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BY

AHTI SIMONEN

with 49 figures in text, 29 tables

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PREFACE

The deeply eroded section of the pre-Cambrian Svecofennidic folded zone in southern and western Finland is characterized by an abundance of plutonic rocks, mainly granodiorites and granites, whose emplacement was closely connected with the Svecofennidic mountain folding. Field evidence shows that the plutonic rocks penetrate the metamorphic Svecofennidic schists.

In an earlier paper the present author (Simonen, 1953) presented a general picture of the stratigraphy and sedimentation of the Svecofennidic supracrustal rocks in southwestern Finland, stressing the geosynclinal character of the Svecofennian formations. Now he has undertaken to describe the plutonism that has taken place in the root zone of the Svecofennidic geosyncline.

The Svecofennidic plutonic rocks, especially granites, have been described in many geological studies, and the conclusions presented in this paper are based on geological, mineralogical, and chemical data published by various authors. Furthermore, the present study is essentially based on the results of geological remapping operations in southern Finland and East Bothnia carried out by the Geological Survey of Finland under the leadership of the present author. New geological map sheets have been published on the scale 1 : 100 000 with explanatory texts.

The author wishes to thank his colleagues in the Geological Survey for helpful discussions of many problems and to acknowledge the value of geological excursions which afforded an opportunity to see the most noteworthy outcrops of plutonic rocks in the field. He wishes especially to express his appreciation to Mr. Matti Laitala, M. A., Mr. Osmo Nykänen, M. A., and Mrs. Tuula Kuokkanen, who assisted in collecting the mineralogical and chemical data, as well as Mr. Atso Vorma, M. A., who has done the optical determinations published in this paper. To Miss Thyra Åberg and Mrs. Kyllikki Konkola, who drew the maps and diagrams, the author extends hearty thanks.

To the Finnish Scientific Research Council (Valtion luonnontieteellinen toimikunta) the author is very grateful for the financial aid given him.

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HISTORICAL OUTLINES OF THE STUDY OF THE SVECOFENNIDIC PLUTONIC ROCKS

The oldest geological mapping in southern Finland, carried out about one century ago, revealed the fact that the plutonic rocks of the area are younger than the highly metamorphic Svionian crystalline schists. In addition, the age relation between the commonest plutonic rock types became clear. The gneissose, grey-colored »oligoclase granites» were older than the massive, red-colored microcline-rich granites. Sederholm (1893) described these granites as older and younger granites. He believed that the age interval between intrusions of these two granite groups was so great that during it the Bothnian sediments were deposited on the deeply denuded crystalline basement composed of the highly metamorphic Svionian supracrustal rocks and of the older granites. Therefore, the older gneissose granites were called pre-Bothnian granites and the younger massive rocks post-Bothnian granites.

According to Sederholm (1932) every orogenic cycle was associated with intrusions of a granite group and he classified the pre-Cambrian granites in Fennoscandia into four groups. The granites of the first group were connected with the folding of the Svionian supracrustal rocks, the granites of the second group were associated with the diastrophism of the Bothnian strata, and the granites of third group with the Karelidic cycle. The granites of the fourth group were represented by the late pre-Cambrian rapakivi granites which had not taken part in the orogenic movements.

After the life work of Sederholm (1863—1934) great progress has taken place in the knowledge of pre-Cambrian formations of southern Finland. Nowadays there is general agreement that both Svionian and Bothnian formations belong to the supracrustal formations folded during the Svecofennidic orogeny. In the light of the new orogenic classification it is apparent that both the older and younger granites of Sederholm belong to the plutonic rocks of the Svecofennides.

Wahl (1936) presented new lines for the classification of the Svecofennidic plutonic rocks. He stressed the intimate relation that exists between the processes of mountain folding and intrusions of granite groups. In a root zone of the ancient mountain chain there always occur two kinds of granitoids. On the other hand, there are gneissose granites that had intruded at an early stage of the orogenesis and received their present gneissose character during subsequent periods of orogenesis. On the other hand, there are massive, pegmatitic granites which form migmatites. Both these granites belong to a period of mountain folding and are thus of orogenic character. Wahl (1936) called these orogenic granite groups prim-orogenic and ser-orogenic granites. Nowadays these granite groups are usually named synkinematic and late-kinematic granites, according to the terms proposed by Eskola (1930).

The synkinematic intrusive rocks of the Svecofennidic zone in southwestern Finland are mainly gneissose granodiorites associated with more basic differentiates. This fact was already presented by Wahl (1936) and additional data on chemical characteristics of the Svecofennidic gneissose granodiorites have been published by Simonen (1948 a).

New geological studies in southern Finland revealed the fact that the Svecofennidic synkinematic plutonic rocks also include the rocks of the trondhjemite and charnockite suite. The trondhjemite suite of the Kalanti area has been described by Hietanen (1943) while charnockitic plutonic rocks occur in the Turku district (Hietanen, 1947; Metzger, 1945) and in western Uusimaa (Parras, 1941, 1958).

The synkinematic plutonic rocks of southern Finland are represented by the rocks of the granodiorite, trondhjemite and charnockite suites. Most of the investigators have attributed a magmatic origin to these suites, and the different paths of rock differentiation were due to the different amounts of volatile substances in the parent magma (cf. Hietanen, 1943; Simonen, 1948 a).

The late-kinematic plutonic rocks of the Svecofennides in southern Finland are represented by microcline granites, which form migmatites with the Svecofennidic schists and synkinematic intrusive rocks. The granites of the second group of Sederholm, represented by the so-called coast granites of the Hanko type, belong among the late-kinematic granites, whose migmatites have been described in many classical papers written by Sederholm (1907, 1923, 1926, and 1934). The microcline granite provides much field evidence contradictory to the mode of origin resulting from magmatic crystallization. The relict stratigraphy and relict structures, or »old designs», of Wegmann (1935) show that another solid rock, a Svecofennidic crystalline schist or synkinematic plutonic rock, formally occupied the place of the present microcline granite. This makes clear that the process of metasomatic granitization played a great role in the origin of the late-kinematic granites in southern Finland.

Petrochemically, the synkinematic plutonic rocks in southern Finland are characterized by the preponderance of soda over potash, whereas the late-kinematic granites are rich in potash. Furthermore, a marked compositional break occurs between the synkinematic and late-kinematic plutonic rocks (cf. Simonen, 1948 a). Eskola (1956) has pointed out that the so-called ideal granitic composition of the late-kinematic granites does not correspond to the minimum-melting mixture in the eutectoid granite system as established by experimental investigations carried out in the Geophysical Laboratory. The ideal granitic composition is characterized especially by a higher content of K_2O than the eutectoid granite. The excess of potash is caused by the potash metasomatism and the crystallization continued within the hydrothermal range below the minimum temperature of magmatic crystallization.

The separation of the synkinematic and late-linematic plutonic rocks is usually relatively easy in southern Finland, where the orogenic movements have caused a remarkable gneissose texture in the synkinematic rocks, especially at the margins of the concordant plutons. On the other hand, the late-kinematic microcline granites are massive and form migmatites with the schists and synkinematic intrusive rocks. Furthermore, the acid synkinematic plutonic rocks are genetically associated with more basic differentiates, but this is not the case with the late-kinematic granites, which show evidence of potash metasomatism or granitization. Some illuminating examples of granitization of the Svecofennidic plutonic and supracrustal rocks have been described recently by Härme (1958, 1959).

Sederholm's (1897) opinion that the plutonic rocks on the southern side of the Tampere schist belt are older than those of the large granite area of Central Finland has been proved incorrect in the new geological mapping of the area. The plutonic rocks of the Tampere field penetrate the Svecofennidic schists and belong to the intrusions of the Svecofennides, but their characteristics are not very similar to those of the plutonic rocks of southern Finland. Sharp separation of the plutonic rocks in the Tampere area into synkinematic and late-kinematic types is not so easy as in southern Finland, owing to the fact that there are many transitional varieties, ranging from gneissose synkinematic types to massive late-kinematic plutonic rocks. As a general rule, however, it must be mentioned that quartz dioritic and granodioritic plutons and associated basic differentiates usually show slightly developed gneissose margins, whereas potash-rich granites are massive. The migmatites are not so common as in southern Finland. The new geological mapping has shown that the plutonic rock area in Central Finland, north of the Tampere schist belt, described earlier as a wide granite area, consists of many different types of plutonic rocks ranging from ultrabasic to granitic types (Simonen, 1952), and gradual transitions occur between basic and acid varieties. The sharp compositional break between the granodiorites and granites characteristic of the plutonic rocks in southern Finland does not occur. The plutonic rock complex in the Tampere schist belt and the adjoining wide plutonic rock area of Central Finland is designated in this paper as the Svecofennidic granite province, according to the most acid member.

The investigators of the Svecofennidic plutonic rocks in East Bothnia (Mäkinen, 1916; Väyrynen, 1923, 1936; and Saksela, 1935, 1936) have assumed a magmatic origin, but the opinions of various authors on the mutual relationships of the different plutonic rock types are in a great disagreement with each other.

The first comprehensive study of the plutonic rocks in East Bothnia was made by Mäkinen (1916), who concluded that the plutonic rocks are comagmatic and represent a continuous magmatic crystallization series ranging from gabbros to granites. The rocks of this intrusive series penetrate the Svecofennidic schists.

Väyrynen (1923, 1936) studied the plutonic rocks in southern East Bothnia and divided them according to mineral assemblages into two differentation series. Furthermore, he gave different ages for the two series. The older series was represented mainly by the hornblende- and biotite-bearing gneissose granodiorites and the younger series ranges from the basic rocks to the granites, pegmatites, and aplites.

Saksela (1935, 1936) carried out a magmatectonic classification of the plutonic rocks in East Bothnia. He divided the plutonic rocks into synorogenic and late-orogenic intrusion series and both of these series represent a magmatic differentation series ranging from the basic rocks to the granites. The synorogenic rocks are mainly gneissose granites and pegmatites; the late-orogenic rocks range from the peridotites into the granites. Saksela points out that the synorogenic rocks are older than those of the late-orogenic series.

According to Väyrynen and Saksela there are in East Bothnia two independent differentiation series of different age. It should be pointed out, however, that the views of Väyrynen and Saksela concerning the relative ages of the separate plutons differ in many principal points and no valid field evidence has been presented in favor of two differentiation series independent in time. New field work in Middle East Bothnia carried out by Salli (1956) shows that a more acid plutonic rock penetrates a more basic type. This supports Mäkinen's (1916) conception that the plutonic rocks are comagmatic ranging from the peridotites to the granites.

The different mineral associations of the plutonic rocks of southern East Bothnia stressed by Väyrynen (1923) probably do not mean different ages of evolution. They apparently mean only different paths of comagmatic evolution, in the same way as in southern Finland, where the plutonic rocks of the same age have been represented by the granodiorite, trondhjemite, or charnockite provinces with their specific mineral associations. The tectonic classification of Saksela (1935) does not necessarily mean the different ages of his »synorogenic» and »late-orogenic» groups. It shows only the different manner of occurrence of the plutonic rocks in the principal Svecofennidic schist zone and outside it. It seems probable that the intrusions into different tectonic environments have taken place simultaneously from a common parent magma.

In the light of the foregoing discussion we may conclude as a working hypothesis that the Svecofennidic plutonic rocks in East Bothnia are comagmatic (Mäkinen, 1916). The different manner of occurrence stressed by Saksela (1935) has been due to different tectonic environments in the schist zone and outside of it, and the different mineral associations of the plutonic rocks pointed out by Väyrynen (1923) have been caused by different paths of evolution from a common parent magma. This conclusion, based on the principal results of Mäkinen, Saksela, and Väyrynen, is also in good harmony with results obtained in other parts of the Svecofennidic zone. The plutonic rocks in East Bothnia range from peridotites to granites and belong to the Svecofennidic granite province also found in the Tampere area.

The age of the Svecofennidic plutonism has been measured by different methods of radioactive age determinations (Kouvo, 1958; Gerling and Polkanov, 1958). The ages for the synkinematic plutonic rocks range within the limits 1750 — 1850 m.y. No distinct age differences between different synkinematic plutonic rock provinces have been established in the Svecofennidic zone.

PLUTONIC ROCK PROVINCES AND THEIR MINERALOGICAL AND CHEMICAL CHARACTERISTICS

The historical outlines of the research in this field justify dividing the Svecofennidic plutonic rocks into five provinces, as follows:

- — granodiorite province,
- — trondhjemite province,
- — charnockite province,
- — granite province, and
- — migmatite-forming microcline granites.

This paper will attempt to describe the petrographic characteristics of the above-mentioned plutonic rock provinces of the Svecofennides. The petrographic data have been collected from regional geological studies. The mineralogical composition of the rocks is described by means of variation diagrams. The present data on the physical and chemical properties of separate rock-forming minerals are, however, very incomplete, but the collected and new data will be presented in this connection as material for future mineralogical investigations.

The material for the chemical study of the Svecofennidic plutonic rocks is rich. Altogether 148 complete chemical analyses are used to describe the chemical characteristics of the rock provinces by means of variation diagrams. The original, numerical data of the chemical analyses are not presented in this connection; only the references to the original papers are given.

GRANODIORITE PROVINCE

Large areas of the Svecofennidic rock crust in southern Finland consist almost exlusively of granodiorites and quartz diorites. The largest and most homogeneous plutons of these rocks have been met with in the schist belt of the Hämeenlinna—Loimaa area, where the granodiorites and quartz diorites occupy about 50 per cent of the whole area. A geological map of this type district is presented in Fig. 1. The plutonic rocks penetrate the Svecofennidic schists characterized by an abundance of metamorphic basic volcanics.

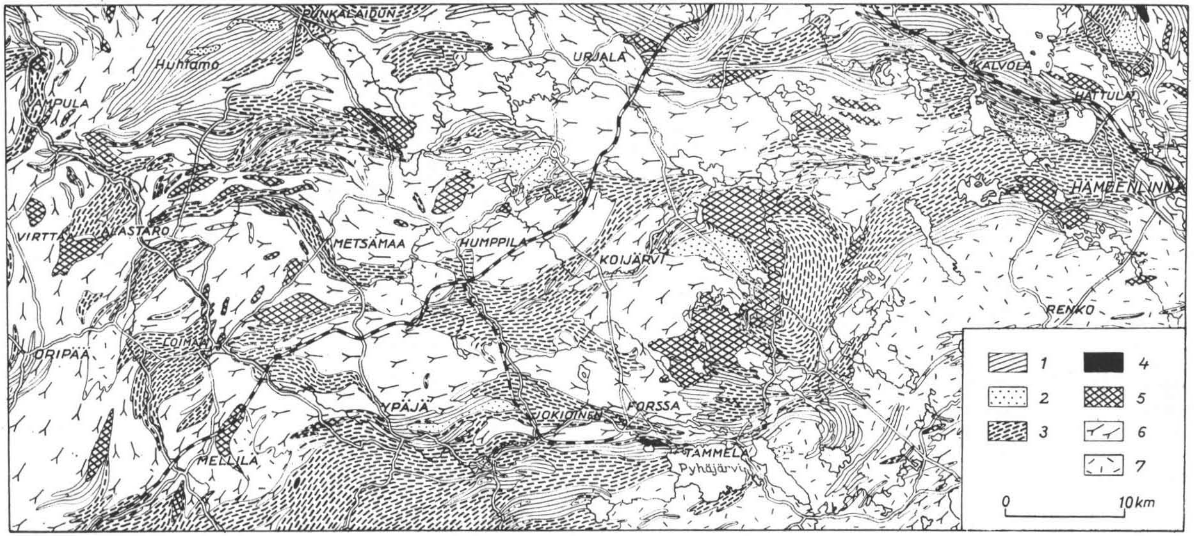

Fig. 1. Geological map of the Loimaa-Hämeenlinna zone in southwestern Finland. 1, mica schists; 2, quartz-feldspar schists; 3, basic metavolcanics; 4, ultrabasic plutonic rocks; 5, gabbros and diorites; 6, quartz diorites and granodiorites; 7, migmatite granite. The map has been drawn according to the new general geological map sheet of Turku (Härme, 1960).

The granodiorites and quartz diorites of the Hämeenlinna—Loimaa zone are associated with minor bodies of ultrabasics, gabbros, and quartz gabbros. Gradual transitions among these plutonic rocks show that the rocks have a genetic relationship owing to a uniform evolution. In addition to the gradual transitions, intrusive contacts among the plutonic rocks of the province are also common. A striking feature of the intrusive contacts is the penetration of basic plutonic rocks of the province by more acid members.

The distribution of the different plutonic rock types of the granodiorite province in the new geological map sheets of Loimaa (Salli, 1953) and Forssa (Neuvonen, 1956) is as follows:

ultrabasics	0.1 %
gabbros and diorites	14.9 %
quartz diorites and granodiorites	85.0 %

The ultrabasic plutonic rocks are partly peridotites, containing serpentinized olivine, diopsidic pyroxene and hornblende, and partly hornblendites. The predominant mafic mineral of the gabbros is hornblende and relics of diopsidic pyroxene surrounded by hornblende have occasionally been found. The mafic minerals of the quartz diorites and granodiorites are hornblende and biotite. The hornblende is commonly surrounded by biotite. The reaction series of the mafic minerals in the granodiorite province is as follows:

olivine → diopside → hornblende → biotite.

Plagioclase is the predominant salic mineral of the province and its content does not show great variations in the rock series gabbro-quartz diorite-granodiorite. The content of anorthite in plagioclase decreases gradually from the gabbros to the granodiorites, and zoned plagioclase with a more anorthitic core is common.

The plutonic rocks of the granodiorite province form a continuous series from basic members to granodiorites. The reaction series of mafic and salic minerals are similar to those of magmatic origin by crystallization differentiation.

Only small bodies of a potash-rich granite have been found in the granodiorite areas of Loimaa-Hämeenlinna. Neuvonen (1956) has pointed out the marked break in the mineralogical composition between the granodiorite and potash granite of the area, and Salli (1953) has produced evidence of a metasomatic origin of the potash granites. The known data show that the potash granites do not belong to the granodiorite province as the most acid end member, but represent outposts of the large microcline granite area south of the Loimaa—Hämeenlinna zone (cf. Fig. 1). The evidence for the potash metasomatism of the granodiorites is as a whole very rare in the middle part of the granodiorite area. At the rand zone against the southern migmatite granite area there has been found, however, evidences of slight granitization, as in the case of the Aulanko granodiorite area (Simonen, 1948 b).

The plutonic rocks of the granodiorite province have also been described from many other areas in southern Finland (Orijärvi area, Eskola 1914; Pellinge area, Sederholm 1923; Åland islands, Sederholm 1934; etc.). In many places the rocks of this province have been attacked by a later granitization, but there are also many areas where the primary composition is well preserved.

A characteristic feature of all the areas composed of granodiorites is that the granodiorite is the most acid member of the province and the silicic types are quantitatively more abundant than the associated peridotites and gabbros. According to planimetric determinations on the new geological maps of southern Finland, the distribution of the different members of the granodiorite province is as follows:

peridotite	0.5 %
gabbro and diorite	20.1 %
quartz diorite and granodiorite	79.4 %

These proportions are very similar to those observed in the Loimaa—Hämeenlinna area.

To illustrate the mineralogical as well as chemical composition of the rocks of the granodiorite province, the author has collected the data published in many regional geological studies. The chemically studied data used and references to the original papers are listed in Table I.

Variations in the mineralogical composition of the rocks are presented in Figs. 2 and 3. These diagrams show a continuous mineralogical series ranging from gabbros to granodiorites.

The nomenclature of the plutonic rocks used in the geological investigations of the Svecofennides has been ambiguous. In the oldest investigations the term »granite» has been applied, for example, to all plutonic rocks containing free quartz. In the newest geological mapping the term »granite» has been used only for silicic rocks whose Or > Ab + An. A different usage appears also in the terms »diorite», »quartz diorite», and »granodiorite». Based on the collected mineralogical data of the granodiorite province, the following classification will be presented:

A. Plutonic rocks without free quartz.

1. Ultrabasic rocks. Color-index is > 90. To this group belong specimens 1, 3, and 4 in Fig. 2.

Table I. Analysed plutonic rocks of the granodiorite province from southwestern Finland.

No	Name of the rock	Locality	Reference
1	Ultrabasic rock	Susimäki, Vampula	Palmunen, 1925
2	Gabbro	Vadviken, Attu	Edelman, 1949 a
3	Ultrabasic rock	Pyhälampi, Suomusjärvi	Eskola, 1914
4	Ultrabasic rock	Naantali	Hietanen, 1947
5	Anorthosite	Kleven, Mustio	Härme, 1954 b
6	Gabbro	Attu	Perman, 1927
7	Gabbro	Skogsböle, Kemiö	Lokka, 1950
8	Gabbro	Tunnholm, Porvoo	Sederholm, 1923
9	Gabbro	Stadslandet, Pernaja	Sederholm, 1923
10	Gabbro	Djupläten, Hiittinen	Edelman, 1956
11	Gabbro	Bällby, Mustio	Härme, 1954 b
12	Anorthosite	Susimäki, Vampula	Palmunen, 1925
13	Gabbro	Tunnholm, Porvoo	Sederholm, 1923
14	Gabbro	Lemnäs, Kemiö	Lokka, 1950
15	Gabbro	Kytäjä, Hyvinkää	Härme, 1954 a
16	Gabbro	Vattola, Pyhäjärvi	Härme, 1954 a
17	Anorthosite	Sajaniemi, Loppi	Härme, 1954 a
18	Gabbro	Sepänlampi, Kisko	Eskola, 1914
19	Gabbro	Sorpo	Edelman, 1949 a
20	Quartz gabbro	Mäkijärvi, Kisko	Eskola, 1914
21	Quartz gabbro	Ruostejärvi, Somero	Simonen, 1956
22	Quartz gabbro	Räntämäki	Hietanen, 1947
23	Quartz gabbro	Tvärminne	Sederholm, 1912
24	Quartz gabbro	Haavisto, Pyhäjärvi	Härme, 1954 a
25	Quartz gabbro	Sorpo	Edelman, 1949 a
26	Quartz diorite	Saloisjärvi, Tammela	Neuvonen, 1956
27	Quartz gabbro	Tömäjärvi	Simonen, 1948 b
28	Quartz diorite	Räntämäki	Hietanen, 1947
29	Quartz diorite	Kumlinge	Lokka, 1934
30	Quartz diorite	Söderskatan, Sundärö	Sederholm, 1923
31	Quartz diorite	Pöytyä	Hietanen, 1947
32	Quartz diorite	Sorpo	Edelman, 1949 a
33	Granodiorite	Våtskär	Sederholm, 1923
34	Quartz diorite	Myllymäki, Hämeenlinna	Simonen, 1948 b
35	Granodiorite	Ypäjä	Neuvonen, 1956
36	Granodiorite	Parola	Simonen, 1948 b
37	Quartz diorite	Peräjoki, Forssa	Neuvonen, 1956
38	Granodiorite	Vanaja	Simonen, 1948 b
39	Granodiorite	Påvskär, Ingå	Sederholm, 1926
40	Granodiorite	Orijärvi	Eskola, 1914
41	Quartz diorite	Bockholm, Kumlinge	Sederholm, 1934
42	Granodiorite	Öster Rysskär, Pernaja	Sederholm, 1923

2. Anorthosites and anorthositic gabbros and diorites. Main mineral is plagioclase and color-index is < 50. To this group belong specimens 12, 5, and IX. Also specimens XIII is related to this group, although it contains minute amounts of free quartz.

3. Gabbros. Color-index of normal gabbros is > 50. To this group belong specimens 6, I, 18, 11, and II in Fig. 2.

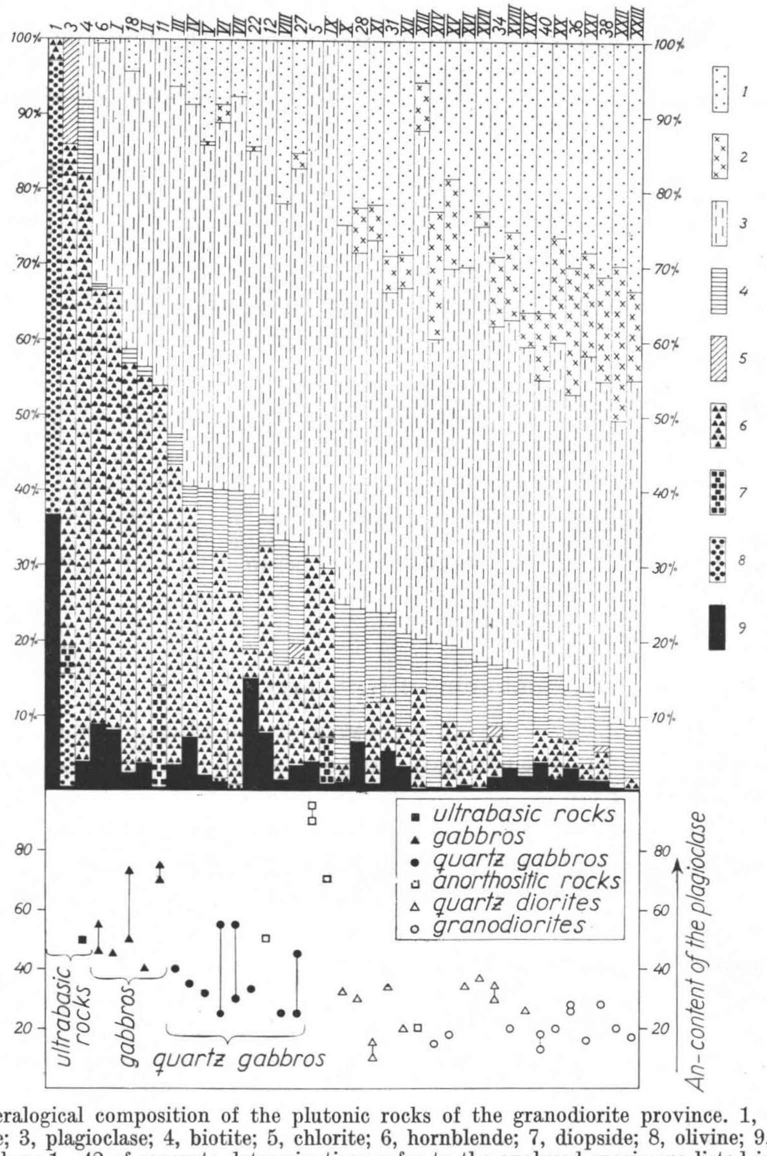

Fig. 2. Mineralogical composition of the plutonic rocks of the granodiorite province. 1, quartz; 2, microcline; 3, plagioclase; 4, biotite; 5, chlorite; 6, hornblende; 7, diopside; 8, olivine; 9, accessories. Numbers 1—42 of separate determinations refer to the analysed specimens listed in Table I. Nos. I—XXIII represent petrographically studied rocks as follows: I, gabbro, Halkjärvi, Somero; II, gabbro, Halkjärvi, Somero; III, quartz gabbro, Vahermajärvi, Pusula; IV, quartz gabbro, Vahermajärvi, Pusula; V, quartz gabbro, Suonpää, Jokioinen; VI, quartz gabbro, Koijärvi; VII, quartz gabbro, Männilä, Kalvola; VIII, quartz gabbro, Halkivaha, Ypäjä; IX, anorthosite, Ilojärvi, Tammela; X, quartz diorite, Nuutajärvi, Urjala; XI, quartz diorite, Lähteenmäki, Kalvola; XII, quartz diorite, Mikkola, Ypäjä; XIII, anorthositic diorite, Ohtisjärvi, Kalvola; XIV, granodiorite, Kotkajärvi, Kalvola; XV, granodiorite, Jänhijoki, Jokioinen; XVI, quartz diorite, Metsämaa; XVII, quartz diorite, Särkijärvi, Urjala; XVIII, granodiorite, Tienhaara, Koijärvi; XIX, quartz diorite, Loimaa; XX, granodiorite, Riihimäki, Forssa; XXI, granodiorite, Ilvesoja, Koijärvi; XXII, granodiorite, Peräjoki, Jokioinen; XXIII, granodiorite, Välijärvi, Tammela. I—IV have been described by Simonen (1956), V—XV, XVII, XVIII, XX—XXIII by Neuvonen (1956), and XVI, XIX by Salli (1953).

