hirvijoki, Pusula
95	Lutogenite		Gar							38/67/36, KP 1943	Koski, Lohja
96	Mi granite		Gar							43$_1$/110/37, KP 1943	Paksalo, Lohja

No.	Rock	Mineralogy		Photo-micrograph	Volatiles	Chemistry				Sampling No.	Locality
		Constituents	Optic. determ.			Mineral	Rock	Trace elem.	Analyst		
97	Mi Granite		Gar							43$_2$/110/37, KP 1943	Paksalo, Lohja
98	Lutogenite		Gar							43$_3$/110/37, KP 1943	Paksalo, Lohja
99	»		Gar			Gar			P. Ojanperä, 1945	44a/170/36, KP 1943	Oinola, Nummi
100	»		Gar							44b/170/36, KP 1943	»
101	»		Gar							44c/170/36, KP 1943	»
102	Fine-grained Px amphibolite	Ho, Hy, Di, Pla$_{An65}$; Ma.	Ho		Ho					45b/197/36, KP 1943	»
103	Mi granite		Gar							47/138/36, KP 1943	Mommola, Nummi
104	Mi granite (average mixture from 12 samples)	Mi, Qua, Pla$_{An18}$, Gar; Bi, Ap, Ma.					+		P. Ojanperä, 1946	KP 1936-1939	WUC
105	Amphibiolite (Interstratified in lutogenite)	Pla$_{An35}$, Ho; Bi, Zr.					+		P. Ojanperä, 1953	1887/01 I 25, KP 1953	Tytyri, Lohja
106	GarHy gneiss (Intermed. parachr.)	Pla$_{An22}$, Gar, Qua, Bi, Hy; Ma, Ap, Zr.					+		»	1888/01 I 25, KP 1953	»
107	Bi-rich Hy gneiss (Intermed. parachr.)	Pla$_{An35}$, Bi, Hy, Gar, Qua; Ma, Ap, Zr.					+		»	1890/01 I 25, KP 1953	»
108	GarHy gneiss (Basic parachr.)	Pla$_{An22}$, Gar, Hy, Bi; Ma, Qua, Ap, Zr.					+		»	1891/01 I 25, KP 1953	»
110	Limestone (average mixture from 7 samples)	Cal; Acc.						+	K. Parras, 1945	KP 1936-1939	WUC
111	Ultrabasic rock	Amf, Ol; Ma, Bi.						+	»	61/KP 1936	Oinola, Nummi
116	Leucocratic Hy quartz diorite (Intermed. chr.)	Pla$_{An30}$, Qua; Hy, Bi, Pfs, Ap.						+	»	9/KP 1936	Hyvelä, Nummi
127	Fine-grained quartz norite	Pla$_{An55}$, Hy, Di; Bi, Qua, Ma.						+	»	76/KP 1938	Kourla, Vihti

Table 1 (cont.)

No.	Rock	Mineralogy		Photo-micrograph	Volatiles	Chemistry				Sampling No.	Locality
		Constituents	Optic. determ.			Min-eral	Rock	Trace elem.	Analyst		
129	Fine-grained Px gneiss (Intermed. parachr.)	Pla$_{An46}$, Hy, Di, Qua; Bi, Ma.						+	K. Parras, 1945	306/KP 1938	Tuohilampi, Vihti
132	Hy gneiss (Intermed. parachr.)	Pla$_{An40}$, Qua, Hy, Bi; Pfs, Ma, Ap, Zr.						+	»	573/KP 1937	Vanjärvi, Vihti
134	Hy gneiss (Intermed. parachr.)	Pla$_{An}$?, Bi, Qua, Hy; Ap, Zr.						+	»	50c/EM 1937	Pipola, Karja-Lohja
135	Px gneiss (Basic parachr.)	Pla$_{An40}$, Di, Bi, Hy; Ma, Qua.						+	»	439a/KP 1936	Luskela, Sammatti
136	PlaDi gneiss	Pla$_{An}$?, Di, Qua, Bi; Ap, Ma.						+	»	A. Simonen, 1939	Esbo
138	Px gneiss (Basic parachr.)	Pla$_{An40}$, Hy, Bi, Di; Qua, Ap, Ma.						+	»	666/KP 1937	Suksela, Vihti
140	Px gneiss (Basic parachr.)	Pla$_{An45}$, Di, Hy, Ho; Bi, Ma.						+	»	171/KP 1938	Kirvelä-Korppila, Vihti
142	Fine-grained quartz noritic rock.	Pla$_{An43}$, Hy, Di, Qua; Bi, Ap, Ma.						+	»	502/KP 1938	Korpi, Nurmijärvi
146	PlaBiDi gneiss	Pla$_{An37}$, Di, Qua, Bi; Grf, Ap, Zr.						+	»	340c/KP 1936	Kettula, Suomusjärvi
149	BiDi gneiss	Di, Qua, Bi, Pla$_{An}$?, Mi; Ap, Ma, Zr.						+	»	641/VP 1936	Karkalinniemi, Karjalohja
150	»	Di, Bi, Qua, Pla$_{An}$?, Mi; Ap, Grf, Zr.						+	»	136b/EM 1936	Siitojärvi, Suomusjärvi
153	MiDi gneiss	Mi, Di, Pla$_{An35}$, Qua; Sph, Grf, Ap.						+	»	748/KP 1937	Suksela, Vihti
155	HoDi gneiss	Pla$_{An60}$, Di, Ho, Mi; Qua, Ap, Ma.						+	»	169/KP 1938	Kirvelä—Korppila, Vihti
156	Di gneiss (Granitized)	Pla$_{An30}$, Qua, Mi, Di, Bi; Ap, Ma.						+	»	728/KP 1938	Haavisto, Pyhäjärvi, U. L.
159	MeiDi gneiss (Siliceous)	Qua, Mi, Di, Mei, Pla$_{An32}$; Cal, Sph, Zr.		+				+	»	913/KP 1937	Hirvijoki, Pusula

No.	Rock	Mineralogy: Constituents	Mineralogy: Optic. determ.	Photo-micrograph	Volatiles	Chemistry: Mineral	Chemistry: Rock	Chemistry: Trace elem.	Chemistry: Analyst	Sampling No.	Locality
162	PlaDi gneiss	Pla$_{An35}$, Di, Qua; Sph, Mi, Ap, Grf.						+	K. Parras, 1945	449b/KP 1937	Paksalo, Lohja
----											
167	Light Px amphibolite (Basic chr.)	Pla$_{An45}$, Di, Hy, Ho, Bi; Ap, Ma.						+	»	219/KP 1936	Leikkilä, Sammatti
168	»	Pla$_{An70}$, Di, Ho, Hy; Ma, Ap.						+	»	66/KP 1937	Pälölä, Nummi
169	»	Pla$_{An45}$, Di, Ho, Hy; Bi, Ma.						+	»	87/KP 1937	»
170	»	Pla$_{An62}$, Di, Hy, Ho; Ap, Ma.						+	»	299/KP 1937	Vaanila, Lohja
171	»	Pla$_{An40}$, Hy, Di, Ho; Bi, Ap, Ma.						+	»	109a/KP 1938	Kourla, Vihti
172	»	Pla$_{An40}$, Di, Hy, Ho; Bi, Ap, Ma.						+	»	489/KP 1938	Lappajärvi, Nurmijärvi
173	»	Pla$_{An45}$, Hy, Di, Ho; Ma.						+	»	251/EM 1936	Karstu, Lohja
174	Dark Di amphibolite	Di, Ho, Pla$_{An}$?; Cal, Sph, Ap, Ma.						+	»	126/KP 1936	Oinola, Nummi
----											
177	Di granodiorite (Intermed. chr.)	Pla$_{An33}$, Qua, Bi, Mi, Di; Ap, Ma.						+	»	769/KP 1938	Haavisto, Pyhäjärvi, U. L.
178	Ho gneiss (Non-chr. type from N boundary of WUC)	Pla$_{An}$?, Ho, Qua, Mi, Bi; Ep, Ma, Ap.						+	»	162/KP 1939	Järvenpää, Pyhäjärvi, U. L.

181	Ho leptite (Non-chr. type from N boundary of WUC)	Pla$_{An}$?, Ho, Ep, Qua; Sph, Chl.						+	»	163/KP 1939	»
182	BiHoPla gneiss (Non-chr. type from N boundary of WUC)	Bi, Pla$_{An}$?, Qua, Ho; Chl, Ma, Ap, Zr.						+	»	168/KP 1939	Tuorila, Pyhäjärvi, U. L.
183	GrsDi gneiss	Qua, Cal, Di, Grs, Mi, Pla$_{An}$?; Sph, Ap.		+						28e/KP 1943	Haimoo, Vihti

Table 2. Main elements and mineralogical composition of rocks (WUC)

No.	1		2		3		5		9		12		13		14		16	
	Weight	Cation	W	C	W	C	W	C	W	C	W	C	W	C	W	C	W	C
	%																	
SiO$_2$	70.32	65.47	70.52	64.89	61.28	57.60	51.35	47.75	57.73	56.87	65.48	62.87	64.00	60.35	62.14	58.28	50.10	46.57
AlO$_{3/2}$	16.32	17.91	17.45	18.92	17.15	18.99	20.02	21.94	12.53	14.55	16.89	19.11	13.97	15.52	16.41	18.13	19.42	21.27
FeO$_{3/2}$	0.58	0.41	0.13	0.09	1.12	0.79	0.21	0.15	0.40	0.30	0.84	0.61	0.96	0.68	1.08	0.76	0.36	0.25
FeO	1.37	1.07	0.71	0.55	5.08	3.99	9.22	7.17	14.40	11.86	3.71	2.98	5.69	4.49	3.49	2.74	8.14	6.32
MnO	0.03	0.02	0.02	0.02	0.09	0.07	0.13	0.10	0.08	0.07	0.08	0.06	0.12	0.10	0.08	0.06	trace	—
MgO	0.49	0.68	0.35	0.48	1.45	2.03	3.04	4.21	3.44	5.05	1.19	1.70	1.30	1.82	3.02	4.22	5.03	6.96
CaO	2.64	2.63	3.08	3.03	4.99	5.02	6.57	6.55	6.63	6.99	5.90	6.07	6.10	6.16	5.84	5.86	8.44	8.40
NaO$_{1/2}$	4.05	7.31	5.38	9.52	4.41	8.03	3.86	6.95	1.11	2.12	0.69	1.29	4.14	7.56	3.93	7.14	3.49	6.28
KO$_{1/2}$	3.62	4.30	1.80	2.11	1.99	2.39	2.81	3.33	0.13	0.16	3.96	4.85	2.01	2.42	1.94	2.32	1.10	1.30
TiO$_2$	0.28	0.20	0.18	0.13	1.40	0.99	1.85	1.30	2.63	1.95	0.63	0.46	1.10	0.78	0.62	0.44	3.33	1.30
PO$_{5/2}$	n. d.	—	0.24	0.19	0.13	0.10	0.70	0.55	0.09	0.08	n. d.	—	0.15	0.12	0.06	0.05	0.41	0.32
H$_2$O +	0.56	(1.73)	0.27	(0.83)	0.61	(1.91)	0.34	(1.06)	0.59	(1.93)	0.60	(1.92)	0.96	(3.02)	0.84	(2.62)	0.41	(1.27)
H$_2$O —	0.08	—	0.10	—	0.11	—	0.05	—	0.11	—	0.12	—	0.16	—	0.26	—	0.06	—
Total	100.34	100.00	100.23	100.00	99.81	100.00	100.15	100.00	99.87	100.00	100.09	100.00	100.66	100.00	99.71	100.00	100.29	100.00
Trace elem.	See Table 4																	
	Volume %																	
Planimetric analysis	Pla $_{An25}$	41.0	Pla $_{An23}$	64.8	Pla $_{An30}$	72.0	Pla $_{An30}$	62.4	Pla $_{An55}$	44.0	Pla $_{An38}$	57.0	Pla $_{An34}$	63.0	Pla $_{An28}$	67.3	Pla $_{An50}$	64.6
	Pfs	28.0	Qua	26.0	Qua	26.0	Hy	18.0	Hy	26.0	Qua	32.5	Qua	10.0	Bi	12.7	Hy	21.0
	Qua	25.0	Pfs	4.5	Hy	8.4	Bi	7.8	Qua	25.0	Hy	5.5	Bi	9.5	Qua	11.3	Di	4.0
	Bi	5.0	Bi	3.0	Bi	5.0	Pfs(Mi)	4.5	Ma	5.0	Bi	2.5	Hy	7.2	Di	8.0	Bi	3.6
	Hy	0.8	Hy	1.3	Acc	2.3	Ho	2.5			Di	2.0	Di	7.0	Acc	0.7	Acc	6.7
	Acc	0.2	Acc	0.4			Qua	1.0			Acc	0.5	Acc	3.3				
							Acc	3.8										
	Total	100.0		100.0		100.0		100.0		100.0		100.0		100.0		100.0		100.0
Grain size mm	Felsic	1.0 -1.5	Felsic	1.0 -5.0	Felsic	1.0 -3.0	Pla	2.0 -5.0	Felsic	0.3 -0.6	Felsic	1.0 -5.0	Felsic	1.0 -5.0	Felsic	1.0 -4.0	Pla	1.5 - 5.0
	Mafic	0.5 -1.0	Mafic	1.0 -1.5	Mafic	1.0 -1.5	Mafic	1.0 -5.0	Hy	0.5 -2.0	Mafic	0.5 -1.5	Mafic	1.0 -2.0	Mafic	0.5 -3.0	Mafic	0.5 -10.0
	Acc	0.1 -0.2	Acc	0.1 -0.2	Acc	0.1 -0.2	Acc	0.2 -1.0	Ma	0.1	Acc	0.1	Acc	0.1 -0.5	Acc	0.1 -0.5	Acc	0.1 - 0.3