Table II. Average mineralogical composition of the plutonic rocks of the granodiorite province.

	1	2	3	4	5	6
Quartz	—	1.3	1.0	11.9	27.0	28.0
Microcline	—	1.6	—	0.8	4.0	14.1
Plagioclase	2.7	67.5	38.4	48.3	48.1	43.3
Biotite	3.3	2.6	0.7	11.7	13.2	9.5
Chlorite	4.7	—	—	0.3	0.1	0.1
Hornblende	49.3	22.2	52.6	23.3	5.1	3.1
Pyroxene	1.2	1.6	2.7	0.2	—	—
Olivine	25.1	—	—	—	—	—
Accessories	13.7	3.2	4.6	3.5	2.5	1.9

1. Ultrabasic rock (3 determinations; Nos. 1, 3—4 in Fig. 2).
2. Anorthosite (4 determinations; Nos. 5, 12, IX, and XIII in Fig. 2).
3. Gabbro (5 determinations; Nos. 6, 11, 18, I—II in Fig. 2).
4. Quartz gabbro (8 determinations; Nos. 22, 27, III—VIII in Fig. 2).
5. Quartz diorite (9 determinations; Nos. 28, 31, 34, X—XII, XVI—XVII, XIX in Fig. 2).
6. Granodiorite (10 determinations; Nos. 36, 38, 40, XIV—XV, XVIII, XX—XIII in Fig. 2).

B. Plutonic rocks containing free quartz.

4. Quartz gabbros. A striking feature of the plutonic rocks with color-index 30—50 is that they contain small amounts of free quartz. These rocks have been usually named diorites, but their high amount of mafic minerals and the geological occurrence in a close connection with normal gabbros tend support to the term »quartz gabbro». To this group belong specimens III—VIII, 22, and 27 in Fig. 2. The commonly used term »diorite» is not applicable to these rocks, because their color-index is higher than that of diorite (< 30) and they regularly contain free quartz, not present in normal diorite.
5. Quartz diorites. Color-index is < 30 and An $>$ Or. To this group belong specimens X, 28, XI, 31, XII, XVI, XVII, 34, and XIX in Fig. 2.
6. Granodiorites. The color-index is < 30 and Or $>$ An, but Or $<$ Ab. To this group belong specimens XIV, XV, XVIII, XX—XXIII, 36, 38, and 40 in Fig. 2.

The average mineralogical composition of the afore-mentioned rock types of the granodiorite province are presented in Table II. Average compositions are plotted also in the diagram (Fig. 3) showing variations in the mineralogical composition of the granodiorite province as a function of the silica content. This variation diagram shows clearly a marked continu-

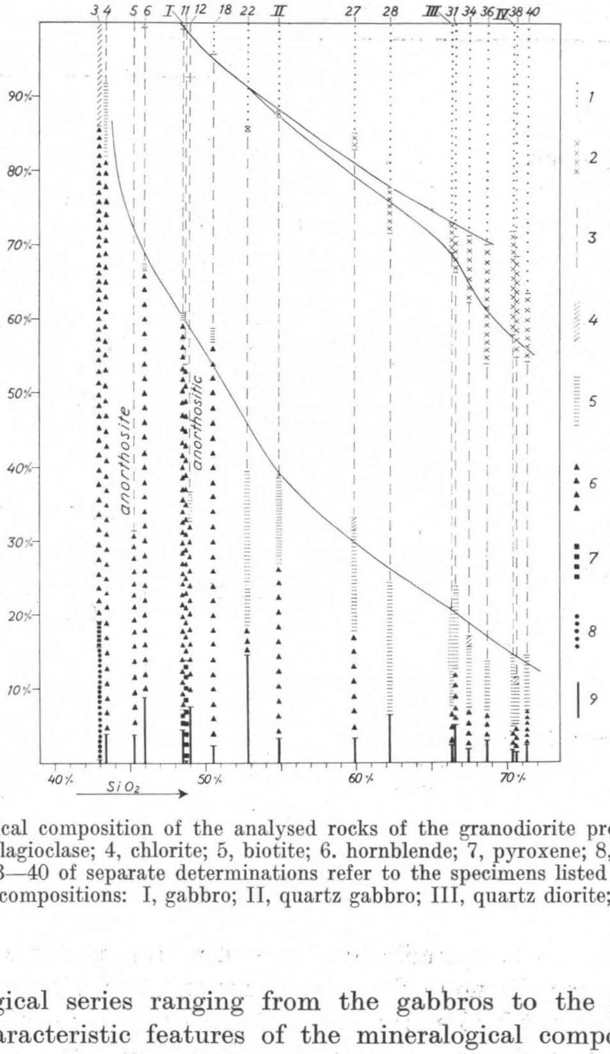

Fig. 3. Mineralogical composition of the analysed rocks of the granodiorite province. 1, quartz; 2, microcline; 3, plagioclase; 4, chlorite; 5, biotite; 6. hornblende; 7, pyroxene; 8, olivine; 9, accessories. Numbers 3—40 of separate determinations refer to the specimens listed in Table I. Average mineralogical compositions: I, gabbro; II, quartz gabbro; III, quartz diorite; IV, granodiorite.

ous mineralogical series ranging from the gabbros to the granodiorites. The most characteristic features of the mineralogical composition are as follows:

Hornblende is the most typical mafic mineral and the association hornblende-biotite, showing the so-called meta-aluminous reaction type of Shand (1949), is characteristic of the plutonic rocks containing free quartz.

Plagioclase is the predominant salic mineral and its content is highest in quartz gabbros and quartz diorites, decreasing towards both the basic and acid members.

Some notes on the occurrence and on the physical and chemical properties of the separate rock-forming minerals of the granodiorite province are given in the following.

Table III. Refractive indices of the rock-forming minerals.

	Reference	α	β	γ
Monoclinic pyroxene:				
Ultrabasic rock (peridotite)	3[1]		1 638	
Gabbro	11	1 675	—	1 702
Anorthosite	17	1 665	1 691	1 710
Gabbro, Vampula	Salli, 1953	1 684	—	1 716
Hornblende:				
Ultrabasic rock (peridotite)	3	—	1 635	—
Ultrabasic rock (hornblendite)	4	1 661	—	1 682
Anorthosite	5	1 631		1 653
Anorthosite	12	1 649	1 660	1 672
Anorthosite	17	1 665	—	1 686
Gabbro	6	1 641	1 656	1 668
Gabbro	11	1 636	—	1 659
Gabbro	18		1 639	
Quartz gabbro	27	1 672	1 684	1 694
Quartz diorite	34	1 662	—	1 684
Quartz diorite, Kalvola		1 666	1 676	1 686
Quartz diorite, Pusula		1 672	1 683	1 690
Granodiorite, Pöytyä	Huhma, 1959	1 680	—	1 702
Granodiorite, Koijärvi		1 682	1 690	1 698
Granodiorite	40		1 688	—
Biotite:				
Ultrabasic rock (hornblendite)	4		1 650	
Anorthosite	12		1 639	
Gabbro	6		1 625	
Quartz gabbro	27		1 649	
Quartz diorite, Kalvola			1 648	
Granodiorite, Koijärvi................			1 651	

Olivine occurs only sporadically in the ultrabasic plutonic rocks. Chemical analysis of the olivine in the ilmenite-magnetite olivinite from Susimäki has been carried out by Palmunen (1925). This analysis (Table IV, anal. 1) and optical properties ($\alpha = 1.721$; $\beta = 1.748$, $\gamma = 1.757$) show the composition Fa_{45}. A more magnesian-rich olivine has been found in the peridotite from Suomusjärvi. Its refractive index is $\beta = 1.674$ (Eskola, 1914). The refractive indices of the olivine in the peridotite from Mustio are $\gamma = 1.690$, $\beta = 1.710$, $\gamma = 1.729$ (Härme, 1954).

Monoclinic pyroxene has been found in ultrabasic and basic varieties. Minute remains surrounded by the hornblende occur sporadically in quartz gabbros. No chemical analysis of the pyroxene has been carried out, but refractive indices are given in Table III.

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[1]) The numbers in this column refer to the analysed specimens listed in Table I.

Table IV. Chemical composition of rock-forming minerals of the granodiorite province.

	1	2	3	4	5	6
SiO_2	35.41	49.32	47.81	46.36	36.74	35.75
TiO_2	0.47	1.20	0.94	1.54	5.40	2.73
Al_2O_3	1.30	9.38	8.80	6.46	15.72	14.08
Fe_2O_3		1.89	0.18	3.98	0.44	3.36
FeO	36.66	5.77	15.10	16.22	16.90	20.68
MnO	0.54	0.16	0.34	0.44	0.06	0.31
MgO	25.22	16.12	12.12	9.84	9.76	8.61
CaO	0.16	13.22	12.27	10.53	5.88	0.31
Na_2O	0.26	0.34	0.44	0.94	2.13	0.55
K_2O		0.16	1.94	0.97	2.53	9.05
H_2O+	} 0.38		} 0.16	2.23	} 4.84	3.94
H_2O-				0.49		0.34
	100.40	97.56	100.10	100.00	100.40	99.71

1. Olivine in ilmetite-magnetite olivinite (No. 1 in Table I). Susimäki, Vampula (Palmunen, 1925).
2. Hornblende in peridotite (No. 3 in Table I). Pyhälampi, Suomusjärvi (Eskola, 1914).
3. Hornblende in anorthosite (No. 12 in Table I). Susimäki, Vampula (Palmunen, 1925).
4. Hornblende in quartz diorite (No. 34 in Table I). Aulanko (Simonen, 1948 b).
5. Biotite in anorthosite (No. 12 in Table I). Susimäki, Vampula (Palmunen, 1925).
6. Biotite in quartz diorite (No. 34 in Table I). Aulanko (Simonen, 1948 b).

Hornblende occurs both in the basic and acid rock types of the granodiorite province. Variations in the composition of the hornblende are illustrated by three chemical analyses (Table IV, anal. 2—4) and the optical properties are given in Table III. The chemical data available show that the ratio of (FeO) : (MgO) increases with the increasing silica content of the plutonic rock type. The optical properties of the hornblende also indicate an enrichment in the content of FeO towards the acid rock types. Great variations in the optical proportions of the hornblende occur in the anorthositic rocks, supporting the idea that the anorthosites may have been separated from the magmas whose composition ranges from gabbro to quartz diorite. The optical properties of the hornblende in the hornblendite are similar to those in quartz diorites, giving the idea that the hornblendite has been crystallized from a quartz dioritic magma.

Biotite is a common mineral in silicic members of the province, but minute amounts of biotite are present also in gabbros containing free quartz. Fig. 2 shows that the biotite and the quartz have a close sympathetic relation appearing simultaneously. The chemical and optical properties of the biotite are little known. Two analyses are available and show the increase of the ratio (FeO) : (MgO) with the acidity of the host rock (Table IV, anal.

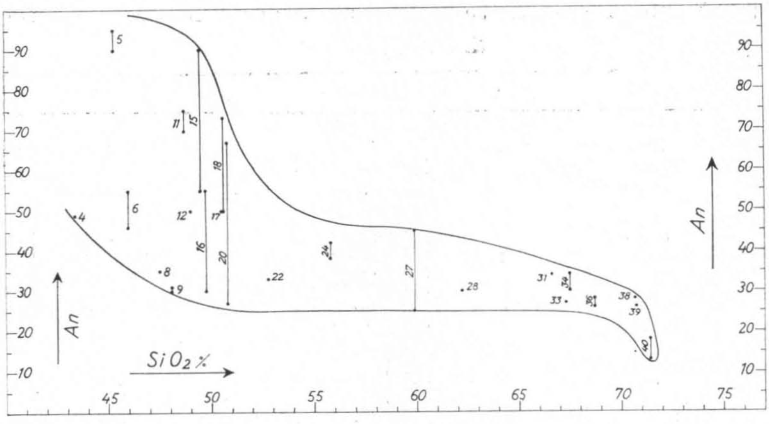


Fig. 4. Composition of plagioclase in the plutonic rocks of the granodiorite province. The numbers of separate determinations refer to the specimens listed in Table I.

5—6). The refractive indices of the biotite (Table III) show also an enrichment in the content of FeO towards the acid members. The high refractive index of the biotite in the hornblendite is in harmony with the high indices of the hornblende in the same rock.

Plagioclase is the predominant salic mineral of the plutonic rocks of the granodiorite province. With the exception of the anorthosites, its content is highest in the quartz gabbros and quartz diorites and slowly decreases towards the basic and acid members. The composition of the plagioclase ranges between wide limits, as is shown in Figs. 2 and 4. The content of anorthite decreases gradually with an increasing content of silica (Fig. 4). A zoned texture of the plagioclase with an anorthite-rich core is common.

Microcline is regularly present in the acid rocks of the granodiorite province also in the areas where no signs of potash metasomatism have been found. Therefore, the microcline must be considered as a primary

Table V. Accessory minerals of the granodiorite province.

	Spinel	Chromite	Serpentine	Pyrrhotite	Pyrite	Carbonate	Magnetite	Chlorite	Apatite	Epidote	Sericite	Sphene	Leucocene	Zircon	Orthite
Ultrabasic rocks	x	x	x	x	x		x	x	x						
Anorthosites					x	x	x	x	x	x	x	x			
Gabbros					x		x	x	x	x	x	x	x		
Quartz gabbros					x		x	x	x	x	x	x	x	x	
Quartz diorites							x	x	x	x	x	x	x	x	x
Granodiorites							x	x	x	x	x	x	x	x	x

Table VI. Average chemical composition of the plutonic rocks of the granodiorite province.

	1	2	3	4
SiO_2	48.68	54.90	66.49	70.40
TiO_2	1.23	1.31	0.76	0.47
Al_2O_3	15.84	16.74	14.71	14.10
Fe_2O_3	1.87	2.15	1.14	1.01
FeO	7.31	7.56	4.08	2.53
MnO	0.17	0.13	0.07	0.08
MgO	8.61	3.68	1.59	1.01
CaO	11.61	7.32	4.26	3.10
Na_2O	1.73	2.94	3.62	3.71
K_2O	0.72	1.82	2.00	2.70
P_2O_5	0.13	0.41	0.25	0.35
H_2O	1.76	0.92	0.87	0.65
	99.66	99.88	99.84	100.11

1. Gabbro (12 analyses; Nos. 6—11, 13—16, and 18—19 in Table I).
2. Quartz gabbro (7 analyses; Nos. 20—25, and 27 in Table I).
3. Quartz diorite (9 analyses; Nos. 26, 28—32, 34, 37 and 41 in Table I).
4. Granodiorite (7 analyses; Nos. 33, 35—36, 38—40, 42 in Table I).

component of the rocks. In the granodiorites occurring in the surroundings where granitization has taken place, a secondary increase of the microcline content is, however, common.

Quartz is sparsely present in the rocks containing over 30 % of the mafic minerals (quartz gabbros) and its content regularly increases toward the acid members.

Accessory minerals of the granodiorite province are listed in Table V. No detailed study of the accessory minerals of the different rock types has been carried out and Table V is based only on the short petrographic notes on the thin sections studied.

Chemical properties of the granodiorite province are presented by variation diagrams (Figs. 5 and 6) and average chemical compositions of principal rock types are given in Table VI.

Average compositions (Table VI) are similar to calcic plutonic rocks of many orogenic zones. The alkali-lime index of the granodiorite province is 62 (Simonen, 1948 a). The chemistry of the granodiorite province shows a gradual transition from gabbros to granodiorites characterized by a regular increase in the ratios (FeO) : (MgO) and ($Na_2O + K_2O$): (CaO).

Variation diagrams of Niggli (Fig. 5) show that the plutonic rocks of the granodiorite province form a continuous, well-limited series typical of a differentiation series. Deviations from the »differentiation curves» are in general very small.

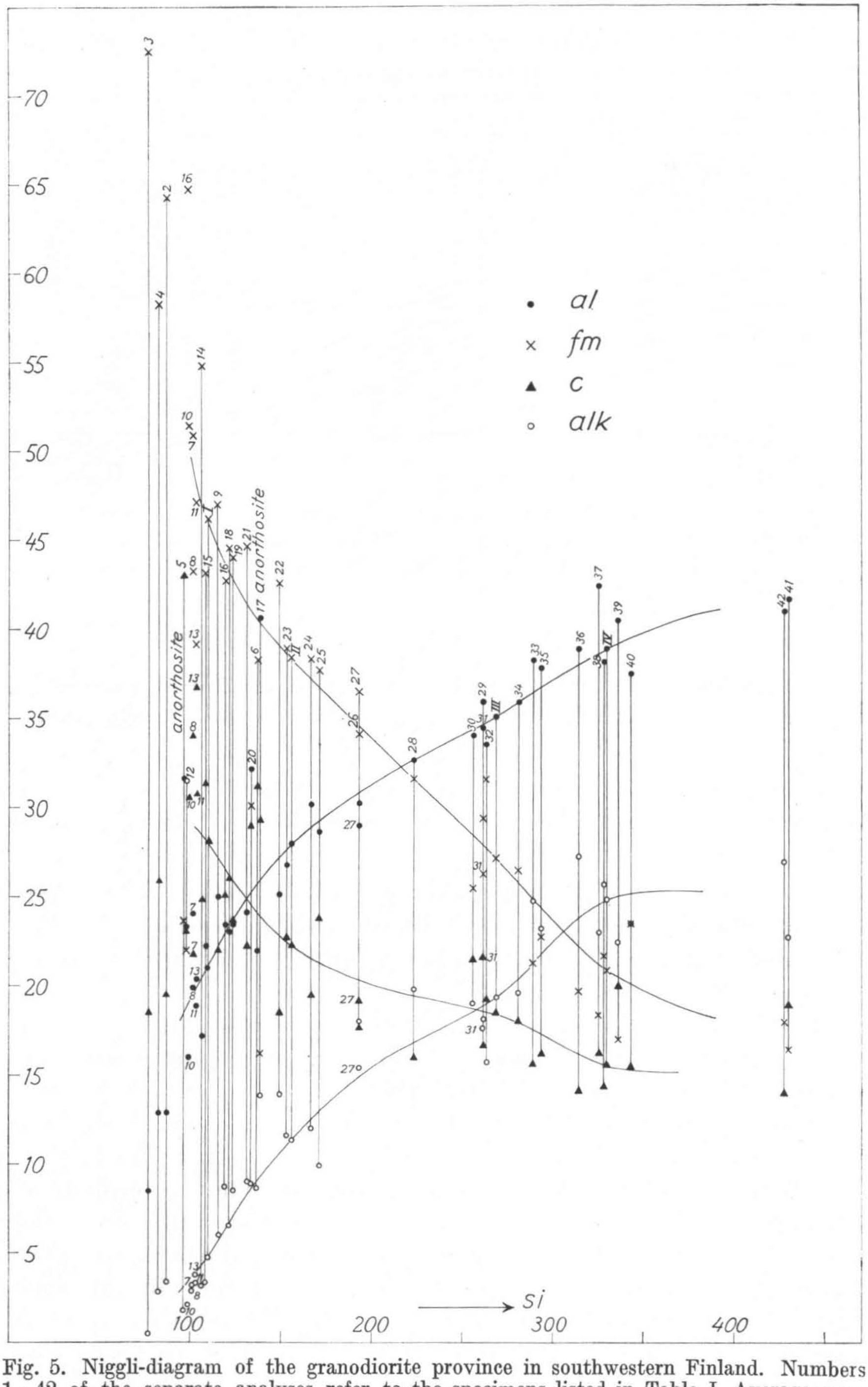


Fig. 5. Niggli-diagram of the granodiorite province in southwestern Finland. Numbers 1—42 of the separate analyses refer to the specimens listed in Table I. Average compositions: I, gabbro; II, quartz gabbro; III, quartz diorite; IV, granodiorite.

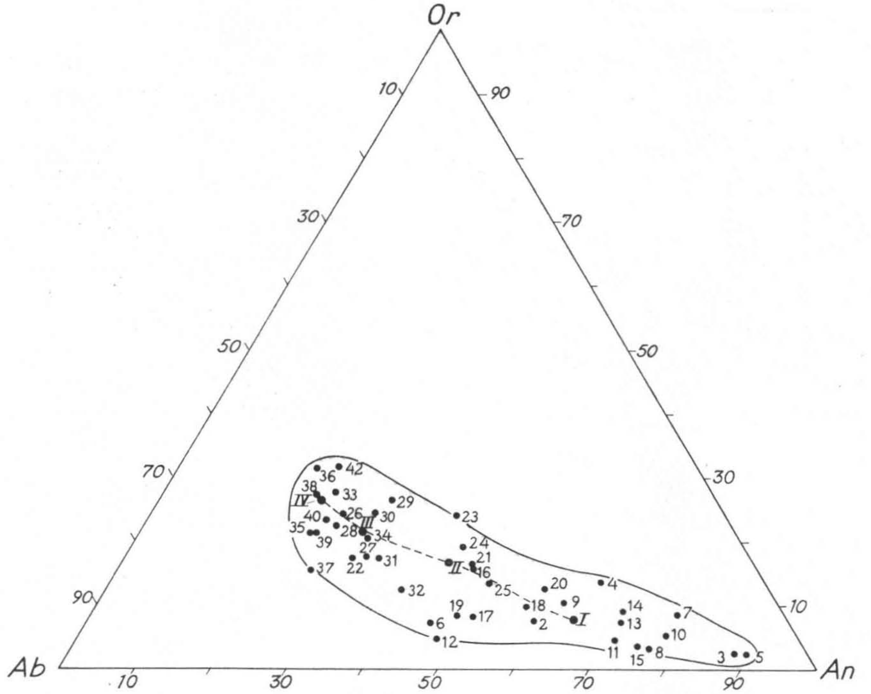


Fig. 6. The normative proportions Or : Ab : An in the plutonic rocks of the granodiorite suite. Numbers 1—42 of the separate determinations refer to the specimens listed in Table I. Average compositions: I, gabbro; II, quartz gabbro; III, quartz diorite; IV, granodiorite.

Normative proportions Or :Ab : An (Fig. 6) show also that the plutonic rocks of the granodiorite province form a well-limited field, which does not continue into the granite field. Granodiorites are characterized by a preponderance of soda feldspar over potash feldspar. Normative proportions Q : Ab : Or (Fig. 39) show that the evolution in the granodiorite province does not lead to an eutectoid granite composition.

TRONDHJEMITE PROVINCE

The trondhjemite suite of the Svecofennidic plutonic rocks has been described by Hietanen (1943) from the Kalanti area in southwestern Finland (Fig. 7). Plutonic rocks of this type area are intrusive in the schist belt, consisting chiefly of highly metamorphic mica gneisses or kinzigites. According to Hietanen (1943) the trondhjemitic plutonic rocks are products of magmatic crystallization from a water-rich magma and the crystallization of biotite at an early phase of magmatic evolution has produced the end

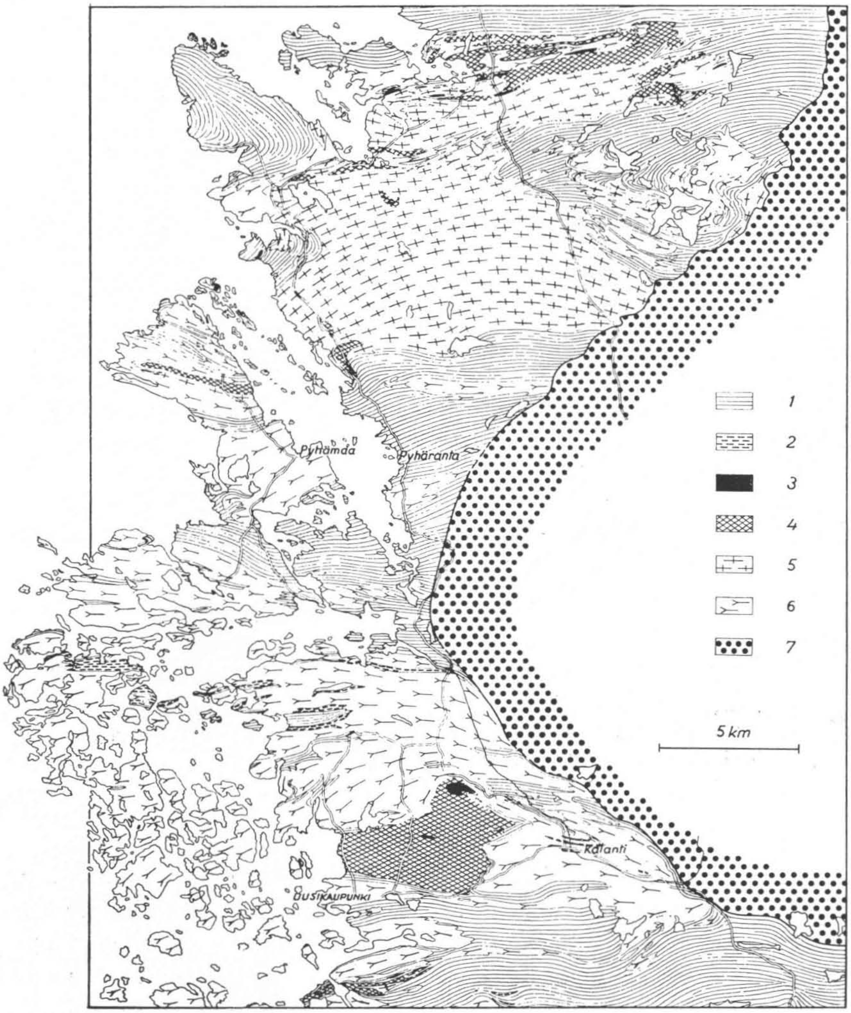


Fig. 7. Geological map of the Kalanti area in southwestern Finland. 1, mica gneiss (kinzigite); 2, amphibolite; 3, gabbro; 4, diorite; 5, diorite trondhjemite; 6, trondhjemite; 7, rapakivi granite. The map has been drawn according to the geological map published by Hietanen (1943).

members poor in potash. It is probable that the parent magma of the trondhjemites has received its high water content from argillaceous sediments in the area.

The trondhjemite province is characterized by a predominance of acid plutonic rocks. The distribution of different plutonic rock types in the Kalanti area (cf. Simonen, 1948 a) is as follows:

Gabbro	2.3 %
Diorite [1])	7.9 %
Diorite trondhjemite [1])	29.1 %
Trondhjemite	60.7 %

The afore-mentioned rock types of the Kalanti area form, according to Hietanen (1943), a comagmatic petrographic province. Gradual transitions between different varieties and observed reaction series support a magmatic origin.

Plutonic rocks of the trondhjemite province continue from the Kalanti area to the Turku district (Hietanen, 1947) and eastwards to the parishes of Koski and Marttila (Huhma, 1959). Sporadic occurrences have been met with also in the geological map sheet of Salo (Lehijärvi, 1957). The whole area occupied by trondhjemites is characterized by an abundance of highly metamorphic argillaceous sediments, whereas the trondhjemites do not occur in the schist belts consisting of basic volcanics. This manner of occurrence supports the thesis that only an environment containing water-rich sediments has been suitable for the evolution of the trondhjemites.

The mineralogical composition of trondhjemites is presented in Figs. 8—9 and Table VIII. Chemically studied specimens and references to the original papers are listed in Table VII.

Nomenclature of Finnish trondhjemites is based on the investigation of Hietanen (1943). She classified the plutonic rocks of the trondhjemite suite as follows:

1. Hornblendites
2. Gabbros
3. Diorites
4. Diorite-trondhjemites. This group is further divided into pyroxene-, hornblende-, and biotite-bearing types.
5. Trondhjemites. This group is divided into a) biotite- rich trondhjemites, b) »normal» trondhjemites, and c) »Tropfenquarz» trondhjemites.
6. Trondhjemite pegmatites.

Hietanen (1943) has described thoroughly typical representatives of the afore-mentioned rock groups, but she does not give exact limits dividing the different groups from each other. The only limit given is that separating the diorite-trondhjemites from trondhjemites. This is based on the anorthite

[1]) According to the terminology used in this paper, diorites are quartz gabbros and diorite trondhjemites belong to the quartz diorite group. Hence the gabbroidic rocks form about 1/10 of the total area of the plutonic rocks in the Kalanti district.