No.	17		23		24		25]		26		27		28		29		30	
	Weight	Cation	W	C	W	C	W	C	W	C	W	C	W	C	W	C	W	C
	%																	
SiO_2	64.04	62.30	58.91	56.56	64.24	61.21	58.60	55.82	51.60	48.98	52.76	48.81	61.04	58.62	55.28	52.03	67.18	64.78
$AlO_{3/2}$	11.37	13.03	14.24	16.11	15.73	17.66	12.71	14.27	15.93	17.81	20.02	21.82	15.18	17.18	15.77	17.49	11.35	12.90
$FeO_{3/2}$	2.56	1.87	1.96	1.41	1.04	0.74	0.92	0.66	2.81	2.01	0.56	0.39	1.68	1.21	0.40	0.28	0.56	0.41
FeO	7.09	5.77	8.03	6.45	4.11	3.27	10.51	8.37	10.40	8.25	7.16	5.54	4.10	3.29	7.56	5.95	4.10	3.31
MnO	0.07	0.06	0.11	0.09	0.05	0.04	0.10	0.08	0.17	0.14	0.06	0.04	0.07	0.06	0.02	0.02	0.05	0.04
MgO	4.30	6.23	3.32	4.75	2.02	2.87	3.90	5.53	5.00	7.06	4.44	6.12	2.58	3.69	2.98	4.18	1.54	2.21
CaO	4.12	4.29	5.56	5.71	7.36	7.51	5.87	5.99	7.07	7.19	5.15	5.10	8.32	8.55	10.16	10.24	7.84	8.09
$NaO_{1/2}$	2.12	4.00	3.17	5.90	2.94	5.42	2.86	5.28	2.92	5.37	3.04	5.45	2.34	4.35	2.34	4.27	1.21	2.26
$KO_{1/2}$	1.41	1.75	1.53	1.87	0.71	0.86	1.79	2.17	1.76	2.13	4.97	5.86	2.05	2.51	3.85	4.62	3.56	4.38
TiO_2	0.95	0.70	1.20	0.86	0.58	0.42	2.02	1.45	1.13	0.80	0.59	0.41	0.75	0.54	1.11	0.79	0.42	0.31
$PO_{5/2}$	n. d.	—	0.36	0.29	n. d.	—	0.47	0.38	0.33	0.26	0.59	0.46	trace	—	0.17	0.13	n. d.	—
H_2O+	1.57	(5.09)	1.17	(3.74)	1.08	(3.43)	0.39	(1.24)	0.40	(1.27)	0.75	(2.31)	1.68	(5.38)	0.51	(1.60)	1.44	(4.63)
H_2O-	0.35	—	0.26	—	0.08	—	0.04	—	0.13	—	0.17	—	0.28	—	0.13	—	0.24	—
CO_2	n. d.	—	n. d.	—	n. d.	—	n. d.	—	n. d.	—	n. d.	—	n. d.	—	n. d.	—	1.00	1.31
Total	99.95	100.00	99.82	100.00	99.94	100.00	100.18	100.00	99.65	100.00	100.26	100.00	100.07	100.00	100.28	100.00	100.49	100.00
Trace elem.	See Table 4																	
Planimetric analysis	Volume %																	
	Pla$_{An40}$	40.0	Pla$_{An37}$	47.6	Pla$_{An35}$	54.0	Pla$_{An38}$	47.3	Pla$_{An55}$	59.0	Pla$_{An45}$	49.0	Pla$_{An44}$	48.0	Pla$_{An40}$	42.0	Qua	31.0
	Qua	30.0	Qua	18.5	Qua	22.0	Qua	15.3	Hy	16.8	Bi	24.0	Qua	18.5	Di	27.0	Mi	27.5
	Bi	15.0	Ho	11.4	Bi	9.5	Hy	15.3	Bi	10.5	Pfs	13.0	Di	15.0	Mi(Pfs)	21.0	Pla$_{An55}$	22.7
	Hy	14.0	Bi	11.2	Hy	7.7	Di	10.6	Di	5.0	Hy	9.0	Bi	9.2	Bi	8.6	Di	16.0
	Acc	1.0	Hy	10.3	Di	6.0	Pfs	6.7	Qua	5.0	Di	4.0	Mi	8.0	Sph	0.3	Sph	1.3
			Acc	1.0	Acc	0.8	Bi	1.4	Acc	3.7	Ho	0.4	Acc	1.3	Cal	0.1	Cal	0.6
							Acc	3.4			Qua	0.1			Qua	0.1	Acc	0.5
											Acc	0.5			Acc	0.9		
	Total	100.0		100.0		100.0		100.0		100.0		100.0		100.0		100.0		100.0
Grain size mm	Felsic	0.5 -1.5	Pla	0.5 -2.0	Felsic	0.5 -2.0	Felsic	0.5 -3.0	Felsic	0.5 - 1.5	Pla	1.0 -5.0	Felsic	1.0 -2.0	Felsic	0.5 -1.5	Felsic	0.5 -1.5
	Mafic	0.5 -4.0	Mafic	1.0 -5.0	Mafic	0.5 -3.0	Mafic	0.5 -3.0	Mafic	0.5 -10.0	Mafic	0.5 -5.0	Mafic	0.5 -1.5	Mafic	0.5 -1.5	Di	0.5 -1.5
	Acc	0.1	Acc	0.1	Acc	0.1 -0.5	Acc	0.1 -0.5	Acc	0.1 - 0.5	Acc	0.1	Gra	0.5 -2.0	Acc	0.1 -0.5	Sph	0.1 -0.3
													Ap	0.1 -0.2			Ap	0.05

Table 2 (cont.)

No.	31		33		40		41		44		45		47		49		53	
	Weight	Cation	W	C	W	C	W	C	W	C	W	C	W	C	W	C	W	C
	%																	
SiO_2	67.78	64.11	68.14	65.98	60.24	57.07	60.92	58.21	48.02	44.59	50.51	47.51	35.80	33.46	37.46	34.84	68.41	65.40
$AlO_{3/2}$	10.18	11.34	10.53	12.01	13.04	14.56	14.50	16.33	22.11	24.19	17.53	19.43	10.26	11.30	7.23	7.93	15.70	17.68
$FeO_{3/2}$	0.08	0.06	0.60	0.44	1.30	0.93	0.72	0.52	0.20	0.14	1.36	0.96	1.12	0.79	0.92	0.64	0.52	0.37
FeO	3.16	2.50	2.53	2.05	5.88	4.65	5.40	4.32	8.28	6.43	9.22	7.25	6.84	5.34	6.62	5.14	5.83	4.66
MnO	0.08	0.06	0.07	0.06	0.10	0.08	0.11	0.09	0.07	0.06	0.13	0.10	0.14	0.11	0.09	0.07	0.04	0.03
MgO	0.80	1.12	1.10	1.59	2.95	4.17	1.79	2.55	4.14	5.72	3.02	4.23	5.26	7.33	4.42	6.12	3.09	4.40
CaO	9.32	9.45	10.88	11.28	11.01	11.17	12.65	12.95	11.76	11.69	11.18	11.26	26.64	26.66	27.93	27.82	0.50	0.51
$NaO_{1/2}$	1.98	3.63	1.22	2.29	2.48	4.55	1.90	3.52	2.70	4.86	3.61	6.58	0.53	0.96	1.70	3.06	1.30	2.41
$KO_{1/2}$	3.10	3.74	0.98	1.21	0.71	0.86	0.47	0.57	1.15	1.36	0.69	0.82	0.31	0.37	1.60	1.90	3.38	4.12
TiO_2	0.42	0.30	0.38	0.28	0.98	0.70	0.90	0.65	0.85	0.59	1.85	1.31	0.92	0.65	0.86	0.60	0.54	0.39
$PO_{5/2}$	n. d.	—	n. d.	—	0.13	0.10	0.36	0.29	0.47	0.37	0.69	0.55	n. d.	—	0.22	0.17	0.04	0.03
H_2O+	0.64	(2.02)	1.13	(3.65)	0.51	(1.61)	0.23	(0.73)	0.35	(1.08)	0.42	(1.32)	1.46	(4.55)	1.23	(3.81)	0.77	(2.45)
H_2O-	0.16	—	0.35	—	0.12	—	0.20	—	0.06	—	0.09	—	0.54	—	0.18	—	0.12	—
CO_2	2.86	3.69	2.13	2.81	0.90	1.16	n. d.	—	n. d.	—	n. d.	—	10.22	13.03	9.23	11.71	n. d.	—
Cl	n. d.	—	0.04	—	n. d.	—	n. d.	—	n. d.	—	n. d.	—	n. d.	—	n. d.	—	n. d.	—
Total	100.56	100.00	100.08	100.00	100.35	100.00	100.15	100.00	100.16	100.00	100.30	100.00	100.04	100.00	99.69	100.00	100.24	100.00
Trace elem.	See Table 4																	
Planimetric analysis	Volume %																	
	Qua	33.6	Qua	44.0	Pla $_{An50}$	45.0	Pla $_{An63}$	54.0	Pla $_{An65}$	67.3	Pla $_{An40}$	62.0	Di	39.4	Ho	43.3	Pla $_{An20}$	Not measured
	Pla $_{An40}$	28.0	Mei	36.3	Qua	32.0	Di	23.2	Ho	11.0	Di	21.0	Cal	27.5	Di	34.0	Crd	
	Mi(Pfs)	21.0	Di	10.5	Di	20.0	Qua	20.0	Di	8.6	Hy	12.0	Mei	20.0	Pla $_{An50}$	22.0	Qua	
	Di	13.3	Cal	4.0	Sph	1.5	Sph	1.8	Hy	8.0	Bi	1.5	Ho	8.3	Bi	0.2	Mi	
	Cal	2.8	Pla $_{An46}$	3.1	Cal	0.7	Bi	0.1	Bi	3.8	Ho	0.5	Sph	2.0	Acc	0.5	Gar	
	Sph	1.2	Sph	1.3	Acc	0.5	Acc	0.9	Acc	1.3	Acc	3.0	Ma	2.8			Bi	
	Acc	0.1	Mi	0.8													Sill	
																	Acc	
	Total	100.0		100.0		100.0		100.0		100.0		100.0		100.0		100.0		
Grain size mm	Felsic	0.5-1.5	Qua	0.5-5.0	Felsic	0.5 -1.0	Felsic	0.5-1.0	Pla	0.5- 1.0	Pla	0.5-5.0	Mei	1.0	Pla	0.1-5.0	Felsic	1.0-(10.0)
	Di	1.0	Mei	0.5-2.0	Di	0.5 -1.0	Di	0.5-1.0	Mafic	0.5-10.0	Px	0.5-5.0	Cal	0.5-1.0	Mafic	0.1-5.0	Crd	1.0-(10.0)
	Sph	0.1-0.5	Di	0.5-1.0	Sph	0.05-0.1	Sph	0.1	Acc	0.1- 0.3	Ho	0.1-0.5	Mafic	0.5-2.0	Acc	0.1-0.5	Gar	5.0-(30.0)
	Ap	0.1	Sph	0.1	Acc	0.1 -0.3	Acc	0.1			Ma	0.1-2.0	Sph,Ma	0.1-0.3			Acc	0.1-1.0

No.	57		67		68		104		105		106		107		108	
	Weight	Cation	W	C	W	C	W	C	W	C	W	C	W	C	W	C
	%															
SiO_2	64.33	60.84	74.98	71.95	55.82	53.28	72.97	68.94	49.88	46.16	63.39	60.42	62.92	59.53	52.95	49.46
$AlO_{3}/_{2}$	17.12	19.08	12.38	14.00	17.13	19.27	13.91	15.48	18.52	20.20	14.52	16.23	14.59	16.26	19.00	20.92
$FeO_{3}/_{2}$	0.84	0.60	0.48	0.35	1.08	0.77	0.31	0.22	3.03	2.11	1.97	1.41	2.07	1.47	3.69	2.59
FeO	6.08	4.81	2.23	1.79	8.93	7.12	1.60	1.27	6.24	4.83	7.10	5.63	6.03	4.77	7.21	5.63
MnO	0.07	0.06	0.04	0.03	0.04	0.03	0.04	0.03	0.10	0.08	0.12	0.10	0.08	0.06	0.10	0.08
MgO	2.73	3.85	1.35	1.93	3.03	4.30	0.42	0.59	6.84	9.42	3.23	4.56	2.87	4.05	3.49	4.86
CaO	1.74	1.76	0.33	0.34	6.09	6.22	1.06	1.07	5.60	5.56	1.37	1.39	2.13	2.16	1.74	1.74
$NaO_{1}/_{2}$	2.89	5.29	1.89	3.52	2.80	5.18	3.27	5.99	4.26	7.64	3.59	6.60	2.84	5.21	4.39	7.95
$KO_{1}/_{2}$	2.36	2.84	4.52	5.53	2.07	2.52	5.10	6.15	2.82	3.33	2.30	2.78	4.75	5.73	4.76	5.67
TiO_2	0.95	0.68	0.24	0.17	1.52	1.09	0.14	0.10	0.88	0.61	1.00	0.71	0.92	0.65	1.19	0.84
$PO_{5}/_{2}$	0.24	0.19	0.48	0.39	0.27	0.22	0.20	0.16	0.07	0.06	0.21	0.17	0.14	0.11	0.33	0.26
H_2O+	0.89	(2.81)	0.92	(2.95)	0.85	(2.71)	0.63	(1.99)	1.52	(4.70)	0.50	(1.58)	0.33	(1.04)	0.92	(2.87)
H_2O-	0.12	—	0.13	—	0.15	—	0.06	—	0.14	—	0.13	—	0.14	—	0.22	—
Total	100.36	100.00	99.97	100.00	99.78	100.00	99.72	100.00	99.90	100.00	99.73	100.00	99.81	100.00	99.99	100.00
Trace elem.	See Table 4															
					Volume %											
Planimetric analysis	Pla$_{An23}$ Crd Qua Gar Bi Mi Sill Acc	Not measured	Mi Crd Qua Bi Pla$_{An20}$ Acc	Not measured	Pla$_{An35}$ Qua Ho Bi Di Acc	43.0 24.0 16.5 14.6 1.3 0.6	Mi Qua Pla$_{An18}$ Gar Bi Acc	34.0 30.5 29.0 5.0 1.0 0.5	Pla$_{An35}$ Ho Bi	Not measured	Pla$_{An22}$ Gar Qua Bi Hy Acc	Not measured	Pla$_{An35}$ Bi Hy Gar Qua Ma Ap	Not measured	Pla$_{An22}$ Gar Hy Bi Ma Qua Ap	Not measured
					Total	100.0	Total	100.0								
Grain size mm	Felsic 1.0 -(10.0) Crd 1.0 -3.0(10.0) Gar 5.0-20.0(30.0) Acc 0.1- 1.0		Felsic Crd Bi Acc	0.1 - 3.0 0.5 -10.0 0.1 - 1.0 0.1	Felsic Mafic Acc	1.0 -5.0 0.5 -2.0 0.2	Felsic 1.0 -(10.0) Gar 1.0 -5.0(20.0) Bi 0.1 -5.0 Acc 0.1 -1.0		Pla Ho Bi	0.5 -1.5 0.5 -2.0 0.3 -1.0	Felsic 0.5 -1.5 Gar, Hy 1.0 -5.0(10.0) Bi 0.5 -2.0 Acc 0.1 -0.5		Felsic 0.5 -1.5 Hy 1.0 -5.0(10.0) Bi, Gar 0.5 -2.0 Acc 0.1 -0.5		Pla 0.5 -3.0 Gar, Hy 1.0 -5.0(10.0) Bi 0.5 -2.0 Acc 0.1 -0.3	

Table 3. Cation values of rock analyses (WUC)

Ca % ⟶	0.34	0.51	1.07	1.39	1.74	1.76	2.16	2.63	3.03	4.29	5.02	5.10
Anal. No.	67	53	104	106	108	57	107	1	2	17	3	27
$Fe^{3+} + Fe^{2+} + Mn + Mg$	4.10	9.46	2.11	11.70	13.16	9.32	10.35	2.18	1.14	13.93	6.88	12.09
$\frac{Si + Al + Na + K}{Fe^{3+} + Fe^{2+} + Mn + Mg}$	23.17	9.47	45.76	7.35	6.38	9.45	8.38	43.58	83.78	5.82	12.65	6.78
$\frac{K}{Na + K}$	0.61	0.63	0.51	0.29	0.42	0.35	0.53	0.37	0.18	0.30	0.23	0.52
$\frac{Mg}{Mg + Fe^{3+} + Fe^{2+} + Mn}$	0.47	0.47	0.28	0.39	0.37	0.41	0.39	0.31	0.42	0.45	0.30	0.51
$\frac{Fe^{3+}}{Fe^{3+} + Fe^{2+}}$	0.164	0.074	0.148	0.200	0.315	0.111	0.236	0.277	0.141	0.245	0.165	0.066
$\frac{Ti}{Ti + Fe^{3+} + Fe^{2+} + Mn}$	0.073	0.072	0.062	0.091	0.092	0.111	0.094	0.118	0.165	0.083	0.170	0.064
Al	14.00	17.68	15.48	16.23	20.92	19.08	16.26	17.91	18.92	13.03	18.99	21.82
Si	71.95	65.40	68.94	60.42	49.46	60.84	59.53	65.47	64.89	62.30	57.60	48.81
O in oxides	175.37	171.61	171.06	165.53	155.64	167.59	163.76	169.04	168.97	167.58	163.42	155.36
qz (Niggli)	+236.3	+136.4	+163.1	+61.3	–31.1	+74.1	+43.4	+115.1	+111.8	+69.0	+37.8	–23.2
Na + K	9.05	8.13	12.14	9.38	13.62	8.13	10.94	11.61	11.70	5.75	10.42	11.31
Ca + Mg	2.27	4.91	1.66	5.95	6.60	5.61	6.21	3.31	3.51	10.52	7.05	11.22
$\frac{Fe^{3+}}{Fe^{2+}}$	0.196	0.079	0.173	0.250	0.460	0.125	0.308	0.382	0.164	0.324	0.198	0.070

Ca % ⟶	5.56	5.71	5.86	5.99	6.07	6.16	6.22	6.55	6.99	7.19	7.51	8.09
Anal. No.	105	23	14	25	12	13	68	5	9	26	24	30
$Fe^{3+} + Fe^{2+} + Mn + Mg$	16.44	12.70	7.78	14.64	5.35	7.11	12.22	11.63	17.28	17.46	6.92	5.97
$\frac{Si + Al + Na + K}{Fe^{3+} + Fe^{2+} + Mn + Mg}$	4.70	6.33	11.04	5.30	16.47	12.07	6.57	6.88	4.27	4.25	12.30	14.12
$\frac{K}{Na + K}$	0.30	0.24	0.25	0.29	0.79	0.24	0.33	0.32	0.07	0.28	0.14	0.66
$\frac{Mg}{Mg + Fe^{3+} + Fe^{2+} + Mn}$	0.57	0.37	0.54	0.38	0.32	0.26	0.35	0.36	0.29	0.40	0.41	0.37
$\frac{Fe^{3+}}{Fe^{3+} + Fe^{2+}}$	0.304	0.179	0.217	0.073	0.170	0.132	0.098	0.020	0.025	0.196	0.185	0.110
$\frac{Ti}{Ti + Fe^{3+} + Fe^{2+} + Mn}$	0.080	0.098	0.110	0.137	0.112	0.129	0.121	0.150	0.138	0.071	0.094	0.076
Al	20.20	16.11	18.13	14.27	19.11	15.52	19.27	21.94	14.55	17.81	17.66	12.90
Si	46.16	56.56	58.28	55.82	62.87	60.35	53.28	47.75	56.87	48.98	61.21	64.78
O in oxides	152.54	162.74	163.52	161.59	170.13	164.42	160.88	155.78	165.23	156.34	167.69	169.74
qz (Niggli)	−35.4	+34.8	+42.9	+29.2	+109.8	+54.6	+19.0	−20.8	+60.1	− 9.4	+83.5	+116.5
Na + K	10.97	7.77	9.46	7.45	6.14	9.98	7.70	10.28	2.28	7.50	6.28	6.64
Ca + Mg	14.98	10.46	10.08	11.52	7.77	7.98	10.52	10.76	12.04	14.25	10.38	10.30
$\frac{Fe^{3+}}{Fe^{2+}}$	0.435	0.219	0.277	0.079	0.205	0.541	0.108	0.021	0.025	0.244	0.226	0.123

Table 3 (cont.)