Table VII. Analysed plutonic rocks of the trondhjemitic province in southwestern Finland.

N:o	Rock name	Locality	Reference
1	Gabbro	Ruonanperä, Kalanti	Hietanen, 1943
2	Gabbro	Tynki, Kalanti	Hietanen, 1943
3	Quartz gabbro	Orivo, Kalanti	Hietanen, 1943
4	Quartz gabbro	Ruonanperä, Kalanti	Hietanen, 1943
5	Quartz dioritic trondhjemite	Metsämaa	Salli, 1953
6	Quartz dioritic trondhjemite	Sundholm, Uusikaupunki	Hietanen, 1943
7	Quartz dioritic trondhjemite	Sundholm, Uusikaupunki	Hietanen, 1943
8	Quartz dioritic trondhjemite	Halikko	Lehijärvi, 1957
9	Quartz dioritic trondhjemite	Ketteli, Pyhämaa	Hietanen, 1943
10	Quartz dioritic trondhjemite	Uskela, Salo	Lehijärvi, 1957
11	Quartz dioritic trondhjemite	Merimarsku	Hietanen, 1947
12	Quartz dioritic trondhjemite	Masku	Hietanen, 1947
13	Quartz dioritic trondhjemite	Loimaa	Salli, 1953
14	Granodioritic trondhjemite	Haidus, Uusikaupunki	Hietanen, 1943
15	Quartz dioritic trondhjemite	Lepiäinen, Uusikaupunki	Hietanen, 1943
16	Granodioritic trondhjemite	Isokorola, Lokalahti	Hietanen, 1943
17	Quartz dioritic trondhjemite	Kuntikari, Uusikaupunki	Hietanen, 1943
18	Granodioritic trondhjemite	Iso Heinäinen, Uusikaupunki	Hietanen, 1943
19	Granodioritic trondhjemite	Halikko	Lehijärvi, 1957
20	Granodioritic trondhjemite	Suurikkala, Kalanti	Hietanen, 1943
21	Granodioritic trondhjemite	Maurunmaa, Kalanti	Hietanen, 1943
22	Quartz dioritic trondhjemite	Elkkyinen, Kalanti	Hietanen, 1943
23	Granodioritic trondhjemite	Hiujärvi, Kalanti	Hietanen, 1943

content of plagioclase, which is $> An_{25}$ in the diorite trondhjemites and $< An_{25}$ in the trondhjemites. In Hietanen's classification the term »diorite» does not represent a leucocratic plutonic rock without free quartz as is a common usage of the term »diorite», but the diorites of Hietanen are melanocratic, quartz-bearing rocks showing a quartz-gabbroidic character with the color-index > 30. For the diorite-trondhjemites of Hietanen the term quartz dioritic trondhjemite is more correct.

The gabbroidic rocks of the trondhjemite province are mineralogically as well as chemically very similar to basic rocks of the granodiorite province. Therefore, the nomenclature of gabbroidic members of both the provinces mentioned must be similar. Mineralogical and chemical characteristics different from the rocks of the granodiorite province appear in the silicic members of the trondhjemite province and the term »trondhjemite» may be applied to these rocks. The author presents the classification of the plutonic rocks of the trondhjemite province as follows:

1. Ultrabasic rock. The color-index is > 90. To this group belong hornblendites found as small bodies.

2. Gabbro. Color-index is > 50. To this group belong specimens 1 and 2 in Fig. 8.

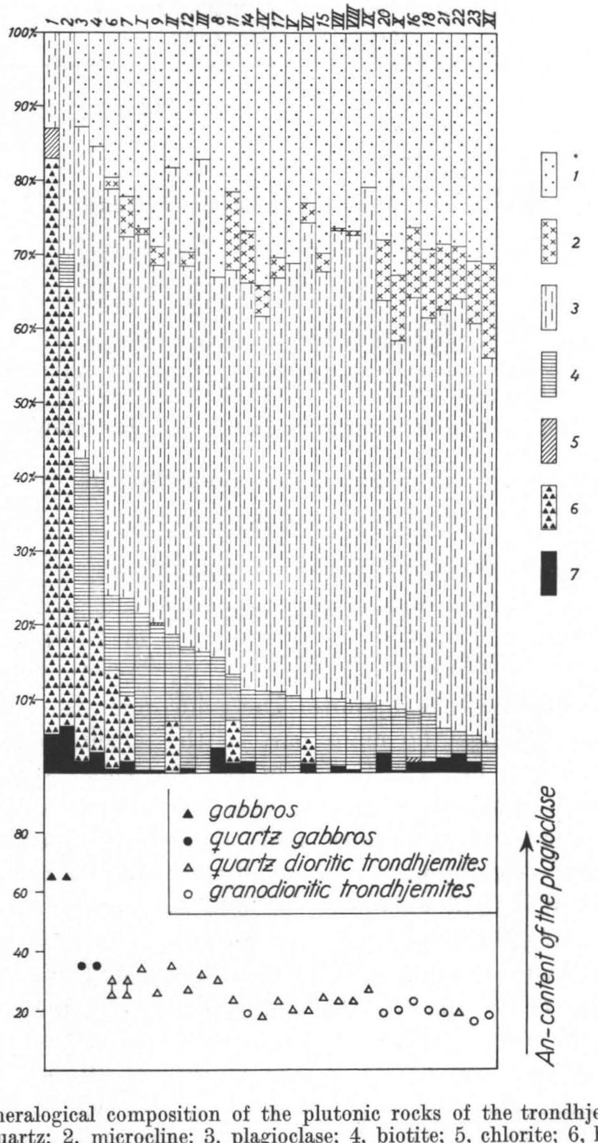


Fig. 8. Mineralogical composition of the plutonic rocks of the trondhjemite suite. 1, quartz; 2, microcline; 3, plagioclase; 4, biotite; 5, chlorite; 6, hornblende; 7, accessories. Nos. 1—23 of the separate determinations refer to the analysed specimens listed in Table VII. Nos. I—XI represent the petrographically studied specimens as follows: I, quartz dioritic trondhjemite, Prunkila, Tarvasjoki; II, quartz dioritic trondhjemite, Ollila, Marttila; III, quartz dioritic trondhjemite, Taipale, Koski; IV, quartz dioritic trondhjemite, Tiskarla, Kuusjoki; V, quartz dioritic trondhjemite, Tautila, Paimio; VI, quartz dioritic trondhjemite, Tiskarla, Kuusjoki; VII, quartz dioritic trondhjemite, Kallela, Tarvasjoki; VIII, quartz dioritic trondhjemite, Tiipilä, Marttila; IX, quartz dioritic trondhjemite, Taipale, Koski; X, granodioritic trondhjemite, Kraatarla, Kuusjoki; XI, granodioritic trondhjemite, Patakoski, Koski, Specimens I—XI have been described by Huhma (1959).

Table VIII. Average mineralogical composition of plutonic rocks of the trondhjemite province.

	1	2	3	4	5
Quartz	—	14.1	20.9	28.0	29.2
Microcline	—	—	4.0	1.7	9.1
Plagioclase	21.5	44.7	57.2	57.4	54.4
Biotite	2.2	20.6	9.1	12.1	6.1
Chlorite	2.0	—	—	0.1	0.1
Hornblende	68.2	18.5	7.9	—	—
Accessories	6.1	2.3	1.0	1.0	1.1

1. Gabbro (2 determinations; Nos. 1—2 in Fig. 8).
2. Quartz gabbro (2 determinations; Nos. 3—4 in Fig. 8).
3. Hornblende-bearing quartz dioritic trondhjemite (5 determinations; Nos. 6—7, 11, II, and VI in Fig. 8).
4. Biotite-bearing quartz-dioritic trondhjemite (13 determinations; Nos. 8—9, 12, 15, 17, 22, I, III—V, VII—IX in Fig. 8).
5. Granodioritic trondhjemite (9 determinations; Nos. 14, 16, 18—21, 23, X, and XI in Fig. 8).

3. Quartz gabbro. Color-index is 30—50. To this group belong specimens 3 and 4 in Fig. 8, representing the diorites in Hietanen's (1943) terminology.

4. Quartz dioritic trondhjemite. The color-index is < 30 and An > Or. To this group belongs the main part of the specimens studied (numbers 6—9, 11, 12, 15, 17, 22, I—IX in Fig. 8). This group may be divided into hornblende- and biotite-bearing quartz dioritic trondhjemites. Biotite-bearing types are usually more acid than those containing hornblende. Quartz dioritic trondhjemites, especially the biotite-bearing types, show both mineralogical and chemical features different from those of quartz diorites belonging to the granodiorite province.

5. Granodioritic trondhjemite or trondhjemite. The color-index is < 30 and normative Or > An. To this group belong the specimens 14, 16, 18, 20, 21, 23, X and XI in Fig. 8. These rocks differ from the granodiorites in respect to their remarkably higher content of albite.

Average mineralogical compositions of rocks of the trondhjemite province are presented in Table VIII. A comparison with the averages of the granodiorite province (Table II) shows the following differences. The gabbros associated with trondhjemites are hornblenditic, containing more hornblende and less plagioclase than the gabbros of the granodiorite province. The quartz gabbros of both provinces are mineralogically closely related; the only difference is an abundance of biotite in the quartz gabbros associated with trondhjemites. The acid trondhjemites contain more plagioclase than the granodiorites, and the most silicic members of the trondhje-

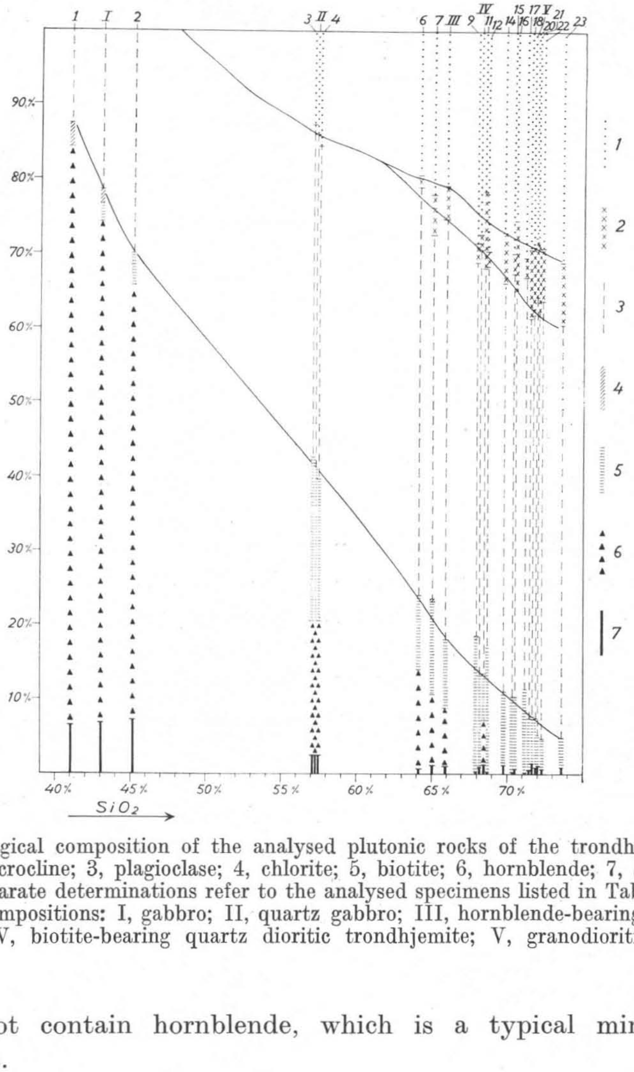


Fig. 9. Mineralogical composition of the analysed plutonic rocks of the trondhjemite province. 1, quartz; 2, microcline; 3, plagioclase; 4, chlorite; 5, biotite; 6, hornblende; 7, accessories. Nos. 1—23 of the separate determinations refer to the analysed specimens listed in Table VII. Average mineralogical compositions: I, gabbro; II, quartz gabbro; III, hornblende-bearing quartz dioritic trondhjemite; IV, biotite-bearing quartz dioritic trondhjemite; V, granodioritic trondhjemite.

mites do not contain hornblende, which is a typical mineral of the granodiorites.

Mineralogical composition of the trondhjemite province shows a continuous series from gabbros into the acid trondhjemites (Fig. 9) and the most characteristic features in the mineralogy are as follows:

Hornblende is the most characteristic mafic mineral of gabbros. Quartz gabbros are characterized by a meta-aluminous association of hornblende and biotite. This same association occurs also in the hornblende-bearing quartz dioritic trondhjemites, whereas hornblende does not occur in the most acid members of the province.

Plagioclase is the predominant salic mineral of the all rock types of the trondhjemite province and its content is highest in the silicic members.

Table IX. Refractive indices of the rock-forming minerals of the trondhjemite province.

Hornblende:		γ
Gabbro	1[1])	1 676
Quartz gabbro	3	1 668
Quartz gabbro	4	1 668
Quartz dioritic trondhjemite	6	1 669
Quartz dioritic trondhjemite.....	7	1 678
		$\beta = \gamma$
Biotite:		
Quartz gabbro	3	1 653
Quartz gabbro	4	1 653
Quartz dioritic trondhjemite.....	8	1 665
Quartz dioritic trondhjemite.....	10	1 658
Trondhjemite	14	1 657

Some notes on the occurrence and the physical and chemical properties of separate rock-forming minerals are given below.

Hornblende occurs in basic and intermediate members of the province, but it is totally lacking in the acid trondhjemites. The optical properties of hornblende are given in Table IX. No chemical analyses are available, but optical determinations show that no great variations in ratio (FeO) : (MgO) occur.

Biotite is present in quartz-bearing varieties. No great variations in the optical properties of biotite (Table IX) have been found.

Plagioclase is the predominant salic mineral of the trondhjemites. The total amount of plagioclase is highest in the acid members and the plagioclase becomes gradually more albitic with an increasing silica content in the rock type (cf. Fig. 10).

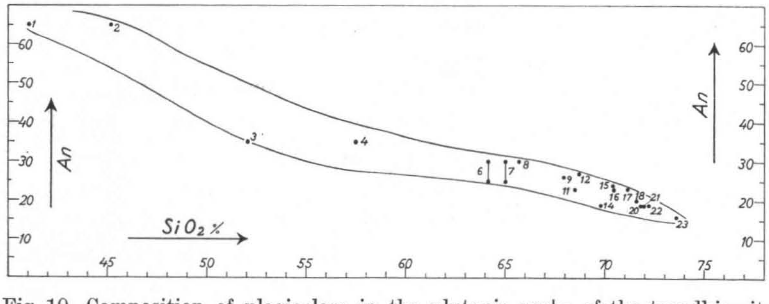


Fig. 10. Composition of plagioclase in the plutonic rocks of the trondhjemite province. The numbers of separate determinations refer to the specimens listed in Table VII.

1) Numbers in this colum refer to the specimens listed in Table VII.

Table X. Accessory minerals of the trondhjemite province.

	Sphene	Magnetite	Apatite	Chlorite	zircon	Calcite	Monazite	Orthite	Muscovite	Rutile	Garnet
Gabbros	x	x	x	x							
Quarts gabbros	x	x	x	x							
Quartz dioritic trondhjemites											
a. hornblende-bearing	x	x	x	x	x	x					
b. biotite-bearing	x	x	x	x	x	x	x	x	x	x	x
Granodioritic trondhjemites		x	x	x	x			x	x	x	x

Microcline is sparsely present in the acid members of the province. In the areas where granitization has taken place, a secondary increase of microcline is common and it is in many cases difficult to say what is the primary content of microcline.

Quartz is sparsely present in the gabbroidic rocks of the province and its amount regularly increases towards the silicic members.

Accessory minerals are listed in Table X. They are not quite similar to those met with in the granodiorite province. The most characteristic accessory minerals of the acid trondhjemites are monazite and rutile, which, so far as is known, do not occur in the granodiorite province.

Table XI. Average chemical composition of the plutonic rocks of the trondhjemite province.

	1	2	3	4	5
SiO_2	43.12	57.30	65.92	68.20	71.62
TiO_2	1.83	1.04	0.35	0.50	0.31
Al_2O_3	14.56	16.14	16.16	16.22	15.33
Fe_2O_3	3.04	1.00	1.17	0.48	0.49
FeO	9.87	6.30	2.64	2.94	1.69
MnO	0.15	0.13	0.06	0.04	0.03
MgO	10.30	4.86	2.19	1.17	0.57
CaO	12.72	6.39	4.22	3.37	2.13
Na_2O	1.66	3.44	4.87	4.54	5.28
K_2O	0.55	1.89	1.65	1.65	2.02
P_2O_5	0.07	0.15	0.06	0.23	0.06
H_2O+	2.28	1.16	0.93	0.68	0.56
H_2O-	0.07	0.13	0.22	0.05	0.10
	100.22	99.93	100.44	100.07	100.19

1. Gabbro (2 analyses; Nos. 1—2 in Table VII).
2. Quartz gabbro (2 analyses; Nos. 3—4 in Table VII).
3. Hornblende-bearing quartz dioritic trondhjemite (3 analyses; Nos. 6—7 and 11 in Table VII).
4. Biotite-bearing quartz dioritic trondhjemite (9 analyses; Nos. 5, 8, 9, 10, 12, 13, 15, 17 and 22 in Table VII).
5. Granodioritic trondhjemite (7 analyses; Nos. 14, 16, 18—21 and 23 in Table VII).

5 3509—60/1,74

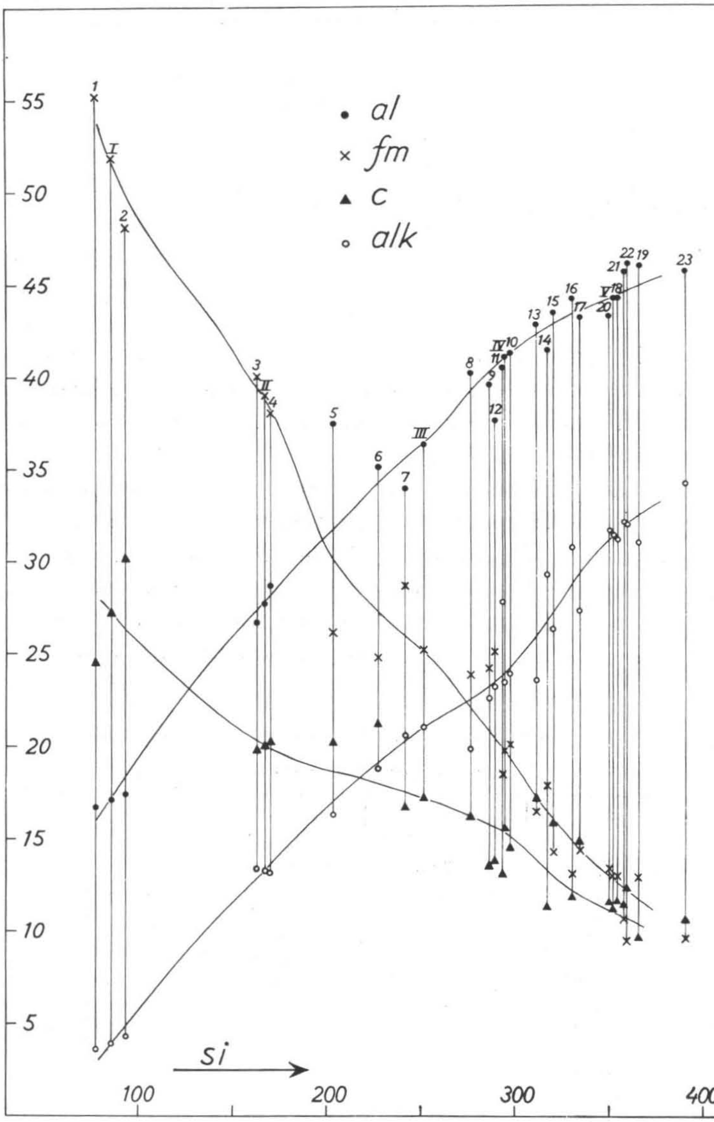


Fig. 11. Niggli diagram of the trondhjemite province. Nos. 1—23 of separate analyses refer to the specimens listed in Table VII. Average compositions: I, gabbro; II, quartz gabbro; III, hornblende-bearing quartz dioritic trondhjemite; IV, biotite-bearing quartz dioritic trondhjemite; V, granodioritic trondhjemite.

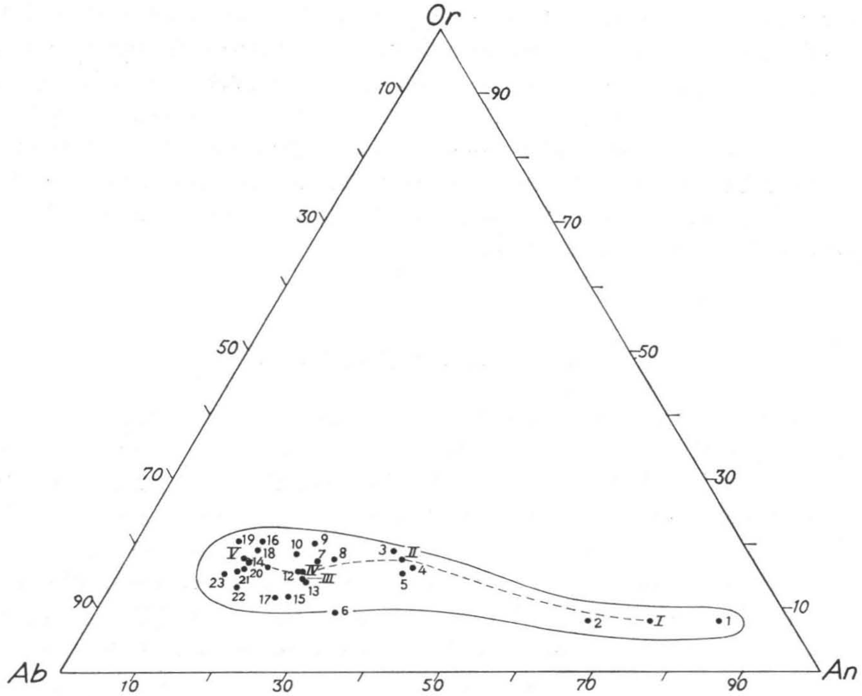


Fig. 12. Normative proportions Or : Ab : An in the rocks of the trondhjemite province. Nos. 1—23 of separate determinations refer to the specimens listed in Table VII. Average compositions: I, gabbro; II, quartz gabbro; II, hornblende-bearing quartz dioritic trondhjemite; IV, biotite-bearing quartz dioritic trondhjemite; V, granodioritic trondhjemite.

Average chemical compositions (Table XI) show that ratios (FeO) : (MgO) and (Na_2O + K_2O)) : (CaO) increase gradually from basic to acid members, as is the case in magmatic rock series. Comparison with corresponding averages of the granodiorite province (cf. Table VI) shows that the quartz gabbroidic and more acid plutonic rocks of the trondhjemite province contain more soda and less lime than the rocks of the granodiorite province. It seems to the author that this marked difference has not been caused only by different paths of magmatic evolution of a common parent magma, but it means a slight primary compositional difference between the parent magmas. The alkali-lime index of the trondhjemite province is, according to Hietanen (1943), 61.

Variation diagrams of Niggli show well-defined continuous differentiation curves. Acid branch of the trondhjemites deviates clearly from the granodiorites. This characteristic has been pointed out earlier by Simonen (1948 a).

Normative proportions Or : Ab : An (Fig. 12) show that different rock types of the trondhjemite province form a well-defined, continuous field characterized by a preponderance of soda feldspar over potash feldspar. A comparison with the corresponding diagram of the granodiorite province (Fig. 6) shows that the acid branch of the trondhjemites deviates clearly from the acid branch of the granodiorites. Normative proportions Q : Ab : Or (Fig. 26) show that the trondhjemites deviate remarkably from an eutectoid granite composition.

CHARNOCKITE PROVINCE

Charnockite plutonic rocks occur in the Svecofennides of southern Finland in the Turku district and in western Uusimaa. The petrography of these rocks has been given in the investigations of Hackman (1923), Metzger (1945), Hietanen (1947) and Parras (1941, 1958). The charnockites are surrounded by highly metamorphic schists characterized by kinzigites and pyroxene-bearing gneisses. They penetrate the Svecofennidic schists and represent Svecofennidic synkinematic plutonic rocks. The charnockitic plutonic rocks are chiefly quartz dioritic in composition and they are associated with small bodies of ultrabasics and noritic gabbros. Field evidence in the Turku district described by Hietanen (1947) shows that the charnockites are closely related to the trondhjemites and all gradations have been observed between rocks of the trondhjemite and charnockite provinces. The acid trondhjemites form the most acid end member of the charnockite series and in some plutonic bodies it is possible to observe the gradual transition from charnockite into an acid trondhjemite.

As a type area of the charnockite province a geological map of the West Uusimaa Complex described by Parras (1958) is given (Fig. 13). Plutonic rocks of this area are mainly quartz dioritic charnockites, and they occur in a metamorphic environment characterized by crystalline schists of granulite facies. The microcline granites of the area do not belong as an acid member to the charnockite province, because a marked compositional break occurs in mineralogical as well as in chemical composition between the pyroxene-bearing acid charnockites and microcline granites.

The mineralogical composition of the charnockites is presented in Figs. 14—15 and the chemically studied specimens with references to the original papers are listed in Table XII.

In classifying the charnockitic plutonic rocks the author has followed the same principles as in the classification of rocks of the granodiorite and trondhjemite provinces. The classification of petrographically studied rocks given in Fig. 14 is as follows.

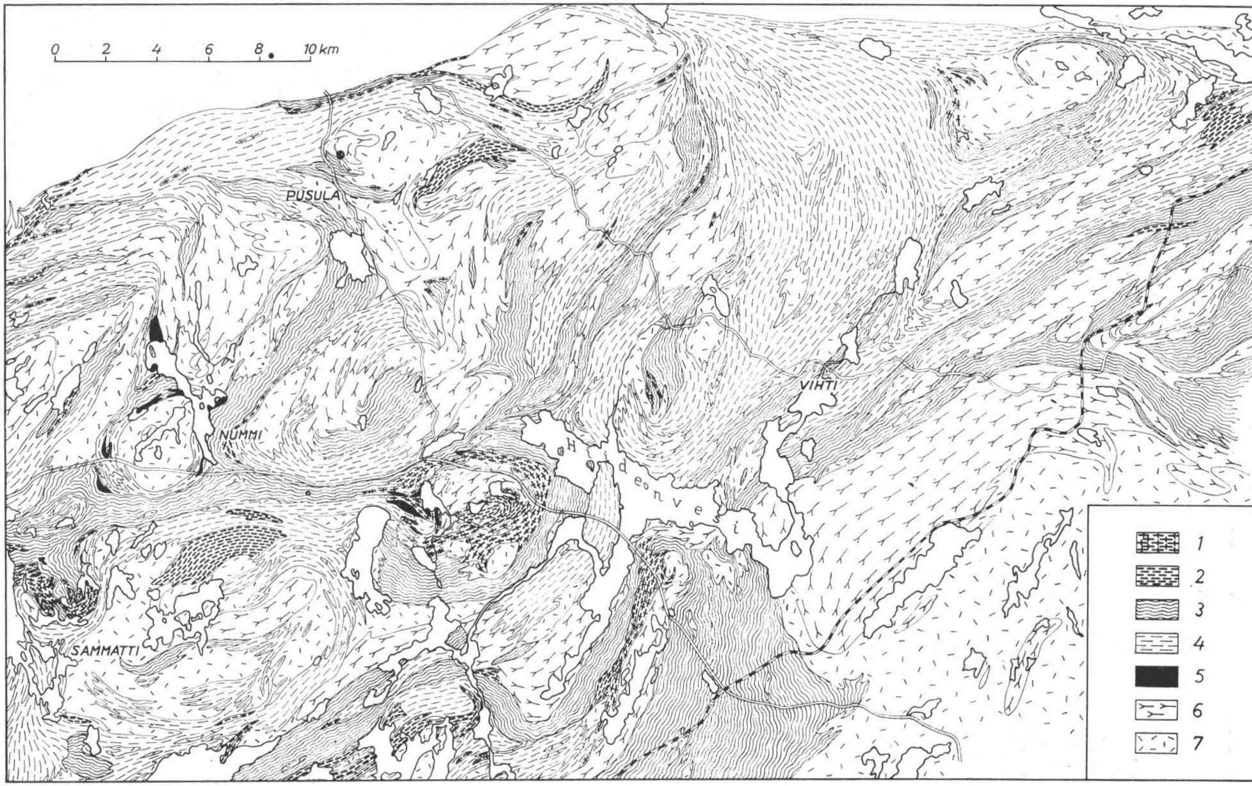


Fig. 13. Geological map of Western Uusimaa in southern Finland. 1, dark meionite-diopside amphibolite; 2, light pyroxene amphibolite; 3, coarse-grained garnet-cordierite gneiss; 4, pyroxene gneiss; 5, ultrabasics; 6, gneissose pyroxene quartz diorite or charnockite; 7, microcline granite. The map has been drawn according to the geological map published by Parras (1941, 1958).