Ca % →	8.40	8.55	9.45	10.24	11.17	11.26	11.28	11.69	12.95	26.66	27.82
Anal. No.	16	28	31	29	40	45	33	44	41	47	49
$Fe^{3+} + Fe^{2+} + Mn + Mg$	13.53	8.25	3.74	10.43	9.83	12.54	4.14	12.35	7.48	13.57	11.97
$\frac{Si + Al + Na + K}{Fe^{3+} + Fe^{2+} + Mn + Mg}$	5.57	10.02	22.14	7.52	7.84	5.93	19.68	6.07	10.51	3.39	4.00
$\frac{K}{Na + K}$	0.17	0.37	0.51	0.52	0.16	0.11	0.35	0.22	0.14	0.28	0.38
$\frac{Mg}{Mg + Fe^{3+} + Fe^{2+} + Mn}$	0.51	0.45	0.30	0.38	0.42	0.34	0.38	0.46	0.34	0.54	0.51
$\frac{Fe^{3+}}{Fe^{3+} + Fe^{2+}}$	0.038	0.269	0.023	0.045	0.167	0.117	0.177	0.021	0.107	0.129	0.111
$\frac{Ti}{Ti + Fe^{3+} + Fe^{2+} + Mn}$	0.262	0.105	0.103	0.112	0.110	0.136	0.099	0.082	0.116	0.094	0.093
Al	21.27	17.18	11.34	17.49	14.56	19.43	12.01	24.19	16.33	11.30	7.93
Si	46.57	58.62	64.11	64.78	57.07	47.51	65.98	44.59	58.21	33.46	34.84
O in oxides	156.36	164.93	170.12	157.46	161.80	156.15	173.55	154.80	165.69	152.52	149.22
qz (Niggli)	−13.8	+55.1	+118.3	+1.1	+48.7	−12.8	+153.5	−18.6	+62.7	−34.0	−46.5
Na + K	7.58	6.86	7.37	8.89	5.41	7.40	3.50	6.22	4.09	1.33	4.96
Ca + Mg	15.36	12.24	10.57	14.42	15.34	15.49	12.87	17.41	15.50	33.99	33.94
$\frac{Fe^{3+}}{Fe^{2+}}$	0.040	0.368	0.024	0.047	0.200	0.132	0.215	0.022	0.120	0.148	0.125

Table 4. Trace elements of WUC

Single samples

Visual determinations

	No.	Rb	Be	Sr	Ba	B	Sc	Y	La	Ce	Nd	Ga	Zr	Sn	V	Cr	Co	Ni
		g/ton																
Hy granites—granodiorites (Charnockites, type: Hy)	1	—	—	85.0	269.0	3.0	<0.7	0	26.0	51.0	<26.0	—	148.0	—	34.0	41.0	—	—
	2	183.0	1.0	169.0	269.0	9.0	<0.7	0	68.0	51.0	<26.0	74.0	74.0	9.0	17.0	21.0	0	0
	3	274.0	0.4	254.0	537.0	9.0	0.7	<8.0	85.0	68.0	26.0	74.0	222.0	0	34.0	21.0	<8.0	5.0
	4	91.0	0.4	254.0	358.0	9.0	<0.7	0	0	8.5	<26.0	74.0	≪74.0	18.0	45.0	55.0	8.0	5.0
	5	274.0	1.0	338.0	90.0	3.0	<0.7	24.0	8.5	26.0	<26.0	74.0	74.0	0	168.0	137.0	≪8.0	0
	6	274.0	0.4	254.0	717.0	31.0	0	8.0	8.5	26.0	≪26.0	74.0	148.0	0	168.0	68.0	<8.0	6.0
	9	27.0	<0.4	254.0	0	31.0	0	8.0	0	0	≪26.0	22.0	<74.0	26.0	336.0	205.0	8.0	6.0
	116	91.0	0.4	254.0	269.0	9.0	<0.7	0	2.5	≪8.5	0	74.0	148.0	9.0	56.0	21.0	<8.0	2.0
Px grano-quartz diorites (Charnockites, type: Hy Di)	12	55.0	<0.4	51.0	9.0	19.0	0.7	8.0	8.5	8.5	0	45.0	74.0	≪9.0	336.0	55.0	8.0	8.0
	13	549.0	0.4	254.0	537.0	31.0	0.7	16.0	26.0	26.0	26.0	22.0	148.0	18.0	168.0	205.0	8.0	16.0
	14	183.0	3.5	254.0	717.0	9.0	0.7	8.0	8.5	26.0	0	7.5	74.0	9.0	168.0	205.0	8.0	16.0
	15	—	—	51.0	537.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	16	91.0	<0.4	507.0	537.0	31.0	0	16.0	0	0	≪26.0	<7.5	≪74.0	0	336.0	411.0	≪8.0	2.0
	127	91.0	0	169.0	627.0	31.0	0.7	8.0	0	0	≪26.0	7.5	74.0	9.0	336.0	411.0	16.0	24.0
	129	27.0	0	169.0	179.0	31.0	<0.7	8.0	0	0	≪26.0	45.0	0	≪9.0	336.0	411.0	16.0	24.0
Hy gneisses (Paracharnockites, type: Hy)	17	183.0	0	85.0	537.0	31.0	<0.7	16.0	8.5	<8.5	<26.0	22.0	222.0	26.0	448.0	547.0	24.0	31.0
	19	—	—	85.0	537.0	9.0	0.7	8.0	0	0	0	—	<74.0	—	336.0	547.0	—	—
	20	—	—	85.0	537.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	22	—	—	—	—	31.0	0.7	24.0	26.0	26.0	<26.0	—	74.0	—	224.0	411.0	—	—
	23	549.0	2.0	85.0	179.0	31.0	2.0	24.0	8.5	8.5	<26.0	22.0	148.0	<9.0	336.0	205.0	—	16.0
	132	—	—	—	—	19.0	2.0	24.0	2.5	8.5	0	—	148.0	—	336.0	411.0	31.0	—
	134	—	—	254.0	537.0	—	—	—	—	—	—	—	—	—	—	—	—	—

Table 4 (cont.)

		No.	Rb	Be	Sr	Ba	B	Sc	Y	La	Ce	Nd	Ga	Zr	Sn	V	Cr	Co	Ni
			g/ton																
Px gneisses (Paracharnockites, type: Hy Di)		24	55.0	1.0	254.0	717.0	31.0	<0.7	24.0	5.0	0	0	22.0	74.0	≪9.0	336.0	205.0	<8.0	16.0
		25	274.0	<0.4	51.0	537.0	19.0	1.3	8.0	0	≪8.5	0	7.5	<74.0	≪9.0	336.0	205.0	16.0	5.0
		26	91.0	0	85.0	537.0	19.0	2.0	24.0	26.0	26.0	<26.0	22.0	74.0	≪9.0	336.0	411.0	47.0	16.0
		27	274.0	0	85.0	537.0	19.0	4.0	<8.0	8.5	8.5	0	22.0	0	0	336.0	68.0	8.0	2.0
		135	—	—	85.0	537.0	—	—	—	—	—	—	—	—	—	—	—	—	—
		136	27.0	0	254.0	537.0	19.0	0.7	0	2.5	8.5	<26.0	7.5	0	0	168.0	205.0	8.0	6.0
		138	—	—	85.0	537.0	—	—	—	—	—	—	—	—	—	—	—	—	—
		140	—	—	254.0	269.0	31.0	1.3	8.0	2.5	≪8.5	0	—	74.0	—	224.0	205.0	—	—
		142	—	—	254.0	717.0	31.0	0.7	8.0	5.0	26.0	0	—	74.0	—	224.0	205.0	—	—
Mei Di gneisses	Type: Di Bi	28	91.0	0.4	169.0	269.0	9.0	0	0	0	0	0	22.0	148.0	<9.0	56.0	137.0	<8.0	16.0
		29	549.0	<0.4	169.0	269.0	31.0	2.0	24.0	26.0	51.0	26.0	7.5	222.0	9.0	336.0	205.0	8.0	16.0
		146	55.0	3.5	25.0	179.0	31.0	0.7	24.0	26.0	26.0	<26.0	22.0	222.0	9.0	224.0	205.0	<8.0	8.0
		149	—	—	25.0	269.0	—	—	—	—	—	—	—	—	—	—	—	—	—
		150	—	—	85.0	269.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	Type: Di Mi	30	274.0	0	507.0	717.0	31.0	2.0	24.0	51.0	51.0	<26.0	7.5	222.0	0	168.0	68.0	0	5.0
		31	183.0	<0.4	254.0	717.0	9.0	0.7	24.0	2.5	≪8.5	0	7.5	297.0	0	45.0	41.0	0	2.0
		32	—	—	51.0	269.0	—	—	—	—	—	—	—	—	—	—	—	—	—
		153	—	—	85.0	269.0	—	—	—	—	—	—	—	—	—	—	—	—	—
		155	—	—	85.0	179.0	—	—	—	—	—	—	—	—	—	—	—	—	—
		156	—	—	85.0	537.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	Type: Di Pla	33	27.0	1.0	169.0	269.0	93.0	0.7	236.0	8.5	8.5	0	22.0	297.0	<9.0	34.0	55.0	0	5.0
		36	—	—	169.0	90.0	93.0	0.7	236.0	8.5	8.5	0	—	222.0	≪9.0	34.0	55.0	—	—
		159	—	—	85.0	537.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	Type: Di Mei	40	55.0	<0.4	25.0	90.0	186.0	2.0	24.0	8.5	8.5	0	22.0	148.0	≪9.0	56.0	68.0	8.0	8.0
		41	55.0	0.4	51.0	<90.0	19.0	0.7	16.0	5.0	8.5	0	22.0	74.0	≪9.0	56.0	68.0	8.0	8.0
		162	—	—	85.0	896.0	—	—	—	—	—	—	—	—	≪9.0	—	—	—	—

	No.	Rb	Be	Sr	Ba	B	Sc	Y	La	Ce	Nd	Ga	Zr	Sn	V	Cr	Co	Ni
		g/ton																
Light Px amphibolites (Basic charnockites)	43	—	—	254.0	717.0	9.0	4.0	16.0	0	0	0	—	≪74.0	—	560.0	55.0	—	—
	44	55.0	<0.4	254.0	896.0	31.0	6.5	8.0	1.0	≪8.5	0	7.5	0	26.0	336.0	68.0	8.0	63.0
	45	27.0	2.0	85.0	269.0	31.0	<0.7	8.0	0	0	0	22.0	<74.0	9.0	224.0	205.0	16.0	63.0
	46	—	—	85.0	269.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	167	—	—	85.0	269.0	19.0	<0.7	0	<1.0	0	0	0	0	0	336.0	684.0	—	—
	168	—	—	85.0	90.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	169	—	—	51.0	90.0	186.0	2.0	8.0	0	0	0	—	≪74.0	—	336.0	205.0	—	—
	170	—	—	85.0	90.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	171	—	—	85.0	269.0	9.0	4.0	16.0	<1.0	0	≪26.0	—	74.0	—	448.0	411.0	—	—
	172	—	—	85.0	269.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	173	—	—	85.0	90.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Dark Mei Di amphibolites	47	55.0	0	51.0	90.0	249.0	4.0	≪8.0	0	0	<26.0	0	0	53.0	56.0	411.0	8.0	79.0
	48	—	—	507.0	90.0	186.0	2.0	≪8.0	<1.0	0	0	—	0	—	56.0	547.0	—	—
	49	55.0	0	507.0	537.0	93.0	4.0	≪8.0	1.0	0	0	0	0	176.0	168.0	684.0	236.0	471.0
	50	—	—	85.0	90.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	51	—	—	85.0	269.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	52	—	—	254.0	90.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	174	—	—	254.0	269.0	—	—	—	—	—	—	—	—	—	—	—	—	—
Lutogenites	53	549.0	0.4	0	269.0	31.0	2.0	39.0	51.0	51.0	26.0	45.0	296.0	0	168.0	205.0	8.0	24.0
	57	274.0	1.0	85.0	537.0	186.0	4.0	16.0	26.0	<8.5	26.0	45.0	444.0	≪9.0	168.0	205.0	8.0	8.0
	67	55.0	3.5	0	537.0	93.0	2.0	24.0	26.0	51.0	26.0	74.0	444.0	0	17.0	21.0	0	0
Rocks not included in the average mixtures	68	91.0	0	51.0	717.0	186.0	0.7	0	0	0	0	7.5	74.0	0	336.0	205.0	8.0	8.0
	111	55.0	0	507.0	537.0	31.0	6.5	0	0	0	≪26.0	0	0	70.0	336.0	2053.0	47.0	157.0
	177	—	—	—	—	31.0	0.7	16.0	26.0	26.0	<26.0	—	222.0	—	168.0	205.0	—	—
	178	—	—	254.0	537.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	181	—	—	254.0	269.0	—	—	—	—	—	—	—	—	—	—	—	—	—
	182	—	—	85.0	896.0	—	—	—	—	—	—	—	—	—	—	—	—	—

Table 5. Trace elements of WUC

Average mixtures

Average mixture from		Visual	Photom.	Visual		Photom.	Visual	Photom.	Visual		
		Rb		Be	Sr		Ba		B	Sc	Y
		g/ton									
17 samples	Hy granites — granodiorites (Charnockites, type: Hy)	183.0	183.0	1.0	85.0	127.0	448.0	573.0	19.0	<0.7	<8.0
12 samples	Px grano- quartz diorites (Charnockites, type: HyDi)	183.0	229.0	1.0	169.0	152.0	358.0	564.0	25.0	0.7	8.0
12 samples	Hy gneisses (Paracharnockites, type: Hy)	274.0	402.0	1.0	85.0	169.0	448.0	627.0	31.0	2.0	24.0
12 samples	Px gneisses (Paracharnockites, type: HyDi)	274.0	311.0	1.0	127.0	152.0	627.0	717.0	31.0	2.0	8.0
10 samples	MeiDi gneisses (Type: DiBi)	274.0	425.0	0.4	85.0	34.0	448.0	358.0	31.0	2.0	24.0
10 samples	MeiDi gneisses (Type: DiMi)	274.0	366.0	0.4	169.0	118.0	627.0	654.0	311.0	2.0	24.0
10 samples	MeiDi gneisses (Type: DiPla)	55.0	75.0	0.4	85.0	76.0	358.0	340.0	93.0	2.0	24.0
10 samples	MeiDi gneisses (Type: DiMei)	183.0	293.0	0.4	127.0	169.0	448.0	358.0	93.0	2.0	24.0
10 samples	Light Px amphibolites (Basic charnockites)	27.0	38.0	0.4	127.0	85.0	269.0	269.0	31.0	4.0	8.0
10 samples	Dark MeiDi amphibolites	27.0	38.0	0	169.0	152.0	179.0	233.0	249.0	4.0	≪8.0
16 samples	Lutogenites	366.0	475.0	1.0	85.0	93.0	627.0	700.0	93.0	4.0	24.0
7 samples	Limestones	27.0	38.0	0	846.0	1 100.0	269.0	224.0	9.0	<0.7	0

Average mixture from		Visual									
		La	Ce	Nd	Ga	Zr	Sn	V	Cr	Co	Ni
		g/ton									
17 samples	Hy granites—granodiorites (Charnockites, type: Hy)	26.0	8.5	<26.0	74.0	148.0	26.0	56.0	55.0	<8.0	6.0
12 samples	Px grano- quartz diorites (Charnockites, type: HyDi)	8.5	<8.5	<26.0	45.0	74.0	9.0	168.0	205.0	8.0	16.0
12 samples	Hy gneisses (Paracharnockites, type: Hy)	8.5	8.5	<26.0	45.0	222.0	<9.0	336.0	274.0	24.0	16.0
12 samples	Px gneisses (Paracharnockites, type: HyDi)	2.5	<8.5	0	22.0	<74.0	0	336.0	205.0	16.0	8.0
10 samples	MeiDi gneisses (Type: DiBi)	26.0	26.0	26.0	7.5	222.0	<9.0	168.0	137.0	<8.0	8.0
10 samples	MeiDi gneisses (Type: DiMi)	26.0	26.0	<26.0	7.5	222.0	<9.0	56.0	68.0	0	6.0
10 samples	MeiDi gneisses (Type: DiPla)	8.5	26.0	0	22.0	148.0	0	56.0	68.0	<8.0	8.0
10 samples	MeiDi gneisses (Type: DiMei)	26.0	26.0	0	7.5	444.0	<9.0	56.0	55.0	0	6.0
10 samples	Light Px amphibolites (Basic charnockites)	<1.0	0	0	7.5	≪74.0	26.0	336.0	411.0	24.0	24.0
10 samples	Dark MeiDi amphibolites	0	0	0	0	≪74.0	70.0	56.0	547.0	236.0	79.0
16 samples	Lutogenites	51.0	68.0	26.0	45.0	444.0	0	336.0	205.0	8.0	16.0
7 samples	Limestones	<1.0	0	0	0	0	0	0.6	0.7	0	0

REFERENCES

BARTH, T. F. W. (1948) Oxygen in rocks: A basis for petrographic calculations. J. Geol. 56, pp. 50—60.

—»— (1952) Theoretical Petrology. New York.

ESKOLA, P. (1952) On the granulites of Lapland. Am. J. Sci., Bowen Volume, 1, pp. 133—171.

—»— (1954) A proposal for the presentation of rock analyses in ionic percentage. Ann. Acad. Sci. Fennicae, A, III, 38.

—»— (1957) On the mineral facies of charnockites. J. Madras Univ., B. 27, pp. 101—119.

—»— (1921 and 1939) (See Pt. I, Bibliography).

FOLINSBEE, R. E. (1941a) The chemical composition of garnet associated with cordierite. Am. Mineralogist 26, pp. 50—53.

—»— (1941b) Optic properties of cordierite in relation to alkalies in the cordierite-beryl structure. *Ibid.* 26, pp. 485—500.

GOLDSMITH, J. R.—LAVES, F. (1954) Potassium feldspars intermediate between microcline and sanidine. Geochim. et cosmochim. Acta 6, pp. 100—118.

HESS, H. H. (1949) Chemical composition and optical properties of common clinopyroxenes, Part I. Am. Mineralogist 34, pp. 621—666.

—»— (1952) Orthopyroxenes of the Bushveld type, ion substitutions and changes in unit cell dimensions. Am. J. Sci., Bowen Volume, pp. 173—187.

—»— and PHILLIPS, A. H. (1940) Optical properties and chemical composition of magnesian orthopyroxenes. Am. Mineralogist 25, pp. 271—285.

KORJINSKY, D. S. (1936—1940) (See Pt. I, Bibliography).

LOKKA, L. (1950) Chemical analyses of Finnish rocks. Bull. Comm. géol. Finlande 151.

PARRAS, K. (1941) Das Gebiet der Pyroxen führenden Gesteine im westlichen Uusimaa in Südfinnland. Geol. Rundschau 32, S. 484—507.

—»— (1946) On the coarse-grained garnet-cordierite gneisses of South and Southwest Finland. Bull. Comm. géol. Finlande 138, pp. 1—7.

—»— (1954) Prospektering och geologiska undersökningar i Lojo-området. (English summary.) Vuoriteollisuus — Bergshantering 2/1954, s. 1—4.

PEHRMAN, G. (1932) Über optisch positiven Cordierit. Acta Acad. Aboensis, Math. et Phys. 6, 11.

—»— (1936) Über Cordierit-führende Gesteine aus dem Migmatitgebiet von Åbo (SW-Finnland). *Ibid.* 10, 6.

POLDERVAART, A. and HESS, H. H. (1951) Pyroxenes in the crystallization of basaltic magma. J. Geol. 59, pp. 472—489.

RAMBERG, H. (1952) The origin of metamorphic and metasomatic rocks. Chicago.

—»— (1948—1956) (See Pt. I, Bibliography).

RANKAMA, K. (1946) On the geochemical differentiation in the Earth's crust. Bull. Comm. géol. Finlande 137.

—»— and SAHAMA, TH. G. (1955) Geochemistry. Chicago.

ROSENQVIST, I. TH. (1951) Investigations in the crystal chemistry of silicates, III. The relation haematite-microcline. Norsk Geol. Tidsskr. 29, pp. 65—76.

—»— (1952) The metamorphic facies and the feldspar minerals. Univ. Bergen Årb., Naturv. R. 4.

—»— (1956) (See Pt. I, Bibliography).

SAHAMA, TH. G. (1945) Spurenelemente der Gesteine im südlichen Finnisch-Lappland. Bull. Comm. géol. Finlande 135.

—»— and TORGESON, D. R. (1949) Thermochemical study of the olivines and orthopyroxenes. U. S. Bur. Mines, Repts. Investigation 4408.

SPENCER, E. (1945) Myrmekite in graphic granite and in vein perthite. Min. Mag. 27.

SUNDIUS, N. (1915) Beiträge zur Geologie des südlichen Teils des Kirunagebietes, 4. Vidensk. Prakt. Unders. Lappland, Uppsala.

SZADECZKY-KARDOSS, E. (1955) Über die Energetik der magmatischen Gesteins- und Erzgebilde. Acta Geol. Ungar. Akad. Wiss. III, p. 163.

TURNER, F. J. and VERHOOGEN, J. (1951) Igneous and metamorphic petrology. New York.

WINCHELL, A. N. and WINCHELL, H. (1951) Elements of optical mineralogy. Pt. II. Descriptions of minerals. 4th ed. New York.

YODER, H. S., Jr. (1952) The MgO—Al_2O_3—SiO_2—H_2O system and the related metamorphic facies. Am. J. Sci., Bowen Volume, pp. 569—627.

—»— (1955) Role of water in metamorphism. The crust of the earth. Geol. Soc. America, Special Paper 62, pp. 505—524.

Bulletin de la Commission géologique de Finlande.

*N:o 1.	Ramsay, Wilhelm und Nyholm, E. T. Cancrinitsyenit und einige verwandte Gesteine aus Kuolajärvi. S. 1—12. 4 Fig. 1895	—
*N:o 2.	Sederholm, J. J. Ueber einen metamorphosierten praecambrischen Quarzporphyr von Karvia in der Provinz Åbo. S. 1—16. 12 Fig. 1895	—
N:o 3.	Ramsay, Wilhelm, jemte Bihang 1 af Hackman, Victor och 2 af Sederholm, J. J. Till frågan om det senglaciala hafvets utbredning i Södra Finland. S. 1—44. 1 karta. Résumé en français: La transgression de l'ancienne mer glaciaire sur la Finlande méridionale. 1896	150: —
*N:o 4.	Frosterus, Benj. Ueber einen neuen Kugelgranit von Kangasniemi in Finland. S. 1—38. 11 Fig. 2 Taf. 1896	—
*N:o 5.	Berghell, Hugo. Bidrag till kännedomen om Södra Finlands kvartära nivåförändringar. S. 1—64. 16 fig. 1 plansch. 1 karta. Deutsches Referat: Beiträge zur Kenntniss der quartären Niweauschwankungen Süd-Finlands. 1896	—
*N:o 6.	Sederholm, J. J. Über eine archäische Sedimentformation im südwestlichen Finland und ihre Bedeutung für die Erklärung der Entstehungsweise des Grundgebirges. S. 1—254. 97 Fig. 5 Taf. 2 Karten. 1897	—
*N:o 7.	Ailio, Julius. Über Strandbildungen des Litorinameeres auf der Insel Mantsinsaari. S. 1—43. 8 Fig. 1898	—
*N:o 8.	Andersson, Gunnar. Studier öfver Finlands torfmossar och fossila kvartärflora. S. 1—210. 21 fig. 4 tafl. Deutsches Referat: Studien über die Torfmoore und die fossile Quartärflora Finlands. 1898	—
N:o 9.	Sederholm, J. J. Esquisse hypsométrique de la Finlande. P. 1—17. 1 carte. 1899	150: —
N:o 10.	Sederholm, J. J. Les dépôts quaternaires en Finlande. P. 1—28. 2 fig. carte. 1899	150: —
*N:o 11.	Hackman, Victor. Neue Mitteilungen über das Ijolithmassiv in Kuusamo. S. 1—45. 7 Fig. 1 Taf. 2 Karten. 1899	—
*N:o 12.	Ramsay, Wilhelm und Borgström, L. H. Der Meteorit von Bjurböle bei Borgå. S. 1—28. 20 Fig. 1902	—
*N:o 13.	Frosterus, Benj. Bergbyggnaden i sydöstra Finland. S. 1—168. 18 fig. 8 tafl. 1 karta. Deutsches Referat: Der Gesteinsaufbau des südöstlichen Finland. 1902	—
*N:o 14.	Borgström, Leon. H. Die Meteoriten von Hvittis und Marjalahti. S. 1—80. 8 Taf. 1903	—
N:o 15.	Hackman, Victor. Die chemische Beschaffenheit von Eruptivgesteinen Finlands und der Halbinsel Kola im Lichte des neuen amerikanischen Systemes. S. 1—143. 3 Tab. 1905	150: —
*N:o 16.	Sundell, I. G. On the Cancrinite-Syenite from Kuolajärvi and a Related Dike Rock. P. 1—20. 1 plate. 1905	—
*N:o 17.	Fircks, Curt. On the Occurrence of Gold in Finnish Lapland. P. 1—35. Frontispiece. 15 fig. 1 map. 1906	—
*N:o 18.	Tanner, V. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. I. Till frågan om Ost-Finmarkens glaciation och nivåförändringar. S. 1—165. 23 fig. 6 tafl. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fenno-Scandia. I. Sur la glaciation et les changements de niveau du Finmark oriental. 1906	—
*N:o 19.	Trüstedt, Otto. Die Erzlagerstätten von Pitkäranta am Ladoga-See. S. 1—333. 80 Fig. 19 Taf. 1 Karte. 1907	—
N:o 20.	Tanner, V. Zur geologischen Geschichte des Kilpisjärwi-Sees in Lappland. S. 1—23. 3 Fig. 2 Taf. 1 Karte. 1907	100: —

---

*) Loppuunmyyty.
Out of print.