Table XII. Analysed plutonic rocks of the charnockite province in southwestern Finland.

N:o	Rock name	Locality	Reference
1	Noritic gabbro	Masku	Hietanen, 1947
2	Noritic gabbro	Nummi	Parras, 1958
3	Noritic gabbro	Merimasku	Hietanen, 1947
4	Noritic gabbro	Nummi	Parras, 1958
5	Quartz dioritic charnockite	Vampula	Salli, 1953
6	Quartz dioritic charnockite	Nummi	Parras, 1958
7	Quartz dioritic charnockite	Vihti	Parras, 1958
8	Quartz dioritic charnockite	Vihti	Parras, 1958
9	Quartz dioritic charnockite	Halikko	Lehijärvi, 1957
10	Quartz dioritic charnockite	Merimasku	Hietanen, 1947
11	Quartz dioritic charnockite	Rymättylä	Hietanen, 1947
12	Granodioritic charnockite	Uusikaupunki	Hietanen, 1943
13	Quartz dioritic charnockite	Nummi	Parras, 1958

1. Noritic gabbros. Color-index is > 30. This group may be classified into two subgroups: a) hornblende-rich noritic gabbros, and b) noritic gabbros, whose main mafic mineral is pyroxene. Color-index of hornblende-rich noritic gabbros (Nos. I, 1, and 3 in Fig. 14) is > 50. These gabbros are very similar to the gabbros associated with the rocks of the granodiorite and trondhjemite provinces. Color-index of the pyroxene-bearing noritic gabbros is 30—50. They also contain remarkable amounts of biotite. To this group belong the rocks (Nos. II—VII, 2, and 4 in Fig. 14) named in earlier investigations mainly as pyroxene diorites. Noritic gabbros usually contain only a small percentage of free quartz, but typical noritic quartz gabbros do not occur. The absence of quartz gabbroidic varieties is a characteristic feature of the charnockite province.

2. Anorthositic diorite charnockite. Color-index is < 30. Main mineral is plagioclase rich in anorthite (An_{45}—$_{60}$). Biotite usual in other varieties of the province is sparse or totally lacking. To this group belong the specimens VIII, and XI in Fig. 14.

3. Quartz dioritic charnockite. Color-index is < 30, and An > Or. To this group belongs the greatest part of the studied specimens (Nos. IX, X, XII, XIII, XIV, 7—11, 13 in Fig. 14). Pyroxene and biotite are the main mafic minerals.

4. Granodioritic charnockite. Color-index is < 30 and Or > An. These plutonic rock types are very rare, because the pyroxene does not usually seem to be present in acid granodioritic types. The most acid members of the charnockite province are represented by granodioritic trondhjemites, containing biotite as mafic mineral. Typical granodioritic charnockites with An < Or have not been found among the specimens described. The

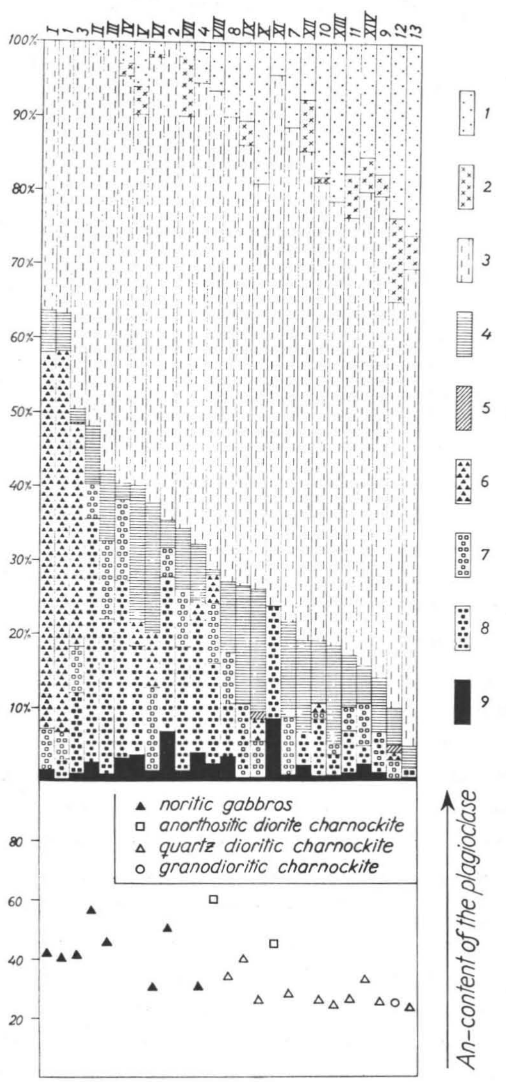


Fig. 14. Mineralogical composition of rocks of the charnockite province. 1, quartz; 2, microcline; 3, plagioclase; 4, biotite; 5, chlorite; 6, hornblende; 7, diopside; 8, hypersthene; 9, accessories. Numbers 1—13 refer to analysed specimens listed in Table XII. Numbers I—XIV represent petrographically studied rocks as follows: I, noritic gabbro, Naantali (Hietanen, 1947); II, noritic gabbro, Kakskerta (Hackman, 1923); III, noritic gabbro, Kakskerta (Hackman, 1923); IV, noritic gabbro, Kalkholmen (Metzger, 1945); V, noritic gabbro, Kalkholmen (Metzger, 1945); VI, noritic gabbro, Merimarsku (Hietanen, 1947); VII, noritic gabbro, Kalkholmen (Metzger, 1945); VIII, anorthositic diorite charnockite, Askainen (Hietanen, 1947); IX, quartz dioritic charnockite, Vampula (Salli, 1953); X, quartz dioritic charnockite, Askainen (Hietanen, 1947); XI, anorthositic diorite charnockite, Kakskerta (Hackman, 1923); XII, quartz dioritic charnockite, Strandby (Metzger, 1945); XIII, quartz dioritic charnockite, Rymättylä (Hietanen, 1947); XIV, quartz dioritic charnockite, Kakskerta (Hackman, 1923).

Table XIII. Average mineralogical composition of the plutonic rocks of the charnockite province.

	1	2	3	4
Quartz	—	2.0	5.4	15.9
Microcline	—	2.3	—	2.7
Plagioclase	40.9	56.9	68.4	62.6
Chlorite	0.1	—	—	—
Biotite	4.1	9.4	0.4	10.1
Hornblende	44.3	1.7	2.0	0.4
Diopside	5.1	6.2	4.0	} 7.1
Hypersthene	4.6	18.6	14.4	
Accessories	0.9	2.9	5.4	1.2

1. Hornblende-rich noritic gabbros (3 determinations; Nos. I, 1, and 3 in Fig. 14).
2. Noritic gabbros, pyroxene-rich (8 determinations; Nos. II—VII, 2, and 4 in Fig. 14.
3. Anorthositic diorite charnockite (2 determinations; Nos. VIII, and XI in Fig. 14).
4. Quartz dioritic charnockite (11 determinations; Nos. IX, X, XII, XIII, XIV, 7—11, and 13 in Fig. 14).

only representative in which the normative Or is higher than that of An is the »pyroxene trondhjemite» from Putsaari (No. 12 in Fig. 14).

Average mineralogical compositions of charnockitic rocks are presented in Table XIII. Charnockites contain more plagioclase and less quartz than corresponding rocks of the granodiorite as well as trondhjemite provinces (cf. Table II and VIII). Main characteristics in mineralogical composition of the charnockite province (cf. Fig. 15) are as follows.

Pyroxene typical of the charnockite province is both rhombic and monoclinic in type and it is the main mafic mineral in many noritic gabbros and anorthositic diorite charnockites. Hornblende occurs abundantly in some gabbros and it is only sporadically present in other members of the province. Characteristic is an abundance of biotite in noritic gabbros and quartz dioritic charnockites. Alterations of mafic minerals have been described thoroughly by Hietanen (1947). As alteration products of hypersthene there occur serpentine, cummingtonite, hornblende or biotite. The alteration of the hypersthene into biotite is common in rocks containing microcline. Diopside sometimes alters into hornblende. These alterations show similarities to discontinuous reaction series originating in magmatic crystallization.

The plagioclase content increases towards the silicic members of the province and in addition the composition of the plagioclase becomes more albitic. Only minute amounts of quartz are present in gabbroidic rocks and the quartz content in the quartz dioritic charnockites is lower than that in the quartz dioritic trondhjemites. The content of potash feldspar is low.

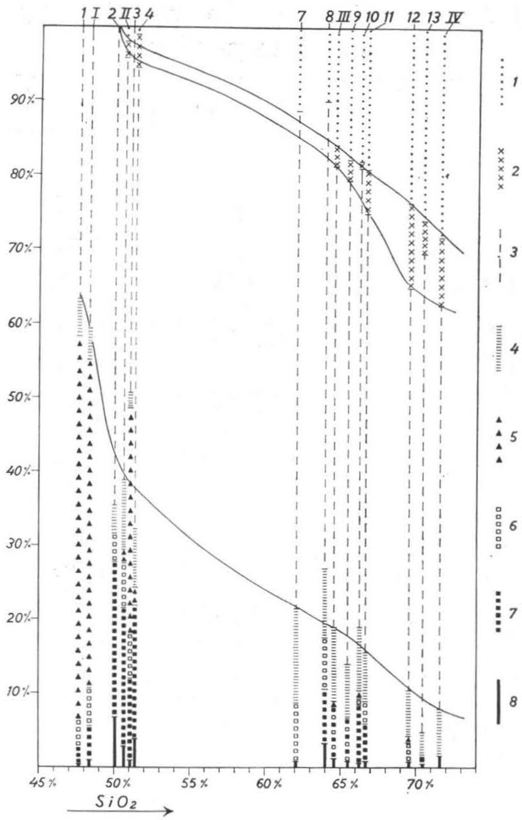


Fig. 15. Mineralogical composition of analysed rocks of the charnockite province. 1, quartz; 2, microcline; 3, plagioclase; 4, biotite; 5, hornblende; 6, diopside 7, hypersthene; 8, accessories. Nos. 1—13 of separate determinations refer to analysed specimens listed in Table XII. Average mineraogical compositions: I, hornblende-rich noritic gabbro; II, noritic gabbro, pyroxene-rich; III, quartz dioritic charnockite; IV, granodioritic trondhjemite.

Variations in mineralogical composition of the charnockitic rocks show many similarities to those met with in the trondhjemite province. The biotite is an abundant mineral in both rocks, and on the contrary the hornblende typical of rocks of the granodiorite province is totally absent in most acid members of the trondhjemites and charnockites. Acid charnockites grade in many cases into trondhjemites when the pyroxene disappears. Granodioritic charnockites are very rare, because pyroxene alters into biotite when microcline is present. Therefore, it is evident, supported also by field evidence described by Hietanen (1947), that the most acid members of the charnockite province are represented by granodioritic trondhjemites. Evolution in the charnockite and trondhjemite provinces

Table XIV. Optical properties of the rock-forming minerals of the charnockite province.

	Reference	α	β	γ
Hypersthene:				
Noritic gabbro	1	1 713	1 725	1 728
Noritic gabbro	3	1 720	1 730	1 734
Noritic gabbro	4	1 722	—	1 742
Anorthositic diorite charnockite	VIII	1 712	1 724	1 728
Quartz dioritic charnockite	8	1 713	1 724	1 728
Quartz dioritic charnockite, Vihti	Parras, 1958	1 714	1 725	1 730
Quartz dioritic charnockite, Vihti	Parras, 1958	1 717	1 729	1 733
Quartz dioritic charnockite	6	1 717	—	1 735
Quartz dioritic charnockite, Vihti	Parras, 1958	1 720	1 733	1 737
Quartz dioritic charnockite, Lohja	Parras, 1958	1 720	—	1 737
Quartz dioritic charnockite	10	1 724	1 734	1 738
Quartz dioritic charnockite, Vihti	Parras, 1958	1 724	—	1 741
Diopside:				
Noritic gabbro	1	1 690	1 696	1 715
Noritic gabbro	3	1 691	1 704	1 718
Anorthositic diorite charnockite	VIII	1 687	1 697	1 715
Quartz dioritic charnockite	5	1 684	—	1 716
Quartz dioritic charnockite	7	1 692	—	1 718
Quartz dioritic charnockite	8	1 694	—	1 720
Quartz dioritic charnockite, Vihti	Parras, 1958	1 698	—	1 722
Quartz dioritic charnockite	10	1 702	1 709	1 720
Granodioritic charnockite	12	1 699	1 708	1 725
Hornblende:				
Noritic gabbro	1	1 673	1 682	1 691
Noritic gabbro	3	—	—	1 690
Noritic gabbro	4	1 675	—	1 699
Anorthositic diorite charnockite	VIII	1 656	1 670	1 676
Biotite:			$\beta = \gamma$	
Noritic gabbro	1		1 647	
Noritic gabbro	3		1 660	
Noritic gabbro	4		1 676	
Anorthositic diorite charnockite	VIII		1 634	
Quartz dioritic charnockite	7		1 648	
Quartz dioritic charnockite, Vihti	Parras, 1958		1 648	
Quartz dioritic charnockite	10		1 650	
Quartz dioritic charnockite	8		1 651	
Quartz dioritic charnockite, Vihti	Parras, 1958		1 660	
Quartz dioritic charnockite, Lohja	Parras, 1958		1 662	
Quartz dioritic charnockite, Vihti	Parras, 1958		1 663	
Quartz dioritic charnockite, Vihti	Parras, 1958		1 664	
Quartz dioritic charnockite	6		1 673	
Granodioritic charnockite	12		1 657	

leads to similar acid end members, represented by biotite-bearing trondhjemites.

Some notes on the properties of separate rock-forming minerals of the charnockite province are given below.

Hypersthene occurs both in the basic and acid members. Hietanen (1947) has pointed out that the refractive indices of the rhombic pyroxene rise with an increasing silica content in the plutonic rock. Two chemical analyses of the hypersthene are available (Table XV, anal. 1—2). The ratio (FeO):(MgO) of the hypersthene in noritic gabbro is lower than that of the hypersthene in quartz dioritic charnockite. This difference between analysed hypersthenes appears also in the refractive indices, which are $\gamma = 1.728$ and $\gamma = 1.733$ respectively.

Diopside is present in all rock types of the charnockite province. Refractive indices (Table XIV) rise along with an increasing silica content in the plutonic rock, as has been previously pointed out by Hietanen (1947). One chemical analysis of diopside is available (Table XV, anal. 3).

Hornblende is abundant in some basic members of the province. Brown hornblende of anorthositic diorite charnockite has much lower refractive indices than hornblendes of noritic gabbros (cf. Table XIV). The hornblende of noritic gabbro has extremely high refractive indices — much

Table XV. Chemical analyses of hypersthene, diopside and biotite in the rocks of the charnockite province.

	1	2	3	4	5
SiO_2	48.94	49.84	48.98	35.98	35.91
TiO_2		0.33	0.43	5.00	2.89
Al_2O_3	1.66	0.00	1.56	13.93	14.36
Fe_2O_3	5.28	1.29	0.22	3.08	3.72
FeO	23.60	29.45	14.21	19.32	19.64
MnO	0.42	0.62	0.33	0.07	0.21
MgO	16.96	15.23	10.35	9.37	8.59
CaO	1.11	1.05	15.79	0.74	0.98
Na_2O		0.46	1.63	0.35	0.84
K_2O		0.12	0.31	8.84	8.14
H_2O+	} 0.35	} 1.80	1.22	2.70	2.99
H_2O-			0.96	0.18	0.82
	98.32	100.19	95.99	99.56	99.07

1. Hypersthene in noritic gabbro (No. 1 in Table XII). Masku (Hietanen, 1947).
2. Hypersthene in quartz dioritic charnockite. Vihti (Parras, 1958).
3. Diopside in granodioritic charnockite (No. 12 in Table XII). Uusikaupunki (Hietanen, 1943).
4. Biotite in quartz dioritic charnockite (No. 6 in Table XII). Nummi (Parras, 1958).
5. Biotite in granodioritic charnockite (No. 12 in Table XII). Uusikaupunki (Hietanen, 1943).

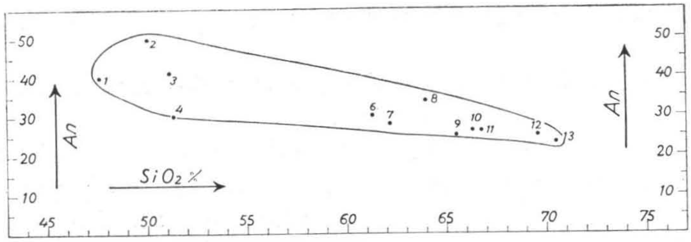


Fig. 16. Composition of plagioclase in the rocks of the charnockite province. The numbers of separate determinations refer to the specimens listed in Table XII.

higher than is usual in the gabbroidic rocks of the granodiorite and trondhjemite provinces.

Biotite is common in plutonic rocks of the charnockite province. The lowest refractive index of the biotite has been reported from the anorthositic diorite charnockite. Available optic determinations (cf. Table XIV) show that the refractive indices of the biotite in noritic gabbros and quartz dioritic charnockites vary within the same limits. Two chemical analyses of the biotite in the acid members of the province are available (Table XV, anal. 4—5).

Plagioclase is the main salic mineral of the charnockites. Its total amount increases towards the acid members and its composition gradually becomes more albitic (Fig. 16).

Microcline is sparsely present and it occurs as anthiperthitic inclusions in plagioclase and as small scattered grains.

Quartz occurs sporadically and in minute amounts in gabbroidic rocks. Its content gradually increases towards the acid members of the province.

Accessory minerals are not well known. The most common accessory minerals occurring in all rock types of the province are oxidic iron ore, apatite, and sphene. Zircon is present in many quartz-bearing varieties, and rutile, typical of the acid trondhjemites, occurs also in the most acid members of the charnockite province.

Average chemical compositions of principal plutonic rock types of the charnockite province (Table XVI) show that they contain more soda than corresponding rock types of the granodiorite province (cf. Table VI). In this relation the charnockitic rocks show a conspicuous similarity to the plutonic rocks of the trondhjemite province. Hietanen (1947) has previously noted that »the chemical composition of the charnockites is very similar to that of the trondhjemites». The alkali-lime index of the charnockite suite is about 61.

Table XVI. Average chemical composition of the rocks of the charnockite province.

	1	2	3
SiO_2	49.42	50.73	64.65
TiO_2	1.49	2.59	0.74
Al_2O_3	14.94	19.72	15.93
Fe_2O_3	2.09	0.29	0.84
FeO	9.04	8.65	3.94
MnO	0.15	0.07	0.08
MgO	7.33	4.04	1.87
CaO	9.88	7.51	4.55
Na_2O	3.04	3.68	4.50
K_2O	1.17	1.96	1.89
P_2O_5	0.18	0.56	0.16
H_2O+	1.19	0.38	0.67
H_2O-	0.25	0.06	0.14
	100.17	100.25	99.96

1. Hornblende-rich noritic gabbro (2 analyses; Nos. 1 and 3 in Table XII).
2. Pyroxene-rich noritic gabbro (2 analyses; Nos. 2 and 4 in Table XII).
3. Quartz dioritic charnockite (8 analyses; Nos. 5—11, and 13 in Table XII).

The Niggli-diagram of the charnockite province (Fig. 17) shows continuous »differentiation curves», which are very similar to those of the trondhjemites and deviate sharply at the acid end from the curves of the granodiorite province. This diagram also supports the view that the evolution in the charnockite province can lead to acid members identical to the granodioritic trondhjemites.

Normative proportions of Or : Ab : An (Fig. 18) show that the charnockites are characterized by a marked preponderance of soda feldspar over potash feldspar. The rocks of the charnockite province occupy a field very similar to that of the trondhjemites (cf. Fig. 12) and deviate clearly from the granodiorites (cf. Fig. 6). Normative proportions of Q : Ab : Or (Fig. 32) show that the charnockite province does not continue to an eutectoid granite composition.

GRANITE PROVINCE

Plutonic rocks passing gradually from basic members into granites have been described both from the Tampere area, including the adjoining part of Central Finland, and from Middle East Bothnia. The plutonic rocks characterized by granitic end members are named in this paper as rocks of the granite province. A petrographic description of both the areas mentioned is given separately.

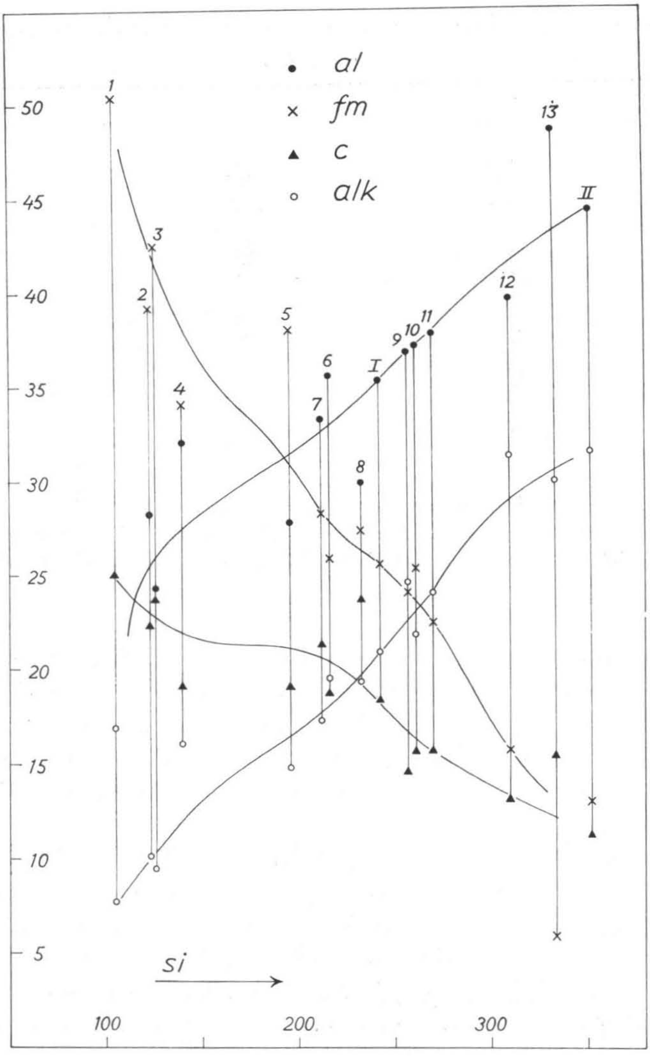
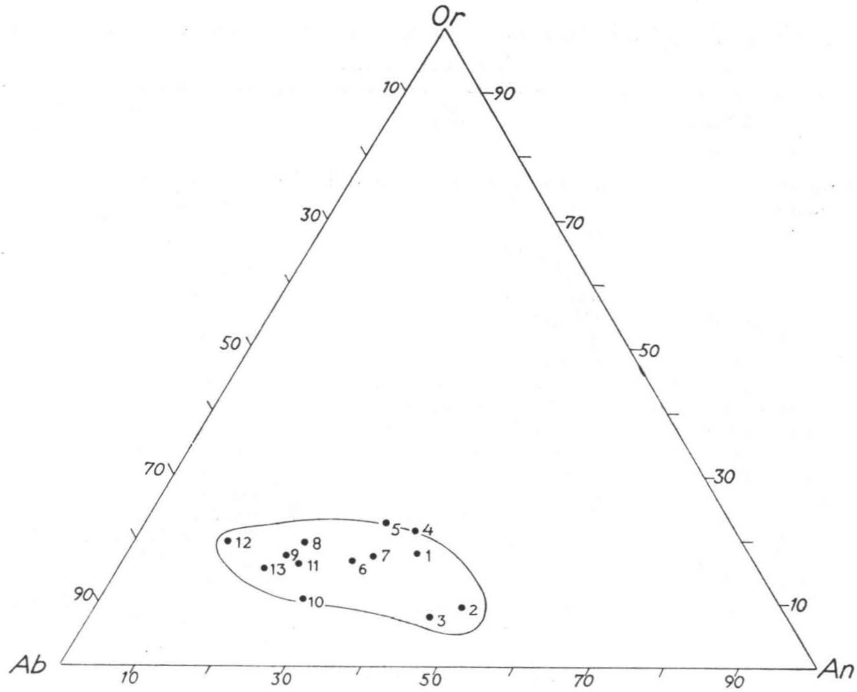


Fig. 17. Niggli diagram of the charnockite province. Nos. 1—13 of the separate analyses refer to the specimens listed in Table XII. Average compositions: I, quartz dioritic charnockite; II, granodioritic trondhjemite.

TAMPERE AREA AND ADJOINING PART OF CENTRAL FINLAND

New investigations in the Tampere area (Huhma, Salli, and Matisto, 1952; Seitsaari, 1951; Simonen, 1952 and 1953) show that plutonic rocks penetrate the Svecofennidic schists of the Tampere field and these plutonic rocks have been considered as Svecofennidic intrusions of the same age as the plutonic rocks of the granodiorite, trondhjemite and charnockite provinces in southern Finland.



iFg. 18. Normative proportions Or : Ab : An in the rocks of the charnockite province. Nos. 1—13 of separate determinations refer to the specimens listed in Table XII.

Geological map of the Tampere area (Fig. 19) shows an abundant occurrence of quartz diorites, granodiorites and granites, whereas ultrabasic and basic plutonic rocks occur only as small bodies. According to the planimetric determinations, the areal distribution of different plutonic rock types in new geological map sheets of Viljakkala—Teisko (Simonen, 1952) and Ikaalinen (Huhma, Salli, and Matisto, 1952) is as follows:

peridotites	0.3 %
gabbros	3.6 %
quartz diorites and granodiorites	62.1 %
granites	34.0 %

Wide massifs of quartz diorite and granodiorite are characteristic of the Tampere schist belt, but in the area of Central Finland these plutonic bodies are associated with abundant occurrence of granites. The relative age succession of the different members of the province is as follows: ultrabasics, gabbros, quartz diorites, granodiorites, and granites. This succession points to a magmatic evolution of the province, and many gradual transitions between different plutonic rocks strengthen this view. Furthermore, a hypidiomorphic texture, reaction series of mafic minerals pyroxene → hornblende → biotite, and zonar texture of plagioclase with anorthite-rich cores are in harmony with an evolution by magmatic crystallization.

Table XVII. Analysed plutonic rocks of the granite province in the Tampere area.

N:o	Rock name	Locality	Reference
1	Gabbro	Teisko N of Lake Paarlahti	Seitsaari, 1951
2	Gabbro	Lavia, Niemi	Mäkinen, 1915
3	Gabbro	Teisko	Seitsaari, 1951
4	Gabbro	Teisko, Hankajärvi	Seitsaari, 1951
5	Gabbro	Teisko, N of Lake Paarlahti	Seitsaari, 1951
6	Gabbro	Lavia, Niemi	Mäkinen, 1915
7	Quartz gabbro	Jalasjärvi, Mustalampi	Lokka, 1950
8	Quartz gabbro	Kuru	Simonen, 1952
9	Quartz gabbro	Lavia, Niemi	Mäkinen, 1915
10	Quartz gabbro	Teisko, Pulasjärvi	Seitsaari, 1951
11	Anorthositic diorite	Teisko, Savonjärvi	Seitsaari, 1951
12	Quartz diorite	Teisko, N of Lake Paarlahti	Seitsaari, 1951
13	Quartz diorite	Lavia, Naarajärvi	Mäkinen, 1915
14	Quartz diorite	Viljakkala	Simonen, 1952
15	Quartz diorite	Lavia, Naarajärvi	Mäkinen, 1915
16	Quartz diorite	Ylöjärvi, Työläjärvi	Simonen, 1952
17	Quartz diorite	Kankaanpää, Taulunoja	Huhma, Salli and Matisto, 1952
18	Quartz diorite	Lavia, Naarajärvi	Mäkinen, 1915
19	Granodiorite	Nokia, Heinlampi	Simonen, 1952
20	Granodiorite	Kankaanpää, Kolmiloppi	Huhma, Salli and Matisto, 1952
21	Granodiorite	Kankaanpää, Heikinlampi	Lokka, 1950
22	Granodiorite	Lavia, Välimäki	Mäkinen, 1915
23	Quartz diorite	Kankaanpää, Vuorenmaa	Huhma, Salli and Matisto, 1952
24	Granodiorite	Jalasjärvi, Leppäkoski	Lokka, 1950
25	Granodiorite	Orivesi, Kutemajärvi	Seitsaari, 1951
26	Granodiorite	Nokia, Rajala	Simonen, 1952
27	Granodiorite	Teisko, Pulasjärvi	Seitsaari, 1951
28	Granodiorite	Teisko, Värmälä	Simonen, 1952
29	Granodiorite	Kankaanpää	Huhma, Salli and Matisto, 1952
30	Granodiorite	Teisko, Sisällyspohja	Seitsaari, 1951
31	Granodiorite	Parkano, Mustajärvi	Lokka, 1950
32	Granite	Kuru,Lörpys	Sederholm, 1913
33	Granite	Peurnajärvi	Seitsaari, 1951
34	Granite	Kankaanpää Vuorenmaa	Huhma, Salli and Matisto, 1952
35	Granite	Kuru, Muurainen	Simonen, 1952
36	Granite	Teisko, Paarlahti	Seitsaari, 1951

Mention must be made in this connection that textures indicating metasomatic processes have also been found in many granites of the area, especially in porphyritic granites. Microcline porphyroblasts with corroded inclusions of plagioclase have been found to grow in quartz diorites and granodiorites. This kind of metasomatic texture does not, however, rule out a magmatic evolution having been undergone by the whole plutonic complex. The present author has observed that it is common for a residual granite magma to have caused metasomatic processes in its surroundings. This kind of »magmatic granitization» is probably very usual in many plutonic complexes. Characteristically the composition of the granites is eutectoid granitic, as in the case of the granite province of the Tampere area (cf. p. 57).

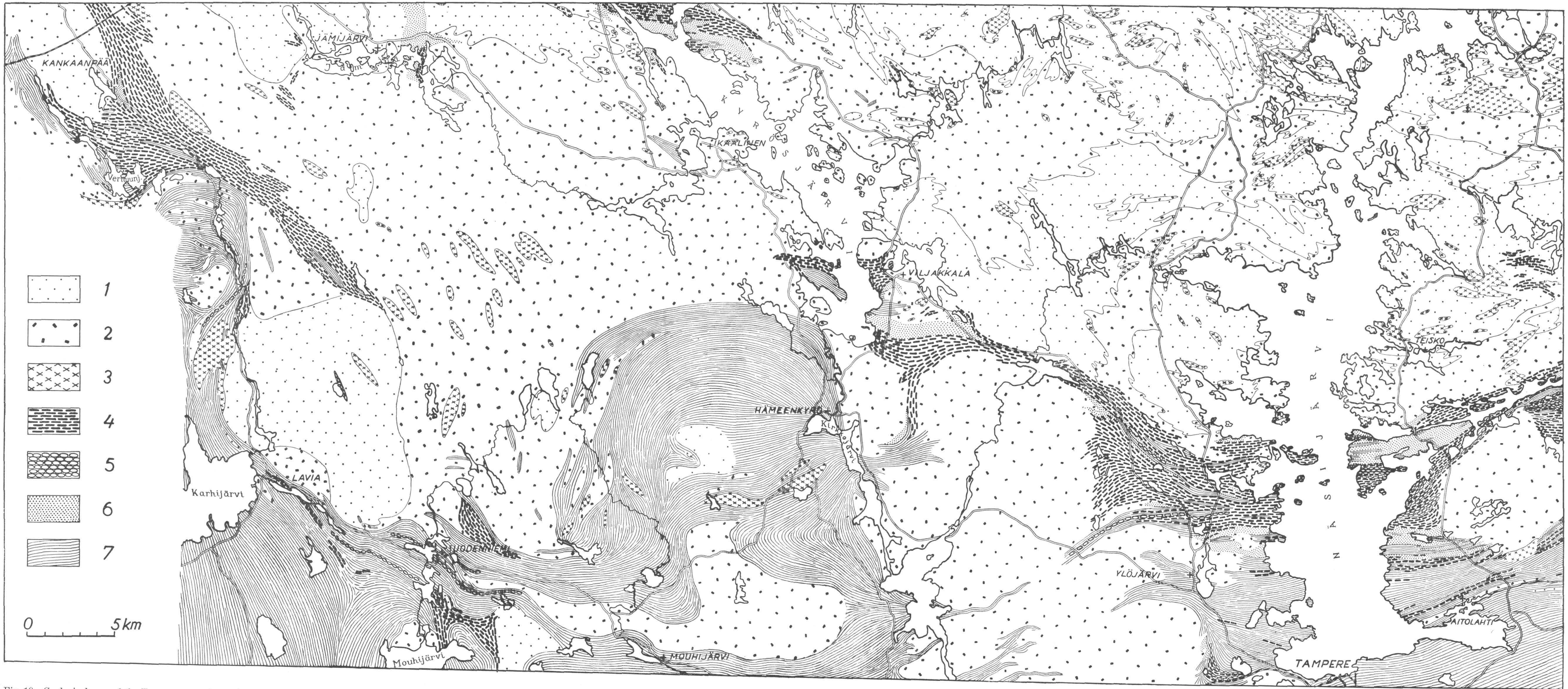


Fig. 19. Geological map of the Tampere area. 1, granite; 2, granodiorite and quartz diorite; 3, quartz gabbros and gabbros; 4, basic volcanics; 5, conglomerates; 6, quartz-feldpar schists; 7, phyllites and mica schists. Drawn according to the geological map sheets of Viljakkala-Teisko (Simonen, 1952) and Ikaalinen (Huhma, Salli, and Matisto, 1952.)

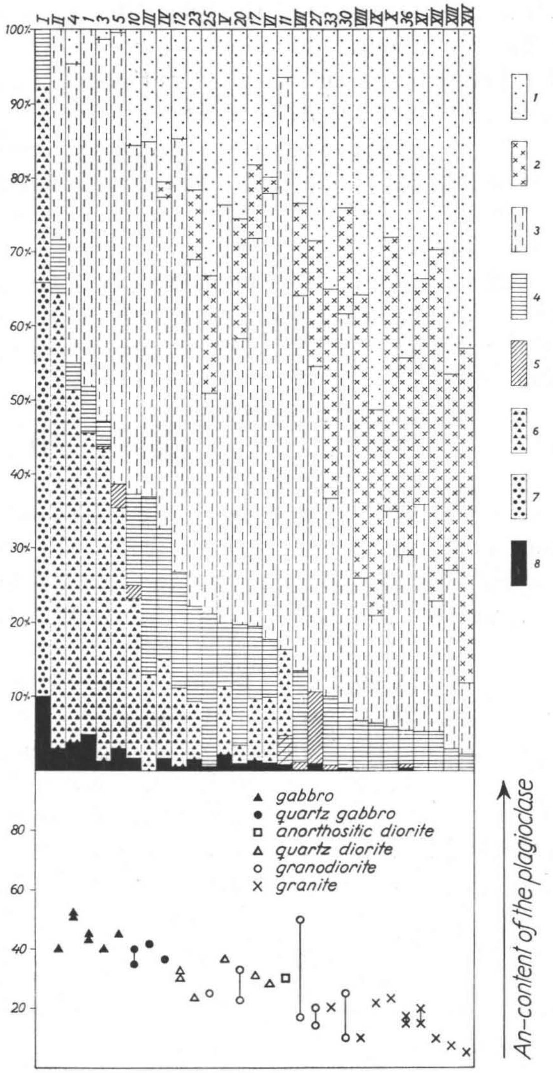


Fig. 20. Mineralogical composition of the rocks of the granite province in the Tampere field and adjoining part of Central Finland. 1, quartz; 2, microcline; 3, plagioclase; 4, biotite; 5, chlorite; 6, hornblende; 7, olivine + serpentine; 8, accessories. Numbers 1—36 of separate determination refer to the analysed specimens listed in Table XVII. Nos. I—XIV represent petrographically studied rocks as follows: I, ultrabasic rock, Ikaalinen; II, gabbro, Ikaalinen; III, quartz gabbro, Kuru; IV, quartz gabbro, Ikaalinen; V, quartz diorite, Ikaalinen; VI, quartz diorite, Ikaalinen; VII, granodiorite, Orivesi; VIII, granite, Ikaalinen; IX, granite, Ikaalinen; X, granite, Kuru; XI, granite, Hämeenkyrö; XII, granite, Ikaalinen; XIII, granite, Ikaalinen; XIV, granite, Ikaalinen. Specimen VII has been described by Seitsaari (1951), III and X are from an unpublished work of Matisto, and all the others have been decribed by Huhma, Salli, and Matisto (1952).

Chemically studied specimens of the plutonic rocks in the Tampere area are listed in Table XVII and the mineralogical composition is presented in Figs. 20—21. These diagrams show a continuous mineralogical series from ultrabasics to granites. Mention must be made of the fact that in other plutonic rock provinces, described previously, a continuous series reaches only a mineralogical composition of a granodioritic rock.

The nomenclature of the plutonic rocks of the granite province used in this paper is as follows:

1. Ultrabasic plutonic rocks. Color index is > 90. To this group belongs specimen I in Fig. 20.

2. Gabbro. Color index is > 40. To this group belong specimens II, 1, and 3—5 in Fig. 20.

3. Quartz gabbro. Color index is 30—40. The content of quartz varies between 10—20 %. To this group belong specimens III, IV, and 10 in Fig. 20.

4. Anorthositic diorite. Color index is < 30. The content of quartz is < 10 %. This rock type (specimen 11 in Fig. 20) is not common.

5. Quartz diorite. Color index is < 30 and Or < An. The content of quartz > 10 %. To this group belong specimens V, VI, 12, 23, and 17 in Fig. 20.

6. Granodiorite. Color index is < 30, and Or > An. To this group belong specimens VII, 20, 25, 27, and 30 in Fig. 20.

7. Granite. Color index is < 30 and Or > Ab + An. To this group belong specimens VIII—XIV, 33, and 36 in Fig. 20.

Average mineralogical compositions of the afore-mentioned rock types are presented in Table XVIII. These average compositions are plotted in Fig. 21, which shows variations in mineralogical composition as a function

Table XVIII. Average mineralogical composition of the plutonic rocks of the granite province.

	1	2	3	4	5
Quartz	1.5	17.0	19.6	26.9	38.6
Microcline	—	0.7	4.3	15.1	34.1
Plagioclase	45.6	46.7	54.8	43.0	21.7
Chlorite	0.7	0.6	—	2.2	0.1
Biotite	4.1	17.8	10.9	11.6	5.4
Hornblende	44.9	16.1	9.0	0.5	—
Accessories	3.2	1.1	1.4	0.7	0.1

1. Gabbro (5 determinations; Nos. II, 1, 3—5 in Fig. 20).
2. Quartz gabbro (3 determinations; Nos. III, IV, and 10 in Fig. 20).
3. Quartz diorite (5 determinations; Nos. V, VI, 12, 23, and 17 in Fig. 20).
4. Granodiorite (5 determinations; VII, 20, 25, 27, and 30 in Fig. 20).
5. Granite (9 determinations; VIII—XIV, 33, and 36 in Fig. 20).

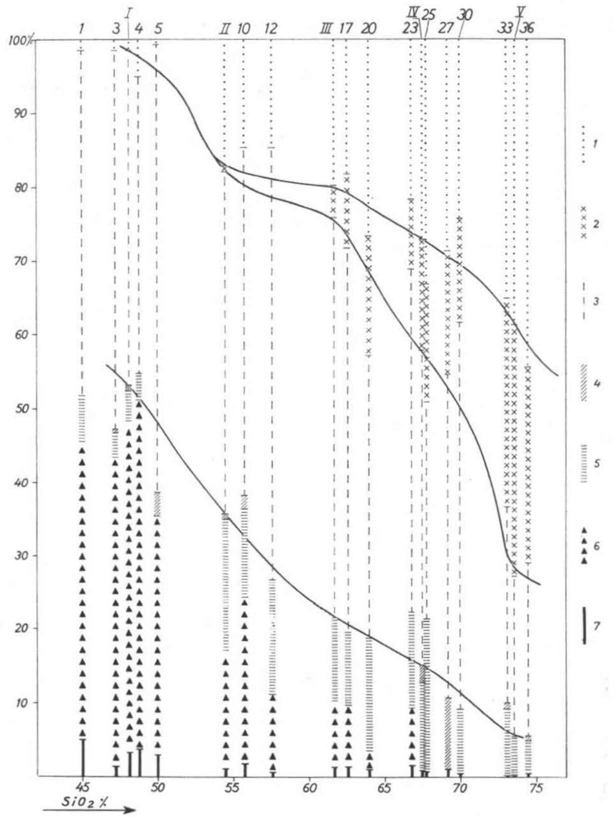


Fig. 21. Mineralogical composition of the granite province. 1, quartz; 2, microcline; 3, plagioclase; 4, chlorite; 5, biotite; 6, hornblende; 7, accessories. Numbers 1—36 of separate determinations refer to the analysed specimens listed in Table XVII. Average mineralogical compositions: I, gabbro; II, quartz gabbro; III, quartz diorite; IV, granodiorite; V, granite.

of the silica content of the rock. This figure shows a continuous mineralogical series from gabbros to granites. Main mineralogical characteristics of the granite province are as follows:

Hornblende is the most common mafic mineral of gabbros and quartz gabbros. The meta-aluminous association of hornblende and biotite is common, especially in quartz gabbros and quartz diorites. Biotite is the predominant mafic mineral in granodiorites and granites, and hornblende is lacking in most of the acid members of the province.

Content of plagioclase is highest in quartz diorites and decreases rapidly towards acid granitic members of the province. Microcline is sparsely present in quartz diorites but its content increases towards the acid members, where it is more abundant than plagioclase.

Table XIX. Refractive indices of hornblende and biotite in rocks of the granite province

Rock type	Reference	α	β	γ
Hornblende:				
Ultrabasic rock	I	—	—	1 649
Ultrabasic rock, Rikalanjärvi	Simonen, 1952	1 640	—	1 657
Ultrabasic rock, Toikko	Simonen, 1952	1 658	—	1 678
Gabbro	II	—	—	1 679
Gabbro	4	1 650	—	1 678
Gabbro	5	1 657	—	1 678
Gabbro	1	1 667	1 679	1 684
Quartz gabbro	10	1 654	—	1 673
Quartz gabbro	8	1 676	1 692	1 697
Quartz diorite	14	1 670	1 685	1 694
Quartz diorite	12	1 685	—	1 708
Quartz diorite, Kankaanpää	—	1 689	1 705	1 712
Biotite:			β = γ	
Quartz gabbro	III		1 652—1 656	
Quartz diorite	16		1 648—1 652	
Quartz diorite	12		1 666	
Granodiorite	19		1 655	
Granodiorite	26		1 655	
Granodiorite	28		1 666	
Granite	X		1 668—1 671	

Table XX. Chemical composition of hornblende in rocks of the granite province.

	1	2	3
SiO_2	39.00	43.30	40.85
TiO_2	3.60	1.28	1.50
Al_2O_3	16.26	8.62	10.97
Fe_2O_3	1.62	3.88	4.81
FeO	16.60	19.26	21.67
MnO	0.24	0.47	0.60
MgO	7.90	7.16	4.18
CaO	10.84	11.71	10.82
Na_2O	1.40	0.90	1.22
K_2O	0.57	1.00	1.36
P_2O_5	—		0.03
H_2O+	2.12	2.23	2.11
H_2O-	0.20	0.02	0.00
	100.35	99.83	100.12

1. Hornblende in gabbro (No. 1 in Table XVII) Teisko, Paarlahti (Seitsaari, 1951).
2. Hornblende in quartz gabbro (No. 8 in Table XVII) Kuru. Anal. H. B. Wiik.
3. Hornblende in quartz diorite, Kankaanpää, Valkjärvi. Anal. H. B. Wiik.

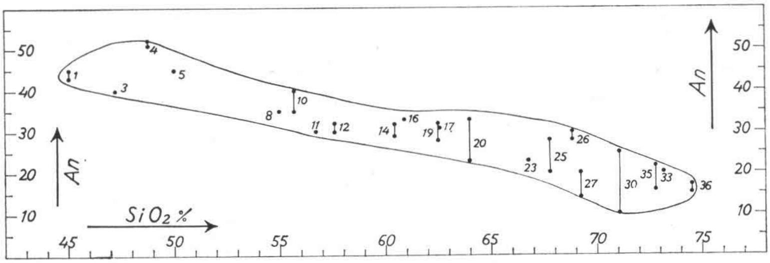


Fig. 22. Composition of plagioclase in rocks of the granite province. Numbers of separate determinations refer to specimens listed in Table XVII.

Some notes on the mineralogy of rock-forming minerals are given below:

Olivine occurs only in some ultrabasic rocks. Refractive indices of olivine in the peridotite of Toikko are $\alpha = 1.670$; $\gamma = 1.700$ (Simonen, 1952).

Diopsidic augite has been found in ultrabasic and basic plutonic rocks. Remnants of diopside in the middle of hornblende crystals have also been found in some quartz gabbros and quartz diorites. Refractive indices of diopsidic augite in the ultrabasic rock of Rikalanjärvi are $\alpha' = 1.680$, $\gamma' = 1.716$ (Simonen, 1952).

Hornblende is a common mineral of basic and intermediate members. Refractive indices of hornblende increase towards the acid members of the province (see Table XIX). Chemical analyses of hornblende (Table XX) show that the ratio (FeO) : (MgO) rises with an increasing silica content in the rock type.

Biotite is present in quartz-bearing plutonic rocks and it is the predominant mafic mineral of granodiorites and granites. The refractive indices of biotite (see Table XIX) show a tendency to rise along with an increasing silica content in the plutonic rock.

Plagioclase is the predominant salic mineral of gabbros and granodiorites. Its content gradually decreases towards the acid members. At the same time it becomes gradually more albitic (see Fig. 22). Zonar texture with more anorthitic cores is common.

Microcline is sparsely present in some quartz diorites but its content gradually increases towards the acid members.

Quartz is present in many gabbros and its content gradually increases towards the granites of the province, whose content of free quartz varies between 30—50 %.

Accessory minerals of the granite province are listed in Table XXI. In addition to these, epidote, chlorite, sericite, and calcite have been found as alteration products.

Average chemical compositions of plutonic rocks (Table XXII) show that ratios (FeO) : (MgO) and ($Na_2O + K_2O$) : (CaO) increase towards

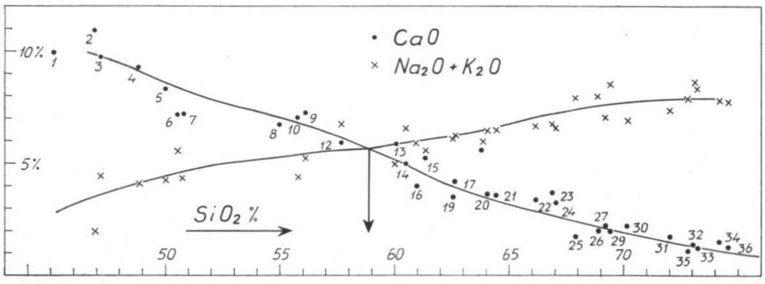


Fig. 23. Alkali-lime index of the granite province in the Tampere area. Numbers 1—36 refer to specimens listed in Table XVII.

Table XXI. Accessory minerals of the granite province.

	Spinell	Oxidic ore	Apatite	Sphene	Zircon	Orthite	Fluorite
Ultrabasic rocks	x	x	x				
Gabbro	x	x	x	x			
Quartz gabbro		x	x	x	x		
Quartz diorite		x	x	x	x		
Granodiorite		x	x	x	x	x	
Granite		x	x	x	x	x	x

Table XXII. Average chemical composition of plutonic rocks of the granite province.

	1	2	3	4	5
SiO_2	48.07	54.36	61.71	67.58	73.55
TiO_2	1.34	1.42	0.76	0.50	0.22
Al_2O_3	19.08	18.06	16.66	15.49	13.85
Fe_2O_3	2.73	1.58	1.02	0.63	0.82
FeO	9.41	7.62	5.47	3.24	1.38
MnO	0.24	0.16	0.08	0.07	0.03
MgO	4.38	3.02	2.16	1.36	0.38
CaO	9.22	7.16	4.96	2.64	1.36
Na_2O	3.08	2.93	3.63	3.34	2.93
K_2O	1.00	1.83	2.47	3.81	5.18
P_2O_5	0.31	0.38	0.32	0.20	0.04
H_2O+	1.36	1.45	0.81	0.98	0.38
H_2O-	0.15	0.07	0.02	0.09	0.12
	100.37	100.04	100.07	99.93	100.24

1. Gabbro (6 analyses; Nos. 1—6 in Table XVII).
2. Quartz gabbro (4 analyses; Nos. 7—10 in Table XVII).
3. Quartz diorite (8 analyses; Nos. 12—18, and 23 in Table XVII).
4. Granodiorite (12 analyses; Nos. 19—22 and 24—31 in Table XVII).
5. Granite (5 analyses; Nos. 32—36 in Table XVII).

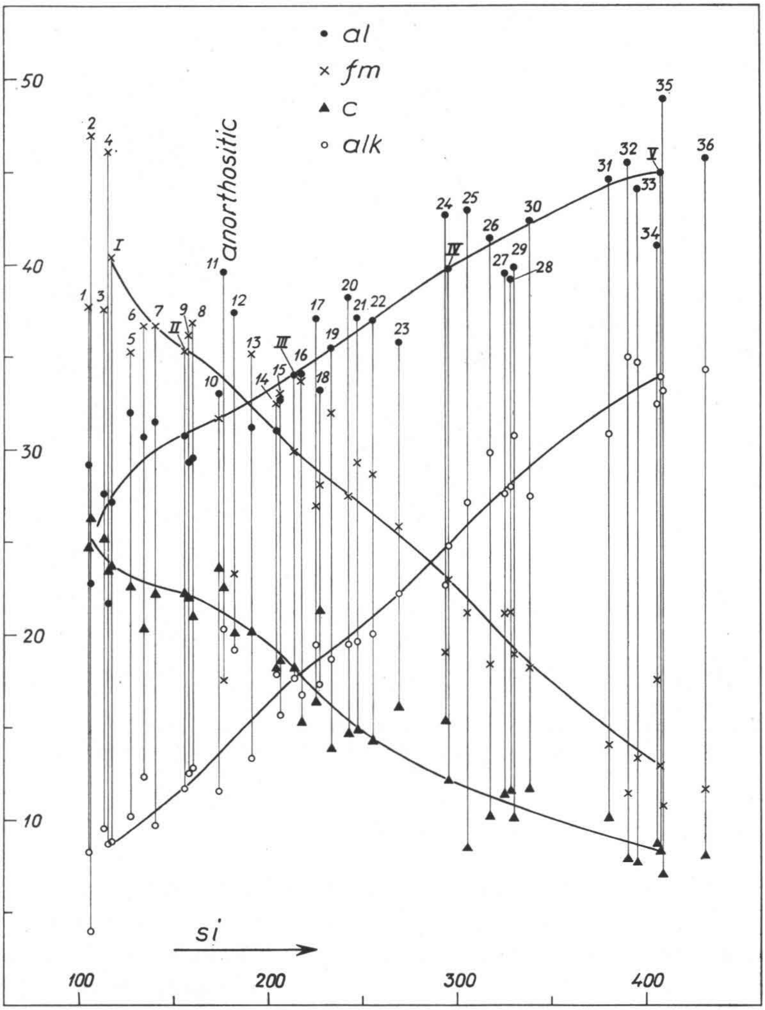


Fig. 24. Niggli diagram of the granite province in the Tampere area. Numbers 1—36 of separate analyses refer to specimens listed in Table XVII. Average compositions: I, gabbro; II, quartz gabbro; III, quartz diorite; IV, granodiorite; V, granite.

acid members. Rocks of the granite province usually contain more alkalies and less lime than the corresponding plutonic rocks described. This appears also in the alkali-lime index of the granite province (Fig. 23), which is lower than that (60—62) of the granodiorite, trondhjemite and charnockite provinces.

Niggli diagram of the granite province (Fig. 24) shows well-defined, continuous series from gabbros to granites. The position of »differentiation

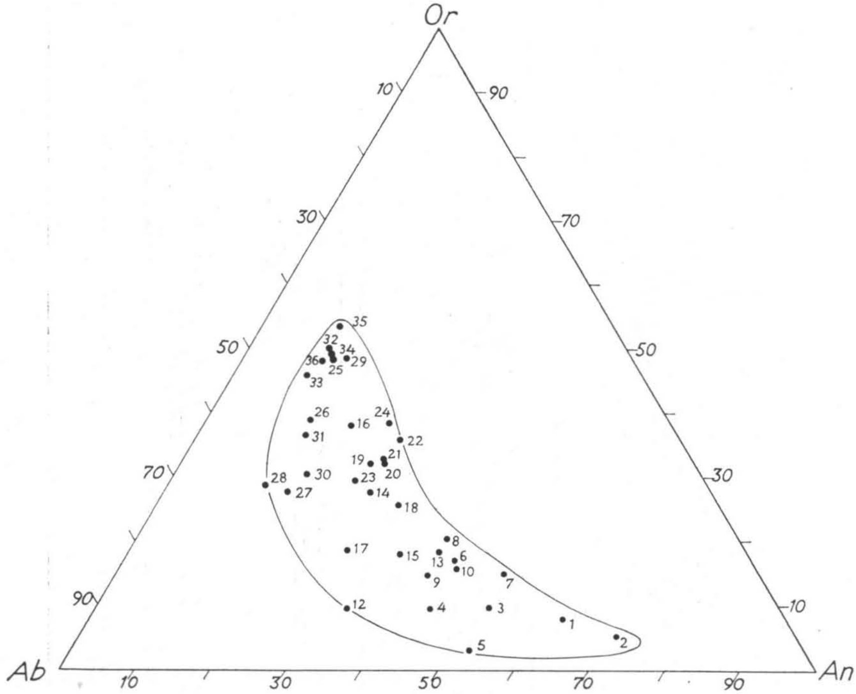


Fig. 25. Normative proportions Or : Ab : An in rocks of the granite province in the Tampere area. Numbers 1—36 of separate determinations refer to specimens listed in Table XVII.

curves» seems to be very similar to those of the trondhjemitic rocks, but in fact there is, however, a great difference, because alk-numbers of acid trondhjemites have been caused mainly by a high content of Na_2O and those of the granite province have been caused mainly by a high content of K_2O.

Normative proportions Or : Ab : An (Fig. 25) show that the rocks of the granite province form a continuous field trending from gabbros into granites. A characteristic feature of the plutonic rocks of the Tampere area is that the potash-rich granites form the most acid member of a continuous series. This characteristic has not been found in the plutonic provinces described in the foregoing.

Furthermore, it is important to note that the chemical composition of the granites in the granite province corresponds very well to the »eutectoid» granite composition as seen in Fig. 26. This supports the view that the granites of the province discussed have been crystallized from a residual granite magma, formed as a product of magmatic evolution.