N:o 21.	Tanner, V. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. II. Nya bidrag till frågan om Finmarkens glaciation och nivåförändringar. S. 1—127. 10 fig. 6 tafl. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fenno-Scandia. II. Nouvelles recherches sur la glaciation et les changements de niveau du Finmark. 1907	250: —
N:o 22.	Borgström, L. H. Granitporphyr von Östersundom. S. 1—20. 3 Fig. 1 Taf. 1907	100: —
*N:o 23.	Sederholm, J. J. Om granit och gneis, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia. S. 1—110. 11 fig. 8 tafl. 1 planteckn. 1 karta. English Summary of the Contents: On Granite and Gneiss, their Origin, Relations and Occurrence in the Pre-Cambrian Complex of Fenno-Scandia. 1907	—
*N:o 24.	Sederholm, J. J. Les roches préquaternaires de la Fennoscandia. P. 1—39. 20 fig. 1 carte. 1910	—
N:o 25.	Tanner, V. Über eine Gangformation von fossilienführendem Sandstein auf der Halbinsel Långbergsöda-Öjen im Kirchspiel Saltvik, Åland-Inseln. S. 1—13. 5 Fig. 2 Taf. 1911	100: —
*N:o 26.	Mäkinen, Eero. Bestimmung der Alkalien in Silikaten durch Aufschliessen mittelst Chlorkalzium. S. 1—8. 1911	—
N:o 27.	Sederholm, J. J. Esquisse hypsométrique de la Finlande. P. 1—21. 5 fig. 1 carte. 1911	100: —
*N:o 28.	Sederholm, J. J. Les roches préquaternaires de la Finlande. P. 1—27. 1 carte. 1911	—
*N:o 29.	Sederholm, J. J. Les dépôts quaternaires de la Finlande. P. 1—23. 5 fig. 1 carte. 1911	—
*N:o 30.	Sederholm, J. J. Sur la géologie quaternaire et la géomorphologie de la Fennoscandia. P. 1—66. 13 fig. 6 cartes. 1911	—
N:o 31.	Hausen, H. Undersökning af porfyrblock från sydvästra Finlands glaciala aflagringar. S. 1—34. 9 fig. Deutsches Referat. 1912	100: —
N:o 32.	Hausen, H. Studier öfver de sydfinska ledblockens spridning i Ryssland, jämte en öfversikt af is-recessionens förlopp i Ostbaltikum. Preliminärt meddelande med tvenne kartor. S. 1—32. Deutsches Referat. 1912	100: —
N:o 33.	Wilkman, W. W. Kvartära nivåförändringar i östra Finland. S. 1—40.9 fig. Deutsches Referat. 1912	150: —
N:o 34.	Borgström, L. H. Der Meteorit von St. Michel. S. 1—49. 1 Fig. 3 Taf. 1912	150: —
N:o 35.	Mäkinen, Eero. Die Granitpegmatite von Tammela in Finnland und ihre Minerale. S. 1—101. 23 Fig. 1913	150: —
N:o 36.	Eskola, Pentti. On Phenomena of Solution in Finnish Limestones and on Sandstone filling Cavities. P. 1—50. 15 fig. 1913	150: —
N:o 37.	Sederholm, J. J. Weitere Mitteilungen über Bruchspalten mit besonderer Beziehung zur Geomorphologie von Fennoskandia. S. 1—66. 27 Fig. I Taf. 1913	200: —
N:o 38.	Tanner, V. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. III. Om landisens rörelser och afsmältning i finska Lappland och angränsande trakter. S. 1—815. 139 fig. 16 tafl. Résumé en français: Études sur le système quaternaire dans le parties septentrionales de la Fennoscandia. III. Sur la progression et le cours de la récession du glacier continental dans la Laponie finlandaise et les régions environnantes. 1915	750: —
N:o 39.	Hackman, Victor. Der gemischte Gang von Tuutijärvi im nördlichen Finnland. S. 1—41. 9 Fig. 1914	100: —
*N:o 40.	Eskola, Pentti. On the Petrology of the Orijärvi region in South-western Finland. P. 1—277. 55 fig. 6 plates. 2 maps. 1914	—
N:o 41.	Borgström, L. H. Die Skapolithlagerstätte von Laurinkari. S. 1—30. 7 Fig. 1913	100: —
N:o 42.	Hackman, Victor. Über Camptonitgänge im mittleren Finnland. S. 1—18. 3 Fig. 1914	100: —

---

*) Loppuunmyyty.
Out of print.

N:o 43.	Wilkman, W. W. Kaleviska bottenbildningar vid Mölönjärvi. S. 1—36. 11 fig. Résumé en français. 1915	100: —
N:o 44.	Eskola, Pentti. Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvitraktens metamorfa bergarter. S. 1—145. 5 fig. English Summary of the Contents. 1915	150: —
N:o 45.	Ailio, Julius. Die geographische Entwicklung des Ladogasees in postglazialer Zeit und ihre Beziehung zur steinzeitlichen Besiedelung. S. 1—158. 51 Abbild. 2 Karten. 1915	250: —
N:o 46.	Laitakari, Aarne. Le gisement de calcaire cristallin de Kirmonniemi à Korpo en Finlande. P. 1—39. 14 fig. 1916	100: —
N:o 47.	Mäkinen, Eero. Översikt av de prekambriska bildningarna i mellersta Österbotten i Finland. S. 1—152. 25 fig. 1 karta. English Summary of the Contents. 1916	250: —
*N:o 48.	Sederholm, J. J. On Synantetic Minerals and Related Phenomena (Reaction Rims, Corona Minerals, Kelyphite, Myrmekite, &c.). P. 1—148. 14 fig. in the text and 48 fig. on 8 plates. 1916	—
N:o 49.	Wilkman, W. W. Om en prekalevisk kvartsitformation i norra delen af Kuopio socken. S. 1—18. 7 fig. Résumé en français. 1916	100: —
N:o 50.	Sauramo, Matti. Geochronologische Studien über die spätglaziale Zeit in Südfinnland. S. 1—44. 5 Abbild. 4 Taf. 1918	150: —
N:o 51.	Laitakari, Aarne. Einige Albitepidotgesteine von Südfinnland. S. 1—13. 5 Abbild. 1918	100: —
N:o 52.	Brenner, T. H. Über Theralit und Ijolit von Umptek auf der Halbinsel Kola. S. 1—30. 4 Fig. 1920	100: —
N:o 53.	Hackman, Victor. Einige kritische Bemerkungen zu Iddings' Classifikation der Eruptivgesteine. S. 1—21. 1920	100: —
N:o 54.	Laitakari, Aarne. Über die Petrographie und Mineralogie der Kalksteinlagerstätten von Parainen (Pargas). S. 1—113. 40 Abbild. 3 Taf. 1921	150: —
N:o 55.	Eskola, Pentti. On Volcanic Necks in Lake Jänisjärvi in Eastern Finland. P. 1—13. 1 Fig. 1921	100: —
N:o 56.	Metzger, Adolf A. Th. Beiträge zur Paläontologie des nordbaltischen Silurs im Ålandsgebiet. S. 1—8. 3 Abbild. 1922	100: —
*N:o 57.	Väyrynen, Heikki. Petrologische Untersuchungen der granitodioritischen Gesteine Süd-Ostbothniens. S. 1—78. 20 Fig. 1 Karte. 1923	—
*N:o 58.	Sederholm, J. J. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part I. The Pellinge Region. P. 1—153. 64 fig. 8 plates. 1 map. 1923	—
N:o 59.	Berghell, Hugo und Hackman, Victor. Über den Quartzit von Kallinkangas, seine Wellenfurchen und Trockenrisse. Nach hinterlassenen Aufzeichnungen von Hugo Berghell zusammengestellt und ergänzt von Victor Hackman. S. 1—19. 19 Fig. 1923	100: —
N:o 60.	Sauramo, Matti. Studies on the Quaternary Varve Sediments in Southern Finland. P. 1—164. 22 fig. in the text. 12 fig., 1 map and 2 diagrams on 10 plates. 1923	250: —
N:o 61.	Hackman, Victor. Der Pyroxen-Granodiorit von Kakskerta bei Åbo und seine Modifikation. S. 1—23. 2 Fig. 1 Karte. 1923	100: —
N:o 62.	Wilkman, W. W. Tohmajärvi-konglomeratet och dess förhållande till kaleviska skifferformationen. S. 1—43. 15 fig. 1 karta. Deutsches Referat. 1923	100: —
N:o 63.	Hackman, Victor. Über einen Quarzsyenitporphyr von Saariselkä im finnischen Lappland. S. 1—10. 2 Fig. 1923	100: —
N:o 64.	Metzger, Adolf A. Th. Die jatulischen Bildungen von Suojärvi in Ostfinnland. S. 1—86. 38 Abbild. 1 Taf. 1 Karte. 1924	150: —
N:o 65.	Saxén, Martti. Über die Petrologie des Otravaaragebietes im östlichen Finnland. S. 1—63. 13 Abbild. 5 Fig. auf 1 Taf. 2 Karten. 1923	150: —
N:o 66.	Ramsay, Wilhelm. On Relations between Crustal Movements and Variations of Sea-Level during the Late Quaternary Time, especially in Fennoscandia. P. 1—39. 10 fig. 1924	100: —

---

*) Loppuunmyyty.
Out of print.