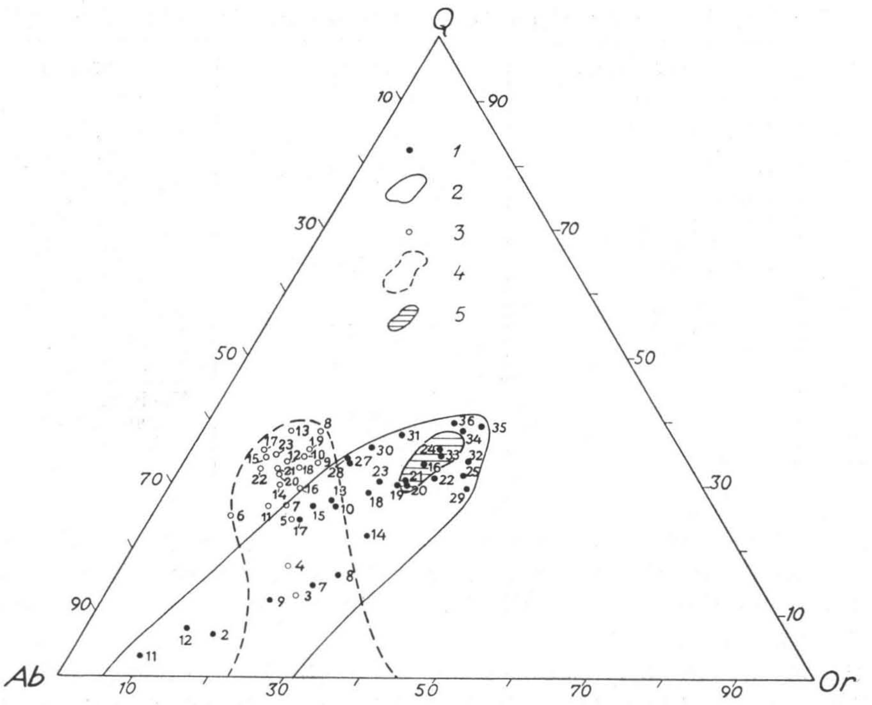


Fig. 26. The normative proportions Q : Ab : Or in quartz-bearing plutonic rocks of the granite and trondhjemite provinces. 1, plutonic rock of granite province; 2, field of granite province; 3, plutonic rock of trondhjemite province; 4, field of trondhjemite province; 5, eutectoid granite composition (Adams, 1952). Numbers of separate determinations refer to specimens listed in Tables XVII and VII.

MIDDLE EAST BOTHNIA

Plutonic rocks of the granite province are widely distributed in Central Finland and they occur also in Middle East Bothnia, where their mineralogical and chemical composition is well known through the studies of Mäkinen (1916) and Wilkman (1931). New geological mapping in East Bothnia carried out by Salli (1956) and Nykänen (1959) has increased the knowledge of petrographic characteristics and manner of occurrence.

Areal distribution of different plutonic rock types in the new geological map sheets of Ylivieska, Kalajoki, Pyhäjoki, Vihanti and Haapavesi is as follows:

ultrabasic rocks	0.1 %
gabbros and diorites	14.1 %
quartz diorites and granodiorites	65.4 %
granites	20.4 %

Table XXIII. Analysed rocks of the granite province in Middle East Bothnia.

No	Name of the rock	Locality	Reference
1	Ultrabasic rock	Merijärvi	Wilkman, 1931
2	Gabbro	Vihanti	Nykänen, 1959
3	Gabbro	Piispsjärvi, Oulainen	Wilkman, 1931
4	Gabbro	Nivala	Lokka, 1950
5	Quartz gabbro	Pylkönmäki	Wilkman, 1938
6	Anorthositic gabbro	Ylivieska	Mäkinen, 1916
7	Quartz diorite	Kaistanmäki, Oulainen	Mäkinen, 1916
8	Quartz diorite	Saloinen	Nykänen, 1959
9	Granodiorite	Oulainen	Mäkinen, 1916
10	Quartz diorite	Heikkilä, Kalajoki	Mäkinen, 1916
11	Quartz diorite	Oulainen	Mäkinen, 1916
12	Granodiorite	Oulainen	Mäkinen, 1916
13	Granodiorite	Oulainen	Mäkinen, 1916
14	Granodiorite	Paasinmäki, Lapua	Hietanen, 1938
15	Granodiorite	Ylivieska	Wilkman, 1931
16	Granite	Kalajoki	Mäkinen, 1916
17	Granite	Raahe	Nykänen, 1959

These values show that the plutonic rocks of Middle East Bothnia are predominantly quartz diorites and granodiorites. Gabbros are more abundant and granites rarer than is the case in the plutonic rock complex of the Tampere area.

Chemically studied specimens of the plutonic rocks in Middle East Bothnia are listed in Table XXIII. Variations in mineralogical composition are presented in Figs. 27—28, which show a continuous mineralogical series from ultrabasics to acid plutonic rocks rich in potash feldspar. Variations in the mineralogical composition are quite similar to those met with in the plutonic rocks of the Tampere area, and therefore the nomenclature

Table XXIV. Average mineralogical composition of the plutonic rocks in Middle East Bothnia.

	1	2	3	4	5
Quartz	1.0	16.0	19.4	24.1	33.3
Microcline	—	2.7	7.0	18.1	32.0
Plagioclase	49.0	43.8	50.3	42.4	27.5
Chlorite	—	0.5	0.6	0.3	0.9
Biotite	9.4	17.3	12.1	9.9	4.4
Hornblende	24.1	17.4	9.2	4.1	—
Pyroxene	12.1	—	—	—	—
Olivine	0.5	—	—	—	—
Accessories	3.9	2.3	1.4	1.2	1.8

1. Gabbro (8 determination; Nos. 3, I—VII in Fig. 27).
2. Quartz gabbro (5 determinations; Nos. 5, VIII—XI in Fig. 27).
3. Quartz diorite (8 determinations; Nos. 7, 10, 11, XIII—XV, XX, and XXIII in Fig. 27).
4. Granodiorite (14 determinations; Nos. 9, 12—15, XVI—XIX, XXI—XXII, XXIV—XXVI in Fig. 27).
5. Granite (4 determinations; Nos. 16, XXVII—XXIX in Fig. 27).

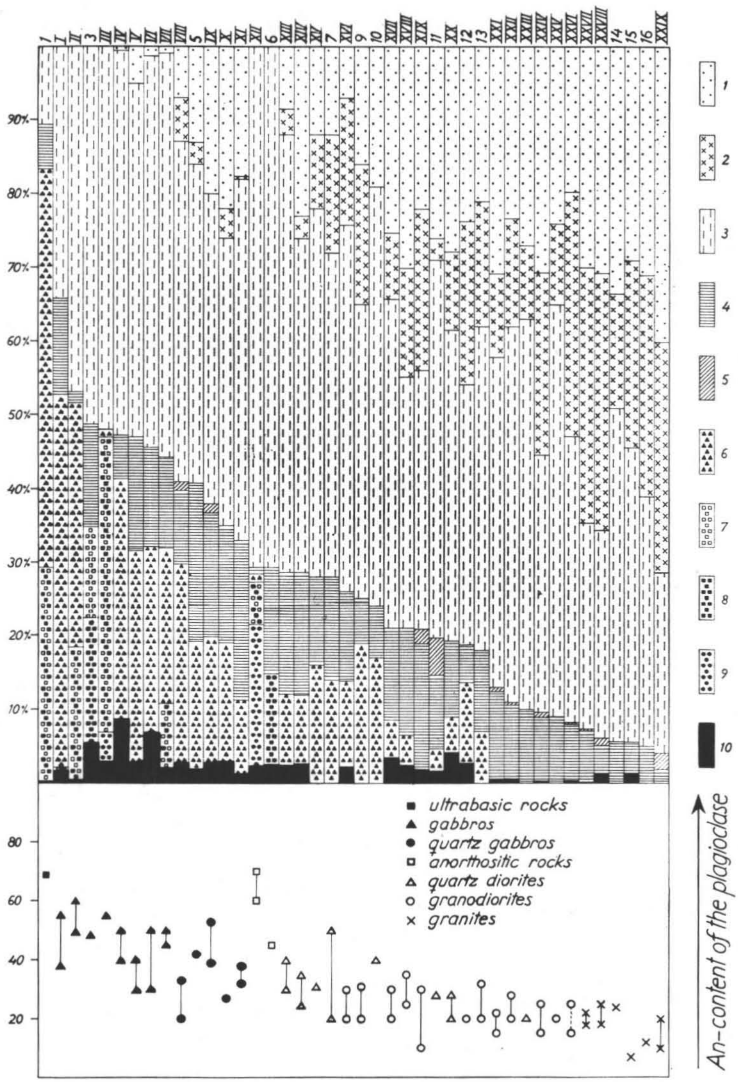


Fig. 27. Mineralogical composition of plutonic rocks in Middle East Bothnia. 1, quartz; 2, microcline; 3, plagioclase; 4, biotite; 5, chlorite; 6, hornblende; 7, hypersthene; 8, diopside; 9, olivine; 10, accessories. Numbers 1—17 of separate determinations refer to the analysed specimens listed in Table XXIII. Nos. I—XXIX represent petrographically studied rocks as follows: I, gabbro, Pattijoki; II, gabbro, Pattijoki; III, gabbro, Ylivieska; IV, gabbro, Lumijoki; V, gabbro, Saloinen; VI, gabbro, Pattijoki; VII, gabbro, Pattijoki; VIII, quartz gabbro, Sievi; IX, quartz gabbro, Ylivieska; X, quartz gabbro, Ylivieska; XI, quartz gabbro, Saloinen; XII, anorthosite, Vihanti; XIII, quartz diorite, Revonlahti; XIV, quartz diorite, Saloinen; XV, quartz diorite, Pyhäjoki; XVI, granodiorite, Siikajoki; XVII, granodiorite, Saloinen; XVIII, granodiorite, Saloinen; XIX, granodiorite, Ylivieska; XX, quartz diorite, Saloinen; XXI, granodiorite, Paavola; XXII, granodiorite, Paavola; XXIII, quartz diorite, Kalajoki; XXIV, granodiorite, Paavola; XXV, granodiorite, Kalajoki; XXVI, granodiorite, Revonlahti; XXVII, granite, Siikajoki; XXVIII, granite, Lumijoki; XXIX, granite, Raahe. Numbers III, VIII—X, XV, XIX, XXIII, and XXV have been described by Mäkinen (1916), all others by Nykänen (1959).

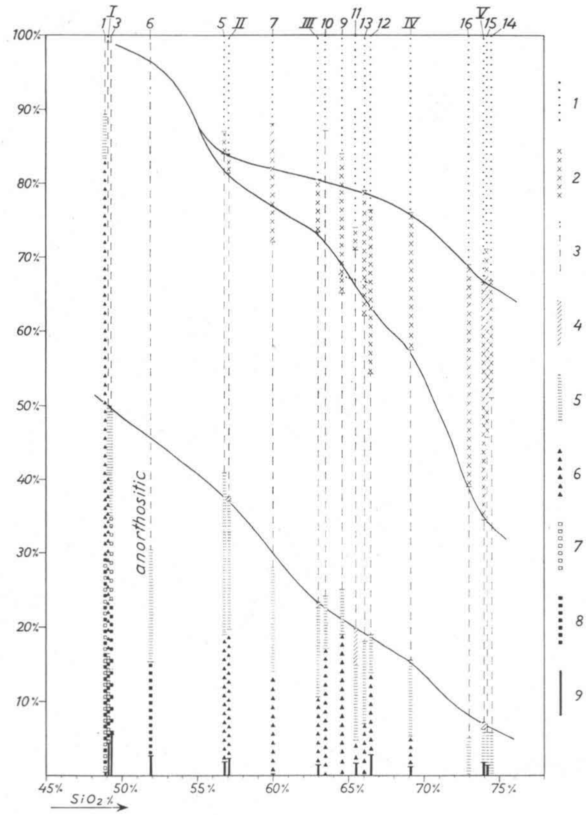


Fig. 28. Mineralogical composition of the analysed plutonic rocks in Middle East Bothnia. 1, quartz; 2, microcline; 3, plagioclase; 4, chlorite; 5, biotite; 6, hornblende; 7, diopside; 8, hypersthene; 9, accessories. Numbers 1—17 of separate determinations refer to analysed specimens listed in Table XXIII. Average mineralogical compositions: I, gabbro; II, quartz gabbro; III, quartz diorite; IV, granodiorite; V, granite.

is same in both cases (see p. 50). The following rock types are represented among the plutonic rocks of Middle East Bothnia:

1. Ultrabasic rock. No. 1 in Fig. 27.
2. Gabbro. Numbers 3, I—VII in Fig. 27.
3. Quartz gabbro. Nos. 5, VIII—XI in Fig. 27.
4. Anorthositic gabbro. Nos. 6 and XII in Fig. 27.
5. Quartz diorite. Nos. 7, 10, 11, XIII—XV, XX, XXIII in Fig. 27.
6. Granodiorite. Nos. 9, 12—15, XVI—XIX, XXI—XXII, XXIV—XXVI in Fig. 27.
7. Granite. Nos. 16, XXVII—XXIX in Fig. 27.

Average mineralogical compositions of the afore-mentioned rock types (Table XXIV) are related to those of the Tampere area. Main characteristics of the mineralogical composition are as follows (cf. Fig. 28):

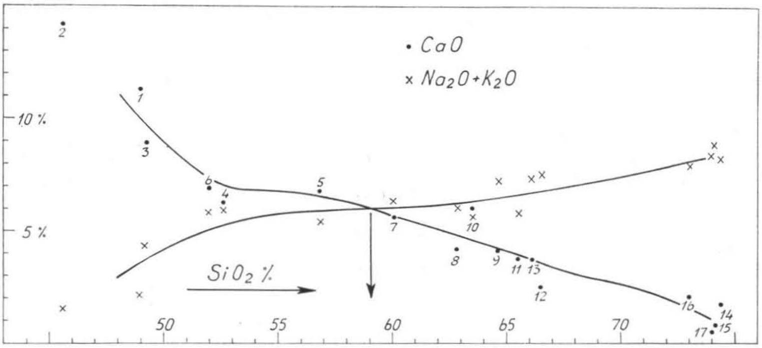


Fig. 29. Alkali-lime index of the granite province in Middle East Bothnia. Numbers 1—17 refer to specimens listed in Table XXIII.

Rhombic and monoclinic pyroxenes are present in ultrabasics, anorthosites, and gabbros, but they are lacking in rock types containing free quartz. The mineral association hornblende and biotite is characteristic especially of quartz gabbros and quartz diorites. Hornblende is lacking in most of the acid members of the province.

The content of plagioclase decreases towards the acid members of the province and it becomes more albitic. Microcline is present in quartz-bearing varieties and its content rises along with an increase in the silica content.

Table XXV. Average chemical compositions of plutonic rocks in Middle East Bothnia

	1	2	3	4	5
SiO_2	49.15	56.85	62.99	69.17	74.06
TiO_2	1.24	1.15	0.56	0.42	0.18
Al_2O_3	16.00	17.64	16.48	14.53	13.46
Fe_2O_3	2.34	1.45	0.53	1.13	0.74
FeO	8.91	5.76	4.06	3.03	1.15
MnO	0.17	0.14	0.09	0.02	0.04
MgO	6.59	4.12	2.99	1.00	0.38
CaO	9.76	6.78	4.88	2.54	1.20
Na_2O	2.86	3.10	3.61	3.77	3.35
K_2O	1.10	2.35	2.35	4.09	4.84
P_2O_5	0.43	—	0.19	0.08	0.03
H_2O+	1.39	0.41	1.06	0.57	0.69
H_2O-	0.12	0.13	0.10	0.04	0.11
	100.06	99.88	99.89	100.39	100.23

1. Gabbro (3 analyses; Nos. 2—4 in Table XXIII).
2. Quartz gabbro (1 analysis; No. 5 in Table XXIII).
3. Quartz diorite (4 analyses; Nos. 7—8, 10—11 in Table XXIII).
4. Granodiorite (5 analyses; Nos. 9, 12—15 in Table XXIII).
5. Granite (2 analyses; Nos. 16—17 in Table XXIII).

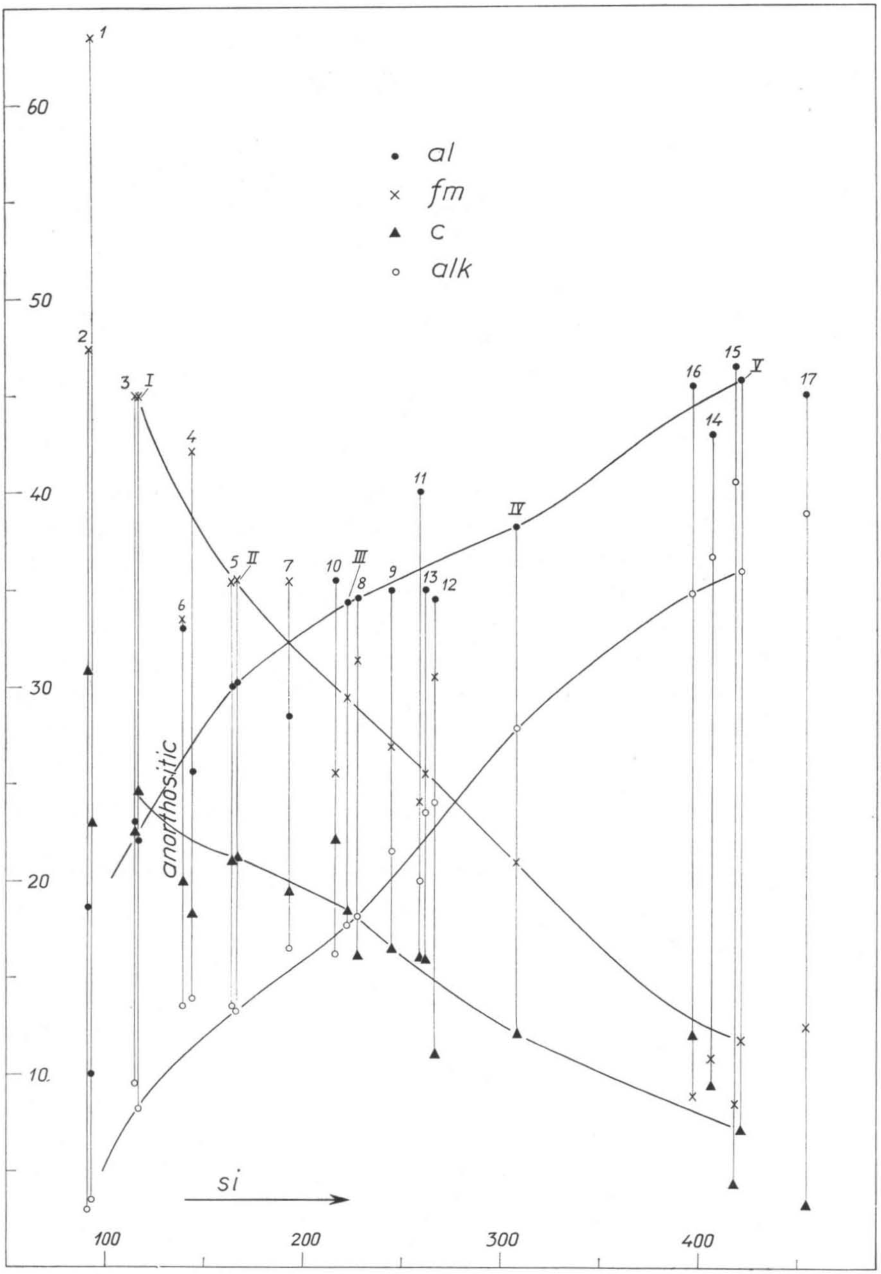


Fig. 30. Niggli diagram of the plutonic rocks in Middle East Bothnia. Numbers 1—17 of separate analyses refer to specimens listed in Table XXIII. Average compositions: I, gabbro; II, quartz gabbro; III, quartz diorite; IV, granodiorite; V, granite.

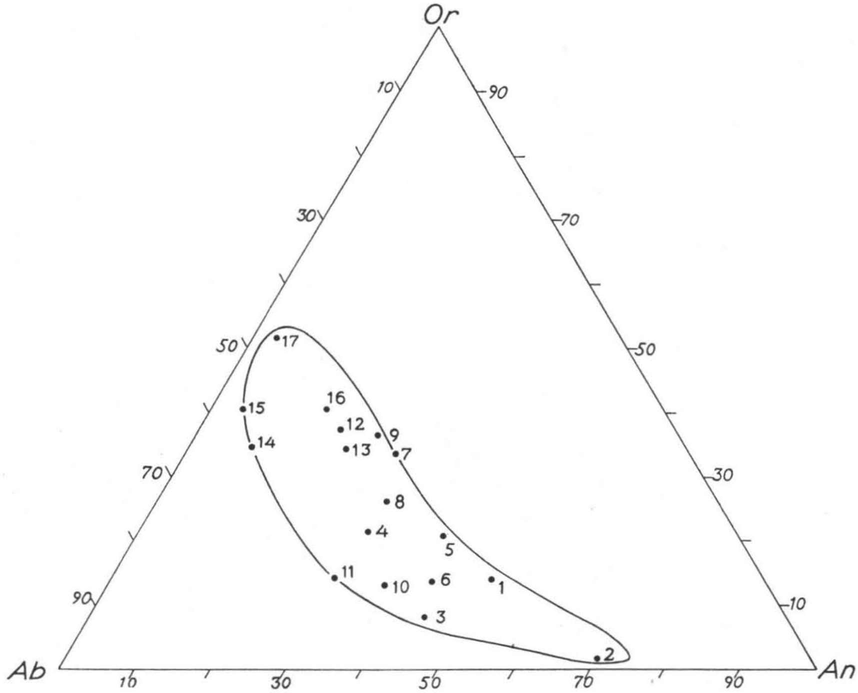


Fig. 31. Normative proportions Or : Ab : An of the plutonic rocks in Middle East Bothnia. Nnmbers 1—17 of separate determinations refer to specimens listed in Table XXIII.

Average chemical compositions of the plutonic rocks in Middle East Bothnia (Table XXV) are quite similar to those in the Tampere area (cf. Table XXII). They contain more alkalies and less lime than the corresponding rocks of the granodiorite, trondhjemite, and charnockite provinces. The alkali-lime index of the plutonic rocks in East Bothnia. (Fig. 29) is 59 and very similar to that of the granite province in the Tampere area.

Niggli diagram of the plutonic rocks in Middle East Bothnia (Fig. 30) shows a continuous rock series ranging from gabbros to granites and the position of the »differentiation curves» is quite similar to that of the granite province in the Tampere area (cf. Fig. 24).

Normative proportions Or : Ab : An of the plutonic rocks in Middle East Bothnia are presented in Fig. 31, which shows a continuous series from gabbros to granites and similarity to the granite province of the Tampere field. Proportions Q : Ab : Or (Fig. 32) show that the evolution leads to an eutectoid granitic composition, as is the case also in the granite province of the Tampere area.

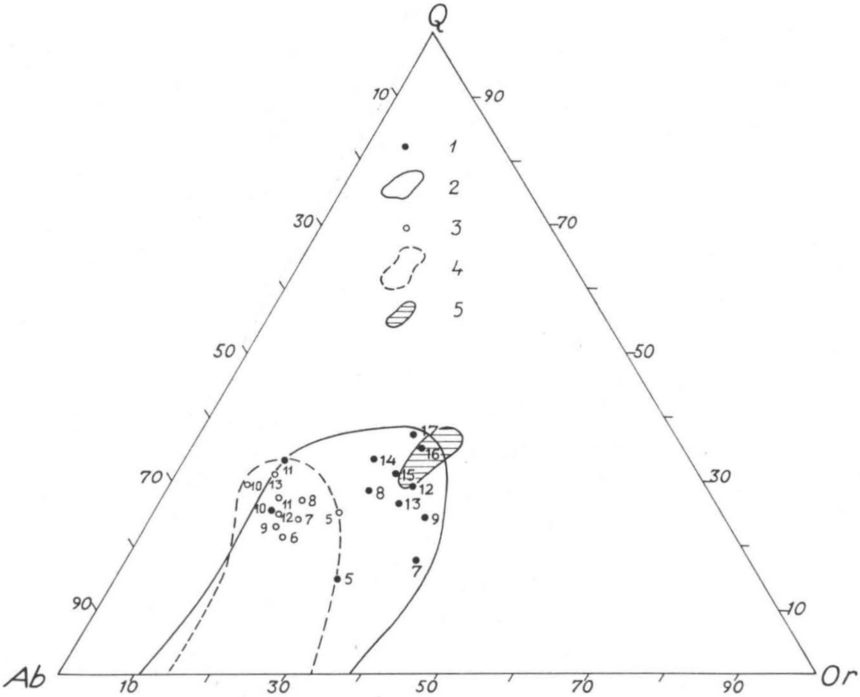


Fig. 32. Normative proportions Q : Ab : Or in the plutonic rocks of the granite (East Bothnia) and charnockite provinces. 1, plutonic rock of granite province; 2, field of granite province; 3, plutonic rock of charnockite province; 4, field of charnockite province; 5, eutectoid granite composition (Adams, 1952). Numbers of separate determinations refer to specimens listed in Tables XXIII and XII.

MICROCLINE GRANITE

Geological mapping operations in southern Finland have brought to light an abundance of potash-rich granites, which form migmatites with Svecofennidic schists and with plutonic rocks of the granodiorite, trondhjemite and charnockite provinces. These potash-rich granites do not belong as an acid end member to the other plutonic rock provinces of the area, because a marked break occurs in mineralogical as well as in chemical composition between the potash granites and granodioritic end members of other plutonic rock provinces of the area. Microcline granites form a unique group without basic and intermediate members.

The potash-rich granites of southern Finland were separated even in the oldest geological studies as an independent group identified by different terms, as younger granites, granites of the second group, granites of the coast type, granites of Hangö type, migmatite-forming granites, etc. These granites belong to the Svecofennidic diastrophism and their emplacement

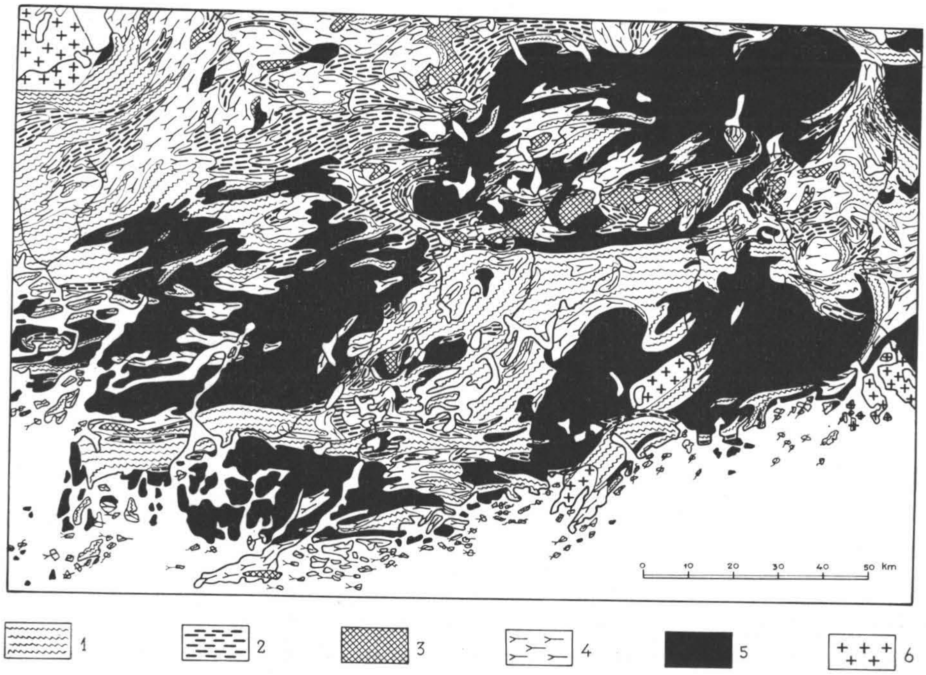


Fig. 33. Geological map of southern Finland showing manner of occurrence of late-kinematic microcline granites. 1, Svecofennidic mica schists, mica gneisses, and quartz-feldspar schists; 2, metabasalts and amphibolites; 3, basic plutonic rocks; 4, synkinematic acid plutonic rocks; 5, late-kinematic microcline granites; 6, anorogenic granites.

has taken place at a late phase of Svecofennidic mountain folding (late-kinematic granites).

Microcline granites occupy large areas in southern Finland (Fig. 33) and considerable field evidence of a metasomatic origin of these granites has been presented. The most valid data are relic structures (old drawings of Wegmann) which show that in place of the present microcline granite there had earlier been another solid rock. The manner of occurrence of microcline granites follows old structural features of the pre-granitic rock crust. An independent tectonical feature of microcline granites is, however, the diapiric dome-like shape of many wide granite areas (cf. Fig. 33).

Mineralogical composition of microcline granites is presented in Figs. 34—35, and analysed specimens are listed in Table XXVI.

Variations in mineralogical composition of microcline granites are very small. Content of mafic minerals is low. Biotite is the predominant mafic mineral and no rection series of mafic minerals, typical of other plutonic provinces, occur. Content of microcline is higher than that of plagioclase.

Average mineralogical composition (Table XXVII) shows that microcline granites contain less quartz and more feldspar than the granites

9 3509—60/1,74

Table XXVI. Analysed microcline granites of southern Finland.

No	Name of the rock	Locality	Reference
1	Microcline granite	Pajback, Parainen	Metzger, 1945
2	» »	Räntämäki	Hietanen, 1947
3	» »	Alajärvi	Simonen, 1948 b
4	» »	Pajback, Parainen	Metzger, 1945
5	» »	Kakola, Turku	Hietanen, 1947
6	» »	Kakola, Turku	Hietanen, 1947
7	» »	Sillanpää, Kisko	Eskola, 1914
8	» »	Mattnäs, Nauvo	Hausen, 1944
9	» »	Metsämaa	Salli, 1953
10	» »	Skarfkyrkan, Hanko	Sederholm, 1912
11	» »	Lövböle, Kemiö	Pehrman, 1945
12	» »	Manngård, Karjaa	Lokka, 1950
13	» »	Hanko	Sederholm, 1912
14	» »	Lauttasaari, Helsinki	Rankama, 1939
15	» »	Kumlinge	Sederholm, 1934
16	» »	Inkoo	Sederholm, 1926
17	» »	Pernaja	Vaasjoki, 1953
18	» »	Lahdenperä, Kisko	Eskola, 1952

belonging to the granite suite (cf. Table XVIII). Furthermore, the mineralogical composition of the microcline granite shows a marked break with that of the acid members of the granodiorite, trondhjemite and charnockite provinces. Therefore, the microcline granites do not represent the most acid granitic end member of the provinces mentioned.

Some notes on rock-forming minerals are given below.

Table XXVII. Average mineralogical composition of microcline granite.

	1	2
Quartz	28.4	30.5
Microcline	37.4	34.0
Plagioclase	24.9	29.0
Biotite	5.6	1.0
Accessories	3.7	5.5

1. Microcline granite (9 determinations; Nos. 1—7 and I—II in Fig. 34).
2. Microcline granite, average from 12 samples (Parras, 1958).

Table XXVIII. Refractive indices of the biotite in microcline granites.

Locality	$\beta = \gamma$
Hanko	1 675
Hanko	1 671
Kirkkonummi	1 669
Inkoo	1.659

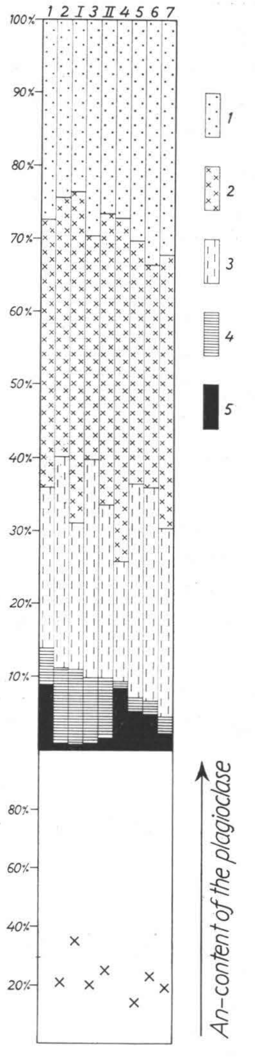


Fig. 34. Mineralogical composition of microcline granites in southern Finland. 1, quartz; 2, microcline; 3, plagioclase; 4, biotite (+ muscovite); 5, accessory minerals. Numbers 1—7 of separate determinations refer to analysed specimens listed in Table XXVI. I—II, microcline granites from Piikkiö described by Lehijärvi (1957).

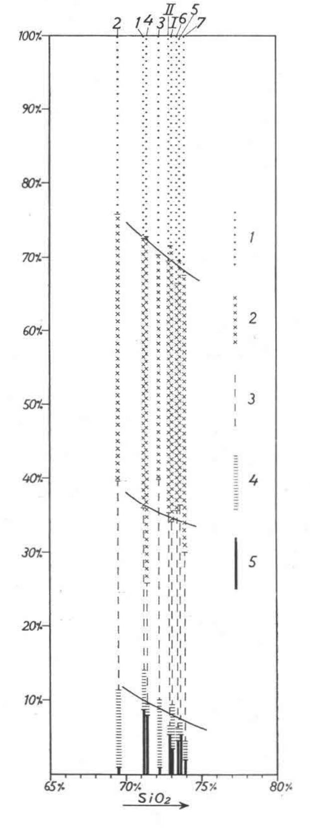


Fig. 35. Mineralogical composition of analysed microcline granites 1, quartz; 2, microcline; 3, plagioclase; 4, biotite (+ muscovite) 5, accessory minerals. Numbers 1—7 refer to Table XXVI. I, average mineralogical composition of microcline granite; II, average mixture from 12 samples (Parras, 1958).

Biotite is predominant mafic mineral of the microcline granite. Refractive indices of the biotite (Table XXVIII) are high, indicating an iron-rich variety.

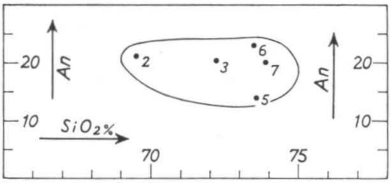


Fig. 36. Composition of plagioclase in microcline granites. Numbers of separate determinations refer to specimens listed in Table XXVI.

Muscovite has been found only in some few specimens.

Plagioclase is usually oligoclase. Its composition does not vary with an increasing silica content in the rock (Fig. 36). Zonar texture has been found only as a rarity.

Microcline is predominant salic mineral of microcline granites and its content is 30—40 %.

Quartz is present in rather equal quantities (c. 30 %).

Accessory minerals of microcline granites are represented by oxidic iron ore, almandine garnet, cordierite, and sillimanite. Minerals indicating an aluminous reaction type are characteristic and they are not common in other Svecofennidic plutonic rocks.

Average chemical composition of microcline granite (Table XXIX) is characterized by a high content of alkalies, especially potash, and a low content of iron, magnesium and lime.

Niggli diagram (Fig. 37) shows that the microcline granites are characterized by higher alk- and lesser c-numbers than the acid end members of other Svecofennidic plutonic rocks.

Table XXIX. Average chemical composition of microcline granite

	1	2
SiO_2	73.04	72.97
TiO_2	0.22	0.14
Al_2O_3	14.03	13.91
Fe_2O_3	0.61	0.31
FeO	1.16	1.60
MnO	0.02	0.04
MgO	0.36	0.42
CaO	1.14	1.06
Na_2O	2.78	3.27
K_2O	6.07	5.10
P_2O_5	0.08	0.20
H_2O+		0.63
H_2O-	0.51	0.06
	100.02	99.71

1. Microcline granite (18 analyses; Nos. 1—18 in Table XXVI).
2. Microcline granite; average from 12 samples (Parras, 1958).

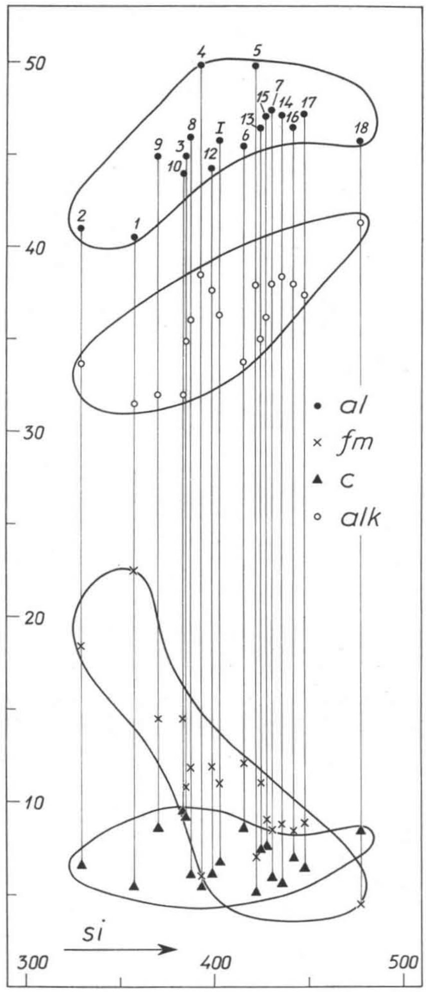


Fig. 37. Niggli diagram of microcline granites. Numbers 1—18 of separate analyses refer to specimens listed in Table XXVI. I, average composition of microcline granite.

Normative proportions Or : Ab : An (Fig. 38) show that microcline granites are characterized by a marked preponderance of potash feldspar over soda feldspar. The microcline granites occupy a field showing a higher content of Or than the granites belonging to the granite province (cf. Fig. 25). Composition of microcline granites does not represent an eutectoid granite composition (Fig. 39), as is the case with the granites belonging to the granite province (cf. Fig. 26), but they have higher values of potash feldspar than those of eutectoid granites. This fact indicates that the microcline granites have not been crystallized from a residual granite

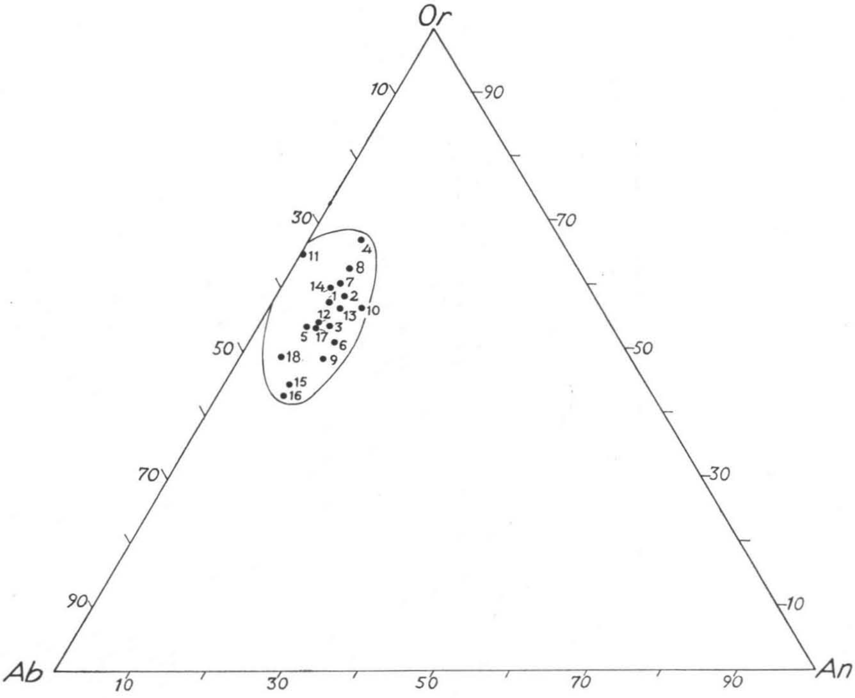


Fig. 38. Normative proportions Or : Ab : An of microcline granites. Numbers 1—18 of separate determinations refer to specimens listed in Table XXVI.

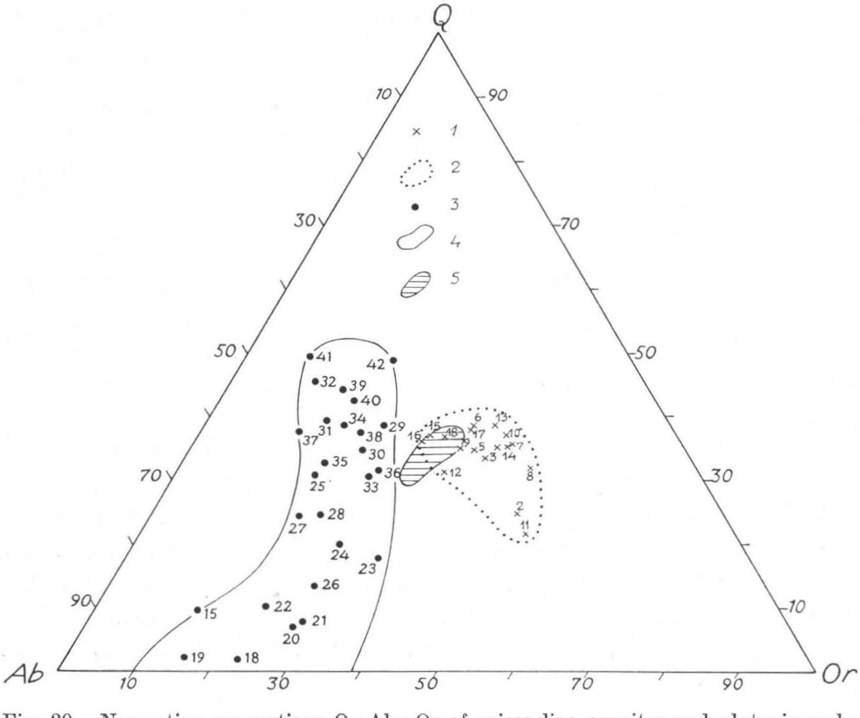


Fig. 39. Normative proportions Q : Ab : Or of microcline granites and plutonic rocks of granodiorite province. 1, microcline granite; 2, field of microcline granite; 3, plutonic rock of granodiorite province; 4, field of granodiorite province; 5, eutectoid granite composition (Adams, 1952). Numbers of separate determinations refer to specimens listed in Tables XXVI and I.

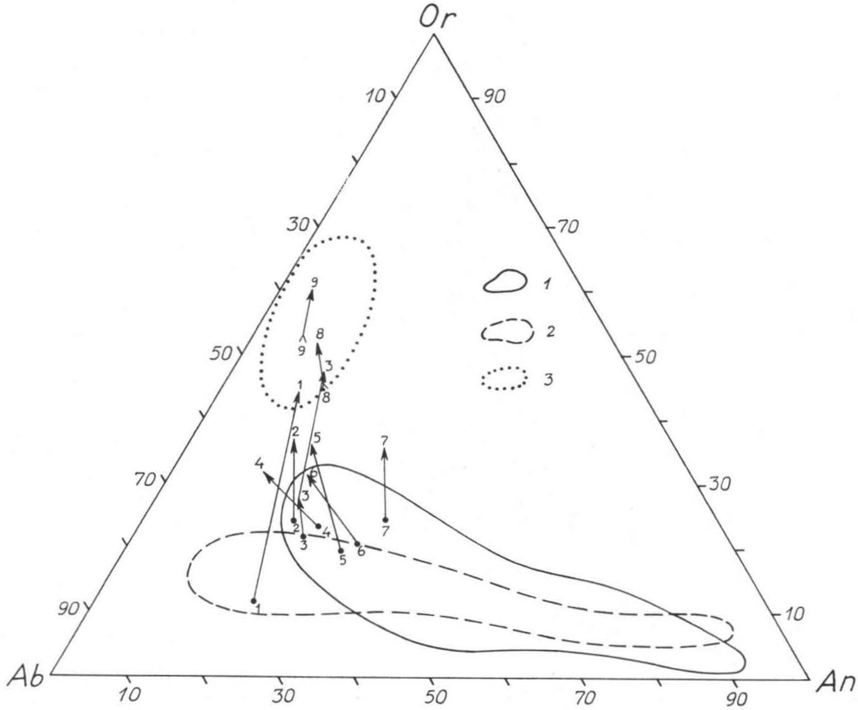


Fig. 40. Normative proportions Or : Ab : An of partly granitized plutonic rocks. 1, field of the granodiorite province; 2, field of the trondhjemite province; 3, field of microcline granites. Numbers 1—9 of separate determinations refer to specimens as follows: 1, granitized trondhjemites, Orimattila (Härme, 1958); 2, granitized oligoclase granite, Virkkala (Härme, 1958); 3, granitized oligoclase granite, Vihti (Härme, 1958); 4, granitization of granodiorite, Orijärvi (Eskola, 1952); 5, granitization of granodiorite, Suomusjärvi (Härme, 1958); 6, granitization of granodiorite, Aulanko (Simonen, 1948 b); 7, granitization of quartz diorite, Hanko (Härme, 1958); 8, granitization products of trondhjemite, Järvenpää (Härme, 1958); 9, granitization products of trondhjemite, Kerava (Härme, 1958).

magma, but hydrothermal processes and potash metasomatism have played an important role in their origin.

The chemical composition of microcline granite has been called by Eskola (1950 b) an ideal granitic composition. The term »ideal granite» is not, however, applicable to granites which do not represent an eutectoid granite composition. In my opinion the microcline granites are »unideal» granites and the term »ideal granite» is better applied to granites showing an eutectoid granite composition. This usage has been suggested also by Fischer (1951) and Mehnert (1959).

Field evidence of granitization in the migmatitic rock crust of southern Finland has been presented by various authors. Rocks with a different primary composition and origin become more granitic, and the end product of granitization is microcline granite. Granitization of plutonic rocks of the granodiorite, trondhjemite, and charnockite provinces is common and

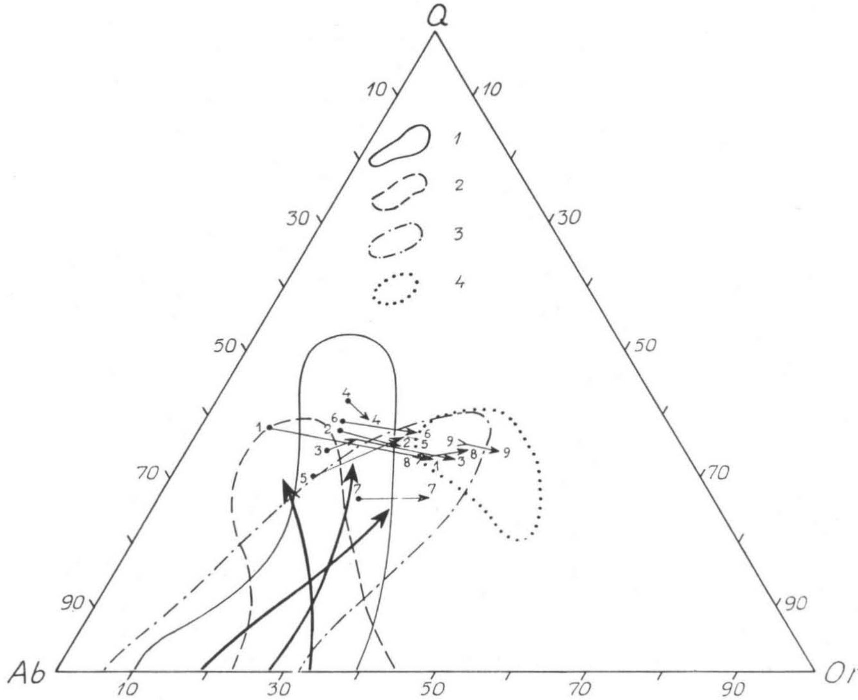


Fig. 41. Normative proportions Q : Ab : Or of partly granitized plutonic rocks. 1, field of the granodiorite province; 2, field of trondhjemite province; 3, field of the granite province; 4, field of microcline granites. Nos. 1—9 refer to specimens listed in Fig. 40.

partly granitized types represent transitional forms of microcline granites. Partly granitized plutonic rocks fill that break in chemical composition which occurs between microcline granite and acid end members of the granodiorite and trondhjemite provinces. Compositional changes of granitization are presented in Fig. 40, which representes normative Or : Ab : An proportions of partly granitized plutonic rocks.

Normative proportions Q : Ab : Or of partly granitized plutonic rocks are presented in Fig. 41. This figure shows that the granitization always tends towards the composition characterizing microcline granite. Furthermore, compositional changes caused by granitization go traverse to compositional changes observed in the evolution of many rock provinces. This shows that the causes of compositional changes, producing, on the one hand, rock series grading from gabbros to acid end members and, on the other, simple microcline granites, have been different. Rock provinces with transitional basic, intermediate, and acid rocks are products of magmatic evolution, and the origin of simple microcline granite is due to metasomatic processes that had taken place in different kinds of solid rocks.

COMPARISON OF MINERALOGICAL AND CHEMICAL CHARACTERISTICS

Geological study of the Svecofennidic rock crust in Finland has revealed the occurrence of different petrographic provinces of orogenic plutonic rocks. The plutonic rocks have been classified as follows:

granodiorite province,
trondhjemite province,
charnockite province,
granite province, and
microcline granites.

The separate provinces have been named according to their most acid end members. These provinces are independent, with their own mineralogical and chemical characteristics. This chapter contains a short summary and comparison of mineralogical and chemical characteristics.

Variations in the mineralogical composition of different plutonic rock provinces are given in Fig. 42. To the separate provinces, excepting the microcline granites, belong basic, intermediate, and acid plutonic rocks, which form continuous rock series suggesting magmatic differentiation. Furthermore, reaction series of the mafic and salic minerals of the provinces indicate magmatic evolution. The most acid end members of the granodiorite, trondhjemite and charnockite provinces are characterized by a preponderance of plagioclase over potash feldspar, whereas real granites ($Or > Ab + An$) are present only in the granite province and among the migmatite-forming microcline granites.

The provinces characterized by plagioclase-rich silicic end members ($Or < Ab + An$; $Or > An$) differ from each other mainly in respect to the different reaction types of mafic minerals. A meta-aluminous association (hornblende and biotite) is characteristic of the granodiorite province, a peraluminous reaction type (biotite) of the trondhjemite province, and a subaluminous reaction type (pyroxene) of the charnockite province. Differences in the mineralogical composition of the provinces mentioned are most apparent in acid end members, whereas the basic rocks of different

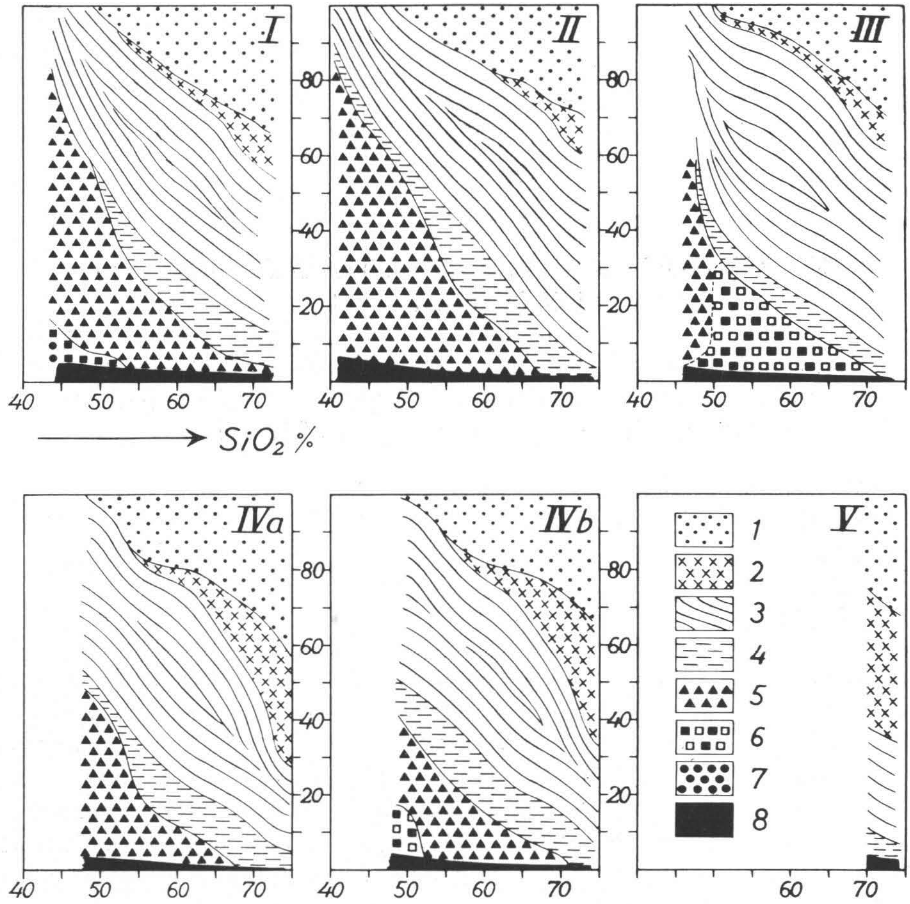


Fig. 42. Mineralogical composition of plutonic rock provinces. I, granodiorite province; II, trondhjemite province; III, charnockite province; IV a, granite province of the Tampere area; IV b, granite province in East Bothnia; V, microcline granite. 1, quartz 2, microcline; 3, plagioclase; 4, biotite; 5, hornblende; 6, pyroxene; 7, olivine; 8, accessories.

provinces are mineralogically closely related. Different reaction types have been caused by varying contents of volatile substances in parent magmas.

The mineralogical composition of the granite province has been described from the Tampere area and Middle East Bothnia. The plutonic rocks of both these areas are closely related (Fig. 42; IV a and IV b). Microcline granites form a unigue group, because they do not belong as an acid end member to a continuous rock series grading from basic into acid types (Fig. 42, V).

Variations in the contents of separate rock-forming minerals with an increasing silica content in the host rock are presented in Fig. 43.

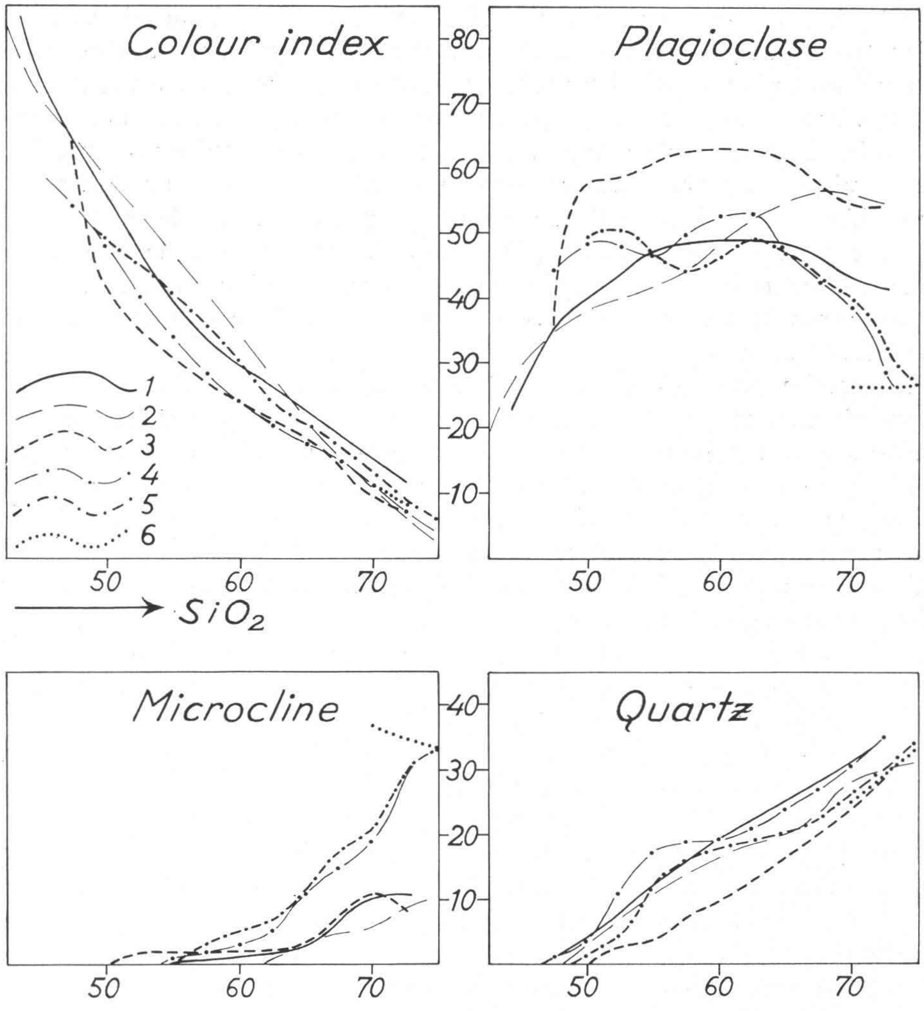


Fig. 43. Color index and variation of separate minerals in the different plutonic rock provinces. 1, granodiorite province; 2, trondhjemite province; 3, charnockite province; 4, granite province in the Tampere area; 5, granite province in East Bothnia; 6, microcline granite.