N:o 67.	Sauramo, Matti. Tracing of Glacial Boulders and its Application in Prospectin. P. 1—37. 12 fig. 1924	100: —
N:o 68.	Tanner, V. Jordskredet i Jaarila. S. 1—18. 2 fig. 10 bild. Résumé en français. 1924	100: —
N:o 69.	Auer, Väinö. Die postglaziale Geschichte des Vanajavesisees. S. 1—132. 10 Fig. 10 Taf. 11 Beil. 1924	250: —
N:o 70.	Sederholm, J. J. The Average Composition of the Earth's Crust in Finland. P. 1—20. 1925	100: —
N:o 71.	Wilkman, W. W. Om diabasgångar i mellersta Finland. S. 1—35. 8 fig. 1 karta. Deutsches Referat. 1924	100: —
N:o 72.	Hackman, Victor. Das Gebiet der Alkaligesteine von Kuolajärvi in Nordfinnland. S. 1—62. 6 Fig. 1 Taf. 1925	150: —
N:o 73.	Laitakari, Aarne. Über das jotnische Gebiet von Satakunta. S. 1—43. 14 Abbild. 1 Karte. 1925	150: —
N:o 74.	Metzger, Adolf A. Th. Die Kalksteinlagerstätten von Ruskeala in Ostfinnland. S. 1—24. 9 Abbild. 2 Karten. 1925	100: —
N:o 75.	Frosterus, Benj. Ueber die kambrischen Sedimente der karelischen Landenge. S. 1—52. 1 Fig. 1925	150: —
N:o 76.	Hausen, H. Über die präquartäre Geologie des Petsamo-Gebietes am Eismeere. S. 1—100. 13 Fig. 2 Taf. 1926	150: —
N:o 77.	Sederholm, J. J. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part II. The Region around the Barösundsfjärd W. of Helsingfors and Neighbouring Areas. P. 1—143. 57 fig. in the text and 44 fig. on 9 plates. 1 map. 1926	300: —
N:o 78.	Väyrynen, Heikki. Geologische und petrographische Untersuchungen im Kainuugebiete. S. 1—127. 37 Fig. 2 Taf. 2 Karten. 1928	200: —
N:o 79.	Hackman, Victor. Studien über den Gesteinsaufbau der Kittilä-Lappmark. S. 1—105. 23 Fig. 2 Taf. 2 Karten. 1927	200: —
N:o 80.	Sauramo, Matti. Über die spätglazialen Niveauverschiebungen in Nordkarelien, Finnland. S. 1—41. 8 Fig. im Text. 11 Fig., 1 Karte und 1 Profildiagr. auf 7 Taf. 1928	100: —
N:o 81.	Sauramo, Matti und Auer, Väinö. On the Development of Lake Höytiäinen in Carelia and its Ancient Flora. P. 1—42. 20 fig. 4 plates. 1928	100: —
N:o 82.	Lokka, Lauri. Über Wiikit. S. 1—68. 12 Abbild. 1928	150: —
N:o 83.	Sederholm, J. J. On Orbicular Granite, Spotted and Nodular Granites etc. and on the Rapakivi Texture. P. 1—105. 19 fig. in the text and 50 fig. on 16 plates. 1928	250: —
N:o 84.	Sauramo, Matti. Über das Verhältnis der Ose zum höchsten Strand. S. 1—17. 1928	50: —
N:o 85.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, I. P. 1—88. 1 stéréogramme. 1929	200: —
N:o 86.	Sauramo, Matti. The Quaternary Geology of Finland. P. 1—110. 39 fig. in the text and 42 fig. on 25 plates. 1 map. 1929	300: —
N:o 87.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, II. P. 1—175. 48 fig. 8 planches. 1929	350: —
N:o 88.	Tanner, V. Studier över kvartärsystemet i Fennoskandias nordliga delar. IV. Om nivåförändringarna och grunddragen av den geografiska utvecklingen efter istiden i Ishavsfinland samt om homotaxin av Fennoskandias kvartära marina avlagringar. S. 1—589. 84. fig. 4 tavl. 1 karta. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fennoscandie. IV. Sur les changements de niveau et les traits fondamentaux du développement géographique de la Finlande aux confins de l'océan Arctique après l'époque glaciaire et sur l'homotaxie du quarternaire marin en Fennoscandie. 1930	750: —
N:o 89.	Wegman, C. E. und Kranck, E. H. Beiträge zur Kenntnis der Svecofenniden in Finland. I. Übersicht über die Geologie des Felsgrundes im Küstengebiete zwischen Helsingfors und Onas. II. Petrologische Übersicht des Küstengebietes E von Helsingfors. S. 1—107. 4 Fig. 16 Taf. mit 32 Fig. 1 Übersichtskarte. 1931	200: —

N:o 90.	Hausen, H. Geologie des Soanlahti-Gebietes im südlichen Karelien. Ein Beitrag zur Kenntnis der Stratigraphie und tektonischen Verhältnisse der Jatulformation. S. 1—105. 23 Fig. im Text und 12 Fig. auf 4 Taf. 1930	250: —
N:o 91.	Sederholm, J. J. Pre-Quaternary Rocks of Finland. Explanatory Notes to accompany a General Geological Map of Finland. P. 1—47. 40 fig. 1 map. 1930	150: —
N:o 92.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, III. P. 1—140. 29 fig. 3 plances. 1930	250: —
N:o 93.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, IV. P. 1—68. 12 fig. 6 planches. 1931	200: —
N:o 94.	Brenner, Thord. Mineraljordarternas fysikaliska egenskaper. S. 1—159. 22 fig. Deutsches Referat. 1931	350: —
N:o 95.	Sederholm, J. J. On the Sub-Bothnian Unconformity and on Archæan Rocks formed by Secular Weathering. P. 1—81. 62 fig. 1 map. 1931	250: —
N:o 96.	Mikkola, Erkki. On the Physiography and Late-Glacial Deposits in Northern Lapland. P. 1—88. 25 fig. 5 plates. 1932	250: —
N:o 97.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, V. P. 1—77. 15 fig. 1932	200: —
N:o 98.	Sederholm, J. J. On the Geology of Fennoscandia. P. 1—30. 1 map. 1 table. 1932	150: —
N:o 99.	Tanner, V. The Problems of the Eskers. The Esker-like Gravel Ridge of Čahpatoaiv, Lapland. P. 1—13. 2 plates. 1 map. 1932	100: —
N:o 100.	Sederholm, J. J. Über die Bodenkonfiguration des Päijänne-Sees. S.1—23. 3 Fig. 1 karte. 1932	250: —
N:o 101.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, VI. P. 1—118. 17 fig. 5 planches. 1933	250: —
N:o 102.	Wegmann, S. E., Kranck, E. H. et Sederholm, J. J. Compte rendu de la Réunion internationale pour l'étude du Précambrien et des vieilles chaînes de montagnes. P. 1—46. 1933	150: —
N:o 103.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, VII. P. 1—48. 2 fig. 1933	150: —
N:o 104.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, VIII. P. 1—156. 33 fig. 7 planches. 1934	250: —
N:o 105.	Lokka, Lauri. Neuere chemische Analysen von finnischen Gesteinen. S. 1—64. 1934	150: —
N:o 106.	Hackman, Victor. Das Rapakiwirandgebiet der Gegend von Lappeenranta (Willmanstrand). S. 1—82. 15 Fig. 2 Taf. 1 Analysentab. 1 Karte. 1934	200: —
N:o 107.	Sederholm, J. J. † On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Part III. The Åland Islands. P. 1—68. 43 fig. 2 maps. 1934	200: —
N:o 108.	Laitakari, Aarne. Geologische Bibliographie Finnlands 1555—1933. S. 1—224. 1934	250: —
N:o 109.	Väyrynen, Heikki. Über die Mineralparagenesis der Kieserze in den Gebieten von Outokumpu und Polvijärvi. S. 1—24. 7 Fig. 1 Karte. 1935	100: —
N:o 110.	Saksela, Martti. Über den geologischen Bau Süd-Ostbothniens. S. 1—35. 11 Fig. 1 Titelbild. 1 Taf. 1 Karte. 1935	150: —
N:o 111.	Lokka, Lauri. Über den Chemismus der Minerale (Orthit, Biotit u. a.) eines Feldspatbruches in Kangasala, SW-Finnland. S. 1—39. 2 Abbild. 1 Taf. 1935	150: —
N:o 112.	Hackman, Victor. J. J. Sederholm. Biographic Notes and Bibliography. P. 1—29. With a vignette. 1935	100: —

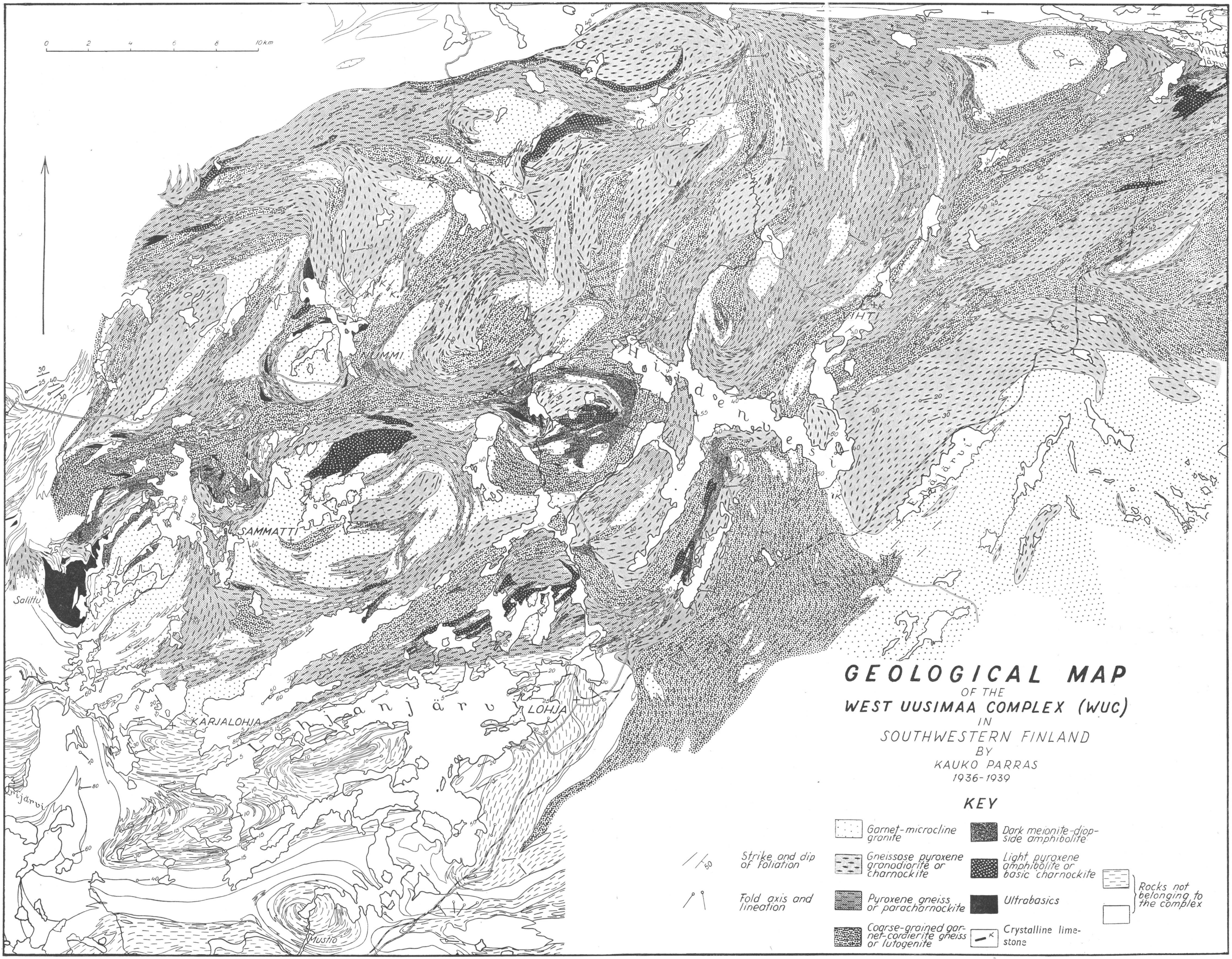
N:o 113.	Sahama (Sahlstein), Th. G. Die Regelung von Quarz und Glimmer in den Gesteinen der finnisch-lappländischen Granulitformation. S. 1—110. 5 fig. 80 Diagr. 3 Taf. 1936	200: —
N:o 114.	Haapala, Paavo. On Serpentine Rocks in Northern Karelia. P. 1—83. 21 fig. 2 maps. 1936	150: —
N:o 115.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, IX. P. 1—505. 83 fig. 20 planches. 1936	500: —
N:o 116.	Väyrynen, Heikki. Petrologie des Nickelerzfeldes Kaulatunturi —Kammikivitunturi in Petsamo. S. 1—198. 71 Abbild. 36 Tab. 1 Karte. 1938	250: —
N:o 117.	Kilpi, Sampo. Das Sotkamo-Gebiet in spätglazialer Zeit. S. 1—118. 36 Abbild. 3 Beil. 1937	250: —
N:o 118.	Brander, Gunnar. Ein Interglazialfund bei Rouhiala in Südostfinnland. S. 1—76. 7 Fig. im Texte u. 7 Fig. auf 2 Taf. 1937	200: —
N:o 119.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, X. P. 1—170. 30 fig. 4 planches. 1937	250: —
N:o 120.	Hyyppä, Esa. Post-Glacial Changes of Shore-Line in South Finland. P. 1—225. 57 fig. 21 tab. 2 append. 1937	250: —
N:o 121.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XI. P. 1—166. 47 fig. 8 tab. 2 cartes. 1938	250: —
N:o 122.	Hietanen, Anna. On the Petrology of Finnish Quartzites. P. 1—118. 20 fig. 2 plates. 3 maps. 1938	250: —
N:o 123.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XII. P. 1—107. 20 fig. 3 planches. 1938	250: —
N:o 124.	Väyrynen, Heikki. On the Geology and Tectonics of the Outokumpu Ore Field and Region. P. 1—91. 11 fig. 2 maps. 1939	250: —
N:o 125.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XIII. P. 1—119. 45 fig. 1 planche. 1939	150: —
N:o 126.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XIV. P. 1—140. 60 fig. 4 planches. 1941	200: —
N:o 127.	Mölder, Karl. Studien über die Ökologie und Geologie der Bodendiatomeen in der Pojo-Bucht. P. 1—204. 7 Abbild. 1 Karte. 14 Diagr. 14 Tab. 1943	250: —
N:o 128.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XV. P. 1—183. 43 fig. 2 planches. 1943	250: —
N:o 129.	Lokka, Lauri. Beiträge zur Kenntnis des Chemismus der finnischen Minerale Glimmer, Pyroxene, Granate, Epidote u. a. Silikatminerale sowie melnikowitähnliches Produkt und Shungit. S. 1—72. 48 Tab. 1943	200: —
*N:o 130.	Hietanen, Anna. Über das Grundbebirge des Kalantigebietes im südwestlichen Finnland. S. 1—105. 55 Fig. 8 Tafeln. 1 Karte. 1943	—
N:o 131.	Okko, V. Moränenuntersuchungen im westlichen Nordfinnland. S. 1—46. 12 Abb. 4 Tab. 1944	150: —
N:o 132.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XVI. P. 1—196. 41 diagr. 9 tabl. 3 vartes. 3 fig. 1944	250: —
N:o 133.	Rankama, Kalervo. On the Geochemistry of Tantalum. P. 1—78. 1 fig. 8 tables. 1944	200: —
N:o 134.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XVII. P. 1—91. 59 fig. carte. 1944	200: —
N:o 135.	Sahama, Th. G. Spurenelemente der Gesteine im südlichen Finnisch-Lappland. S. 1—86. 12 Fig. 29 Tab. 1945	200: —