The content of mafic minerals (color index) decreases regularly with an increasing silica content in the rock (Fig. 43). Basic rocks of the granite province contain less mafic minerals than the corresponding rocks of the granodiorite and trondhjemite provinces. Intermediate plutonic rocks of the charnockite province are characterized by a low content of mafic minerals.

A high content of plagioclase (Fig. 43) is typical of the charnockites. The trondhjemite province is characterized by a gradual increase in the quantity of plagioclase along with an increase in the silica content of the rock, whereas the granodiorite province shows the highest content of plagioclase in the intermediate types. Basic rocks of the granite province have more plagioclase than the corresponding rocks of the granodiorite and trondhjemite provinces but the content of plagioclase in the rocks of the granite province decreases rapidly towards the granitic end members. The microcline granites have the same quantities of plagioclase as the most silicic types of the granite province, but no marked variations in the content have been found.

Microcline (Fig. 43) is sparsely present in the rocks of the granodiorite, trondhjemite, and charnockite provinces, but it is abundant in the silicic members of the granite province, where its content rises rapidly along with an increasing silica content. The variation in the microcline content of the granite province differs from that of the other provinces. Potash feldspar is most abundant in the microcline granites, whose content of microcline does not, however, rise with an increasing silica content as in the case of the other plutonic provinces.

The content of free quartz (Fig. 43) is highest in the granodiorite and granite provinces and lowest in the charnockite province. The plutonic rocks of the granite province in the Tampere area contain more quartz than the corresponding rocks in East Bothnia. The microcline granites contain less quartz than the granites of the granite province.

Sporadic data on the optical properties of the rock-forming minerals of the plutonic provinces are presented in Fig. 44.

The refractive indices of rhombic pyroxene in the charnockitic rocks vary within wide limits and no regularity depending on the silica content of the host rock has been observed.

The refractive indices of monoclinic pyroxene rise with an increasing silica content of the plutonic rock. Monoclinic pyroxenes in the basic rocks of the granodiorite province show lower indices than those of the charnockite province.

The refractive indices of hornblende rise with an increasing silica content of the host rock. High refractive indices have been observed in hornblendites and anorthosites of the granodiorite and trondhjemite provinces; also the hornblende of basic charnockites have extremely high indices. Hornblende in the rocks of the granite province generally has higher refractive indices than is the case with the corresponding rocks of the granodiorite and trondhjemite provinces.

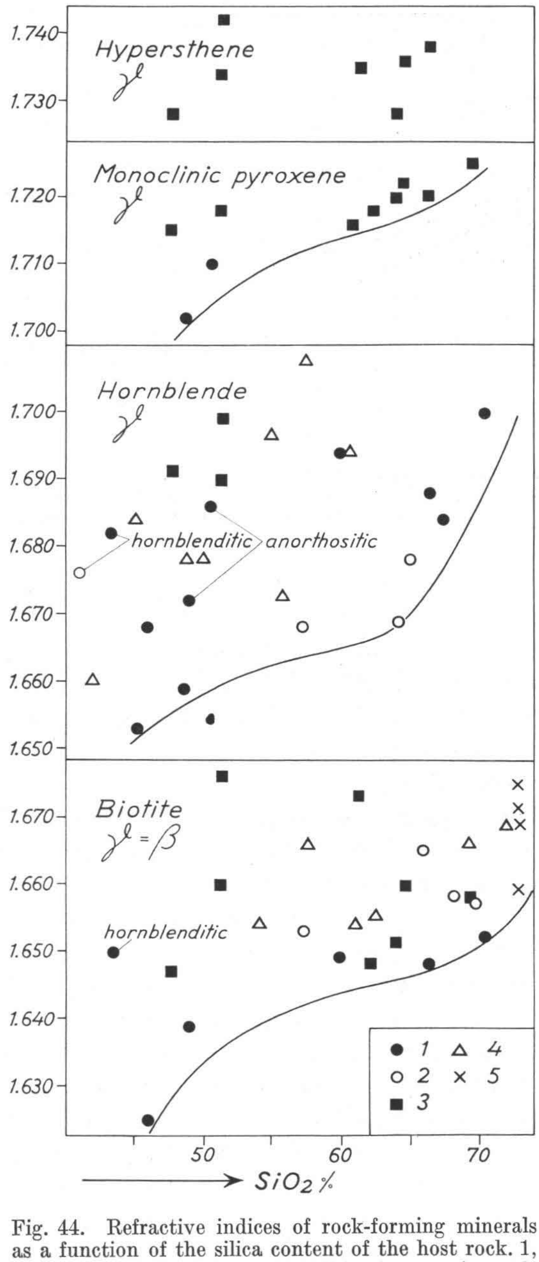


Fig. 44. Refractive indices of rock-forming minerals as a function of the silica content of the host rock. 1, granodiorite province; 2, trondhjemite province; 3, charnockite province; 4, granite province in the Tampere area; 5, microcline granite.

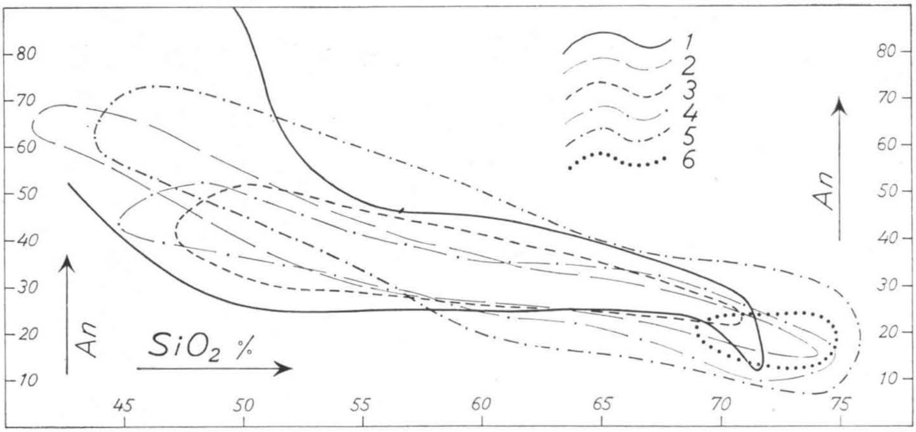


Fig. 45. Composition of plagioclase as a function of the silica content of the host rock. 1, granodiorite province; 2, trondhjemite province; 3, charnockite province; 4, granite province in the Tampere area; 5, granite province in East Bothnia; 6, microcline granite.

The refractive indices of biotite rise with an increasing silica content of the plutonic rock. Extremely high refractive indices have been found in some basic charnockites. Biotite in the rocks of the granite province usually has a higher refractive index than is the case with the corresponding rocks of the granodiorite province. Biotites of the microcline granites have high refractive indices.

The composition of plagioclase becomes more albitic with an increasing silica content in the plutonic rock (Fig. 45). The most albitic plagioclase occurs in the silicic members of the granite province.

Variations in the main oxides in average analyses of the plutonic rock provinces are presented in Fig. 46. The most characteristic differences between the separate provinces appear in the contents of CaO, Na_2O, and K_2O. The rocks of the granodiorite province contain more lime than the corresponding rocks of the other provinces; the trondhjemites are characterized by a high content of soda; a high content of potash is typical both of the granite province and of the microcline granites. These differences indicate a primary chemical difference in the parent magmas of the provinces mentioned. The plutonic rocks of the trondhjemite and charnockite provinces are chemically closely related. Those rocks have been differentiated probably from the same parent magma, but different assemblages of mafic minerals have been produced by different content of volatile substances in magma.

The granite provinces from the Tampere area and East Bothnia are chemically quite similar. The only remarkable difference to have been

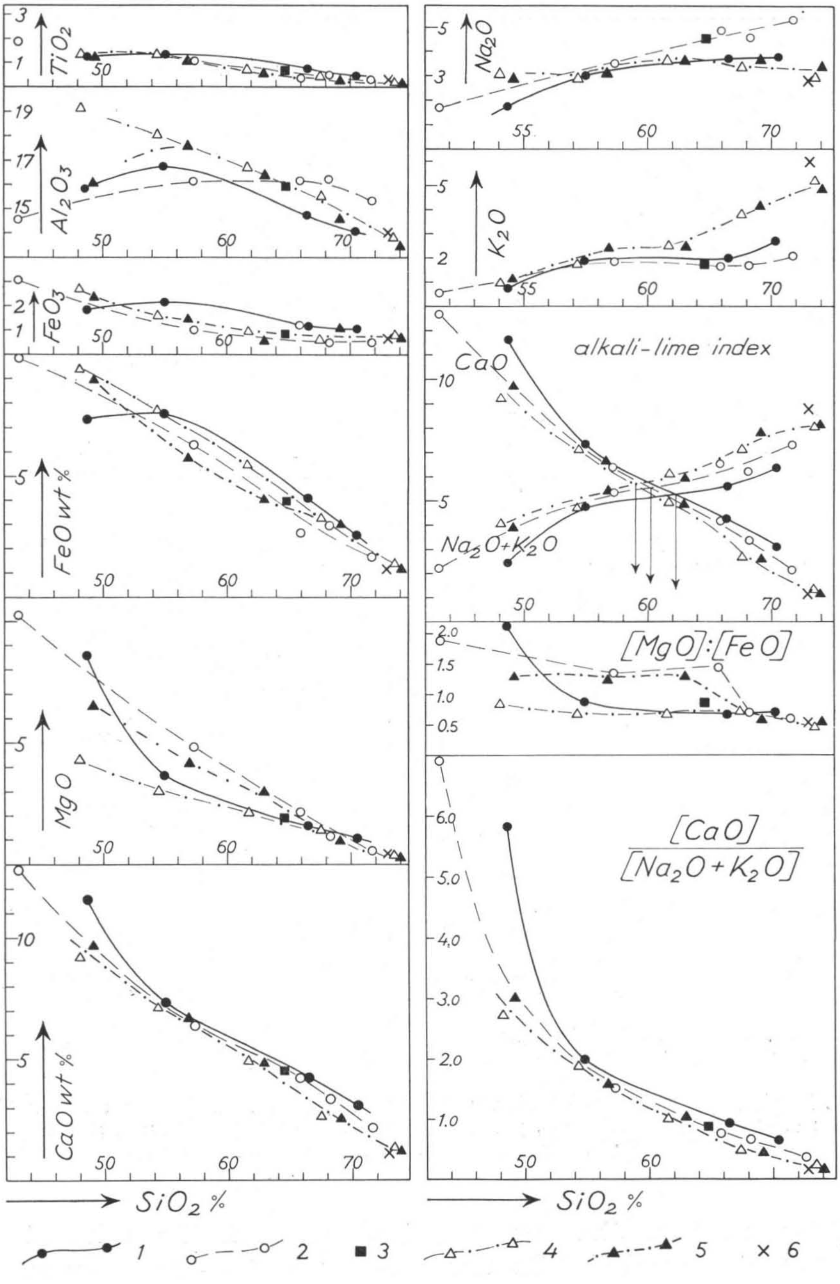


Fig. 46. Chemical composition of plutonic rock provinces based on average chemical compositions in Tables VI, XI, XVI, XXII, XXV and XXIX. 1, granodiorite province; 2, trondhjemite province; 3, charnockite province; 4, granite province in the Tampere area; 5, granite province in East Bothnia; 6, microcline granite.

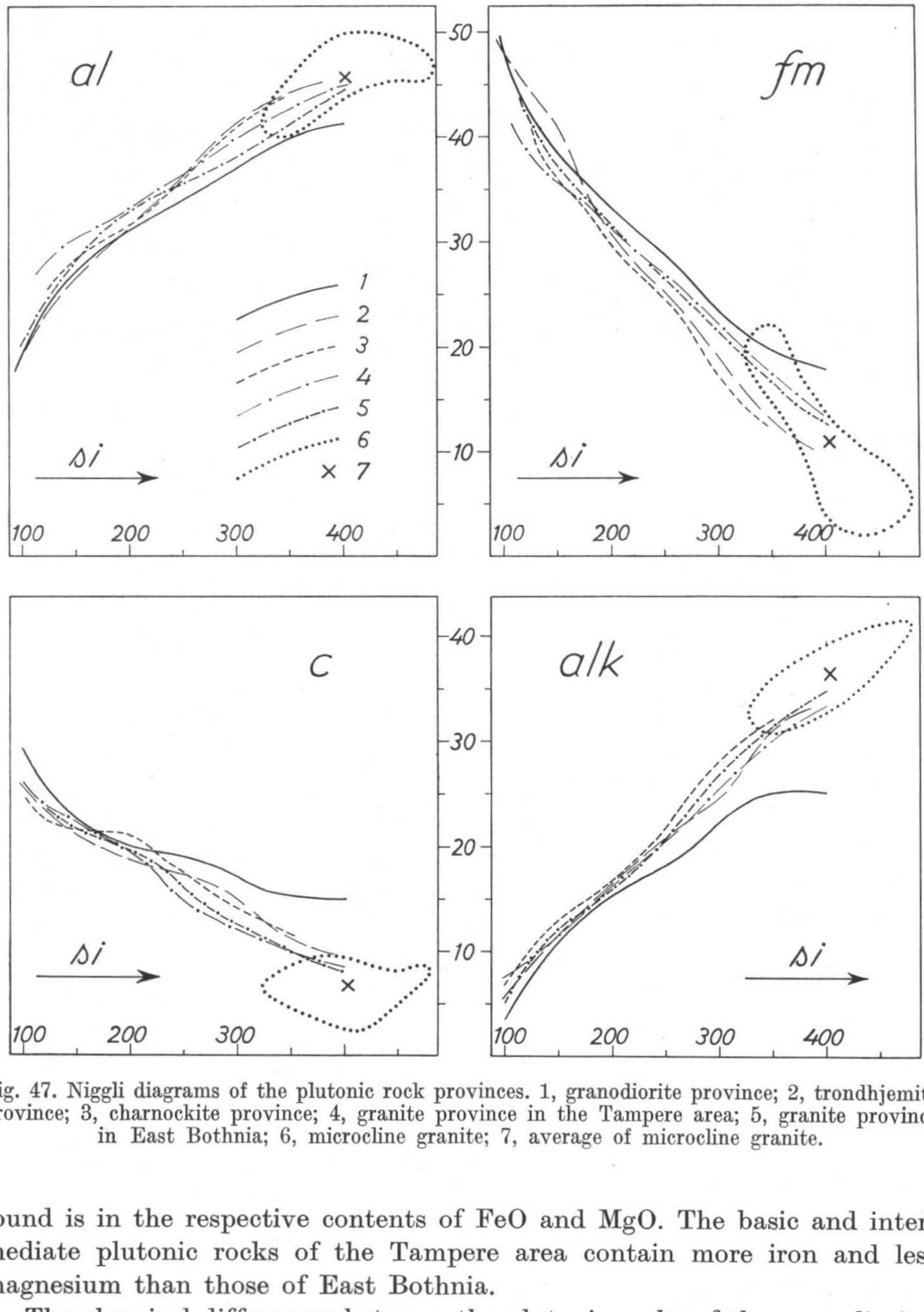


Fig. 47. Niggli diagrams of the plutonic rock provinces. 1, granodiorite province; 2, trondhjemite province; 3, charnockite province; 4, granite province in the Tampere area; 5, granite province in East Bothnia; 6, microcline granite; 7, average of microcline granite.

found is in the respective contents of FeO and MgO. The basic and intermediate plutonic rocks of the Tampere area contain more iron and less magnesium than those of East Bothnia.

The chemical differences between the plutonic rocks of the granodiorite, trondhjemite, and granite provinces are revealed also by the alkali-lime index (Fig. 46). The granodiorite province is the most calcic, with an index

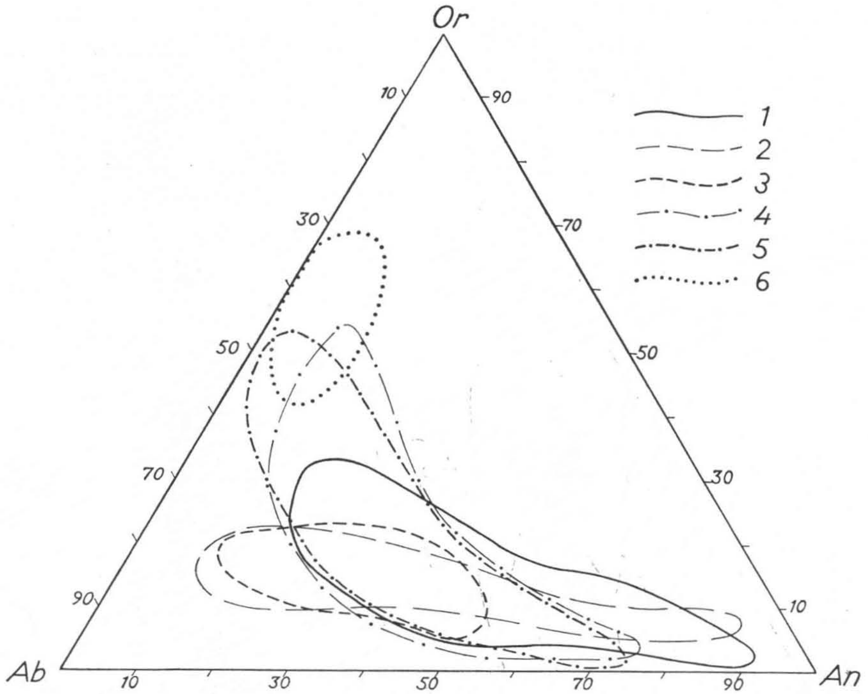


Fig. 48. Normative proportions Or : Ab : An in plutonic rock provinces. Different fields are as follows: 1, granodiorite province; 2, trondhjemite province; 3, charnockite province; 4, granite province in the Tampere area; 5, granite province in East Bothnia; 6, microcline granite.

of 62; the trondhjemite province has an index of 60—61, whereas the granite province is calc-alkalic with an index of 59.

Ratios (MgO) : (FeO) and (CaO) : ($Na_2O + K_2O$) in the Svecofennidic plutonic rock suites decrease along with an increasing silica content (cf. Fig. 46) as in the case of magmatic crystallization. Ratios of (MgO) : (FeO) in the acid members of different suites vary within small limits, but in the basic and intermediate members the ratios vary in different rock provinces. Special mention must be made of the fact that the ratio of (MgO) : (FeO) in the basic and intermediate rocks of East Bothnia is higher than that in the corresponding rocks of the Tampere area. This is the only remarkable difference in the chemistry of these two representatives of the granite province. The ratio of (CaO) : ($Na_2O + K_2O$) is highest in the plutonic rocks of the granodiorite province and lowest in the rocks of the granite province.

Niggli diagrams of the plutonic provinces are presented in Fig. 47. Differentiation curves for plutonic rocks of the trondhjemite and charnockite

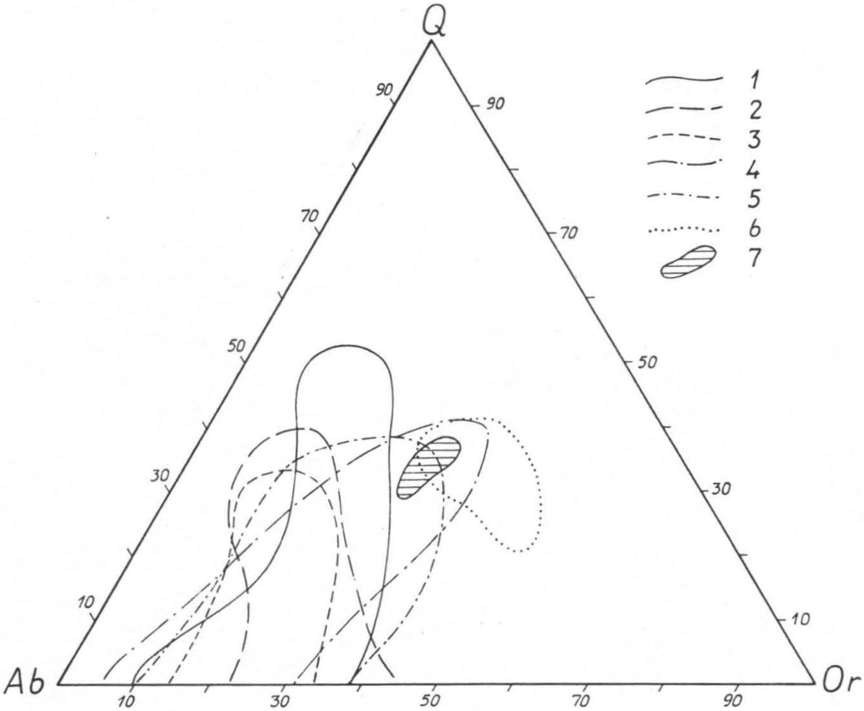


Fig. 49. Normative proportions Q : Ab : Or in plutonic rock provinces. Different fields are as follows: 1, granodiorite province; 2, trondhjemite province; 3, charnockite province; 4, granite province in the Tampere area; 5, granite province in East Bothnia; 6, microcline granite; 7, »eutectoid» granite (Adams, 1952).

provinces are very similar and they deviate clearly from the curves for plutonic rocks of the granodiorite province, especially at the silicic end. The curves for the granite province in the Tampere area and East Bothnia are nearly identical to each other and their trend deviates from that of the other provinces.

Normative proportions Or : Ab : An in the different provinces are presented in Fig. 48. The fields of the trondhjemite and charnockite provinces have the same position, and they distinctly deviate, especially through a high content of Ab, from the other provinces. The granodiorite, trondhjemite and charnockite provinces do not continue into the granite field as in the case of the plutonic rocks of the granite provinces in the Tampere area and the Bothnian region. The microcline granites show higher values of Or than the granites of the granite province.

Normative proportions Q : Ab : Or in the different provinces are presented in Fig. 49. The fields of the trondhjemite and charnockite provinces have the same position and they deviate distinctly from the other provinces. Furthermore, the field of the granodiorite province deviates clearly from that of the granite province. The granite province continues into an eutectoid granite composition, whereas the microline granites are characterized by a higher content of Or than the granites of the granite province.

The data presented show that there are both mineralogical and chemical differences between different plutonic rock provinces belonging to the same orogenic cycle. Every province has its own characteristics, which form an independent petrographic province. Mineralogical and chemical differences between different provinces appear especially in silicic end members, which usually deviate by a marked compositional break from each other. Evolution in different petrographic provinces, leading into different end members, has been controlled by many factors to be discussed later.

STRUCTURAL GEOLOGY

Methods of structural geology to study the evolution of the Svecofennidic rock crust were first used by Wegmann and Kranck (1931) in the archipelago east of the city of Helsinki and this investigation made clear general relationships between deformations of the Svecofennidic schists and intrusions of plutonic rocks. Emplacement of gabbros and diorites (synkinematic intrusions) has taken place during deformation of the Svecofennian supracrustal formations. The deformation and folding have continued also after the intrusions of synkinematic plutonic rocks and have given to these rocks a gneissose texture. Granitization, producing migmatitic and nebulitic microcline granites and pegmatites, follow the deformation and folding of the Svecofennidic schists.

The conclusions of Wegmann and Kranck (1931) have given rise to a magmatectonic classification of the Svecofennidic granitoids. Magmatectonical points of view have been discussed especially by Wahl (1936) and Saksela (1932, 1936, 1953).

Wahl (1936) has pointed out an intimate relation between mountain folding and intrusions of different granite groups. He stated that in southern Finland there are two different magmatectonic types of granitoids belonging to the Svecofennidic orogeny. On the other hand, there are »gneissose granites» with granodioritic composition which have been intruded into the Svecofennidic schist belt at early stage of mountain folding. These granitoids have been called prim-orogenic granites and they form concordant bodies with the surrounding Svecofennidic schists. On the other hand, there are in southern Finland potash-rich granites which are massive with a pegmatitic character and form migmatites. These granites are younger than gneissose granitoids and they have been called ser-orogenic granites.

The new geological mapping in southern Finland has proved the aforementioned principal ideas of Wahl. At the present stage of our knowledge, the prim-orogenic (synkinematic) plutonic rocks also include, in addition to the rocks of the granodiorite group, the plutonic rocks of the trondhjemite and charnockite provinces. The ser-orogenic (late-orogenic, latekinematic) plutonic rocks are represented by migmatite-forming microcline granites, which deviate by a marked compositional break from the synkinematic plutonic rocks. The granitization belonging to the late-kinematic phase plays an important role in the origin of potash-rich granites.

A tectonic classification of the plutonic rocks in East Bothnia has been carried out by Saksela (1932, 1936), who divides them into synorogenic and late-orogenic groups. The synorogenic group of Saksela consists of gneissose granodiorites, porhyritic granites, muscovite-bearing granites and pegmatites. These plutonic rocks occur as concordant bodies in a coherent schist belt of the area and their structural features (foliation and lineation) are similar to those of the surrounding schists. Migmatites characterized by veined gneisses are commonly associated with the synorogenic intrusions. Saksela concludes that the manner of occurrence of his synorogenic group is highly dependent on the tectonics of the schist zone. The late-orogenic group of Saksela contains plutonic rocks ranging from peridotites to granites and this group has been presented as a differentiation series. The plutonic rocks of Saksela's late-orogenic group occur outside a coherent schist belt and the rock bodies have rounded shapes. Intrusive breccias or agmatites are common. The manner of occurrence of the late-orogenic group is not highly dependent on the tectonics of the schist zone. The differences between the modes of occurrence of the synorogenic and late-orogenic groups depend, according to Saksela, on different intrusion mechanics, which means that the intrusions have taken place during different orogenic phases. Saksela assumes that the plutonic rocks of his synorogenic group are older than those of the late-orogenic group.

It is apparent from Saksela's description that the plutonic rocks in East Bothnia can be divided into two structural groups, but the appropriateness of the terms »synorgenic» and »late-orogenic» is disputable, because no valid evidence has been found that these groups are independent in time. The plutonic rocks of East Bothnia represent two structural groups as follows: 1) plutonic rocks in the coherent schist zone (synorogenic group of Saksela); 2, plutonic rocks outside of the schist belt and belonging to the wide plutonic complex of Central Finland (late-orogenic group of Saksela). In my opinion the tectonic classification of Saksela points out only a different manner of occurrence of the plutonic rocks in and outside the schist belt, but it does not give any clue to the mutual age relations between plutonic rocks in East Bothnia. The plutonism may be comagmatic, as observed decades ago by Mäkinen (1916), and the different manner of occurrence of plutonic bodies is controlled by the tectonic environment in which the intrusions have taken place. The concordant bodies (synorogenic group of Saksela) have been controlled by a framework of crystalline schists, whereas this tectonic control is lacking in the wide plutonic rock area outside the schist belt (late-orogenic group of Saksela). The plutonism in the schist belt and outside of it probably took place during the same time interval, ranging from the synkinematic to the late-kinematic phase.

The general outlines of the tectonic classification of the Svecofennidic plutonic rocks reveal differences of opinion. We may, however, conclude that the manner of occurrence of plutonic bodies has been controlled by a tectonic environment in which the emplacement has taken place. The conditions in and outside of the principal schist zones have been different. The framework of the schists controls the elongated, concordant shapes of plutonic bodies, whereas ovoidal, accordant plutons are common in rand zones or outside of the coherent schist belts. A two-fold tectonic classification of plutonic rocks into synkinematic and late-kinematic groups may be too categorical, and it is not always possible to carry out everywhere, especially in the areas