---

*) Loppuunmyyty.
Out of print.

N:o 136.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XVIII. P. I—XXXVIII; 1—67. 3 diagr. 11 tabl. 2 cartes. 11 fig. 2 planches. 1945	250: —
N:o 137.	Rankama, Kalervo. On the Geochemical Differentiation in the Earth's Crust. P. 1—39. 18 tables. 1946	150: —
N:o 138.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XIX. P. 1—120. 7 diagr. 13 tabl. 9 fig. 1 planche. 1946	250: —
N:o 139.	Brenner, Th. Om mineraljordarternas hållfasthetsegenskaper. S. 1—77. 11 fig. Summary in English. 1946	150: —
N:o 140.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XX. P. 1—302. 37 tabl. 103 fig. 6 planches. 2 cartes. 1947	400: —
N:o 141.	Simonen, Ahti. On the Petrochemistry of the Infracrustal Rocks in the Svecofennidic Territory of Southwestern Finland. P. 1—18. 7 tabl. 5 fig. 1948	50: —
N:o 142.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXI. P. 1—129. 45 fig. 1 planche. 4 tabl. 3 cartes. 1948	250: —
N:o 143.	Simonen, Ahti. On the Petrology of the Aulanko Area in Southwestern Finland. P. 1—66. 25 fig. 6 tabl. 1 map. 1948	150: —
N:o 144.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXII. P. 1—165. 70 fig. 3 plances. 4 cartes. 1949	250: —
N:o 145.	Salmi, Martti. Physical and Chemical Peat Investigations on the Pinomäensuo Bog, SW. Finland. P. 1—31. 12 fig. 1 table. 1949	100: —
N:o 146.	Mikkola, Aimo. On the Geology of the Area North of the Gulf of Bothnia. P. 1—64. 20 fig. 10 tabl. 1 map. 1949	150: —
N:o 147.	Härme, Maunu. On the Stratigraphical and Structural Geology of the Kemi Area, Northern Finland. P. 1—60. 29 fig. 4 tabl. 1 map. 1949	150: —
N:o 148.	Edelman, Nils. Structural History of the Eastern part of the Gullkrona Basin, SW-Finland. P. 1—48. 16 fig. 2 tabl. 8 plates. 1949	150: —
N:o 149.	Lokka, Lauri. Contributions to the Knowledge of the Chemistry of the Radioactive Minerals of Finland. P. 1—76. 7 fig. 33 tabl. 1950	200: —
N:o 150.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXIII. P. 1—111. 27 fig. 7 planches. 5 tabl. 2 cartes. 1950	300: —
N:o 151.	Lokka, Lauri. Chemical Analyses of Finnish Rocks. P. 1—75. 1950	200: —
N:o 152.	Kahma, Aarno. On Contact Phenomena of the Satakunta Diabase. P. 1—84. 22 fig. 10 tabl. 5 plates. 1951	250: —
N:o 153.	Seitsari, Juhani. The Schist Belt Northeast of Tampere in Finland. P. 1—120. 53 fig. 9 tabl. 2 maps. 1951	400: —
N:o 154.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXIV. P. 1—241. 95 fig. 3 planches. 24 tabl. 1951	500: —
N:o 155.	Virkkala, K. Glacial Geology of the Suomussalmi Area, East Finland. P. 1—66. 26 fig. 1 plate. 1951	200: —
N:o 156.	Marmo, Vladi — Mikkola, Aimo. On Sulphides of the Sulphide-bearing Schists of Finland. P. 1—44. 7 fig. 4 plates. 1951	150: —
N:o 157.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXV. P. 1—148. 35 fig. 28 tabl. 1952	450: —
N:o 158.	Neuvonen, K. J. Thermochemical Investigation of the Åkermanite — Gehlenite Series. P. 1—57. 7 fig. 12 tabl. 1952	150: —
N:o 159.	Suomen Geologisen Seuran julkaisuja — Meddelanden från Geologiska Sällskapet i Finland — Comptes Rendus de la Société géologique de Finlande, XXVI.	400: —
N:o 160.	Simonen, Ahti. Stratigraphy and Sedimentation of the Svecofennidic Early Archean Supracrustal Rocks in Southwestern Finland. P. 1—64. 17 fig. 8 tabl. 2 maps. 1953	200: —
N:o 161.	Disler, Jürg. Die Kupferkieslagerstätte von Outokumpu, Finnland. (Ihre Lage, ihre Struktur und ihre Form.) S. 1—114. 39 Fig. 9 Diagr. 4 Taf. 1953	400: —

N:o 162.	Kaitaro, Simo. Geologic Structure of the Late Pre-Cambrian Intrusives in the Åva Area, Åland Islands. P. 1—71. 37 fig. 6 tabl. 1 map. 1953	200: —
N:o 163.	Vaasjoki, Oke. On Migmatites and Ore Mineralizations in the Pernaja District, Southern Finland. P. 1—62. 24 fig. 3 tabl. 1 plate 1 map. 1953	200: —
N:o 164.	Vähätalo, Veikko O. On the Geology of the Outokumpu Ore Deposit in Finland P. 1—99. 9 fig. 13 tabl. 19 plates and 3 maps. 1953	650: —
N:o 165.	Wiik, H. B. Composition and origin of Soapstone. P. 1—57. 11 fig. 6 tabl. 1953	150: —
N:o 166.	Suomen Geologisen Seuran julkaisuja. — Meddelanden från Geologiska Sällskapet i Finland. — Comptes Rendus de la Société géologique de Finlande XXVII. P. 1—106. 16 tabl. 43 fig. 1954	350: —
N:o 167.	Hyyppä, Esa. On the Pleistocene Geology of Southeastern New England. P. 155—225. 33 fig. 1955	200: —
N:o 168.	Suomen Geologisen Seuran julkaisuja. — Meddelanden från Geologiska Sällskapet i Finland. — Comptes Rendus de la Société géologique de Finlande XXVIII. P. 1—141. 63 fig. 34 tabl. 1955	450: —
N:o 169.	Salmi, Martti. Prospecting for Bog-Covered Ore by Means of Peat Investigations. P. 1—34. 6 fig. 8 tabl. 1955	150: —
N:o 170.	Okko, Veikko. Glacial Drift in Iceland, its Origin and Morphology. P. 1—133. 35 fig. and one table in text. 32 fig. in plates I—XVI. 1955	400: —
N:o 171.	Pääkkönen, Veikko. Otanmäki, the Ilmenite-Magnetite Ore Field in Finland. P. 1—71. 41 fig. 19 tabl. 2 plates and 3 maps. 1956	300: —
N:o 172.	Suomen Geologisen Seuran julkaisuja. — Meddelanden från Geologiska Sällskapet i Finland. — Comptes Rendus de la Société géologique de Finlande XXIX. P. 1—100. 24 fig. 30 tabl. 1956	350: —
N:o 173.	Ramdohr, Paul. Die Beziehungen von Fe-Ti-Erzen aus magmatischen Gesteinen. S. 1—19. 2 Diagr. 25 Taf. 1956	400: —
N:o 174.	Savolahti, Antti. The Ahvenisto Massif in Finland. The Age of the Surrounding Gabbro-anorthosite Complex and the Crystallization of Rapakivi. P. 1—96. 22 fig. 11 tabl. and 1 map 1956	350: —
N:o 175.	Salmi, Martti. Peat and Bog Plants as Indicators of Ore Minerals in Vihanti Ore Field in Western Finland. P. 1—22. 6 fig. 1 tabl. 1956	100: —
N:o 176.	Marmo, Vladi. Geology of the Nokia region, Southwest Finland. P. 1—38. 16 figs. 1957	150: —
N:o 177.	Tuominen, Heikki. The Structure of an Archaean Area: Orijärvi, Finland. P. 1—32. 16 figs. 6 plates. 1957	500: —
N:o 178.	Mölder, K., Valovirta, V. und Virkkala, K. Über Spätglazialzeit und frühe Postglazialzeit in Südfinnland. S. 1—49. 9 Abb.	200: —
N:o 179.	Repo, R. Untersuchungen über die Bewegungen des Inlandeises in Nordkarelien. S. 1—178. 114 Abbild. 1 Taf. 1 Karte. 1957	600: —
N:o 180.	Suomen Geologisen Seuran julkaisuja. — Meddelanden från Geologiska Sällskapet i Finland. — Comptes Rendus de la Société géologique de Finlande XXX	400: —
N:o 181.	Parras, Kauko. On the Charnockites in the Light of a Highly Metamorphic Rock Complex in Southwestern Finland. P. 1—137. 24 figs. 13 tables and 1 map. 1958	
N:o 182.	Kouvo, Olavi. Radioactive Age of some Finnish Pre-Cambrian Minerals. P. 1—70. 3 figs. 10 tables. 1958	300: —



GEOLOGICAL MAP
OF THE
WEST UUSIMAA COMPLEX (WUC)
IN
SOUTHWESTERN FINLAND
BY
KAUKO PARRAS
1936-1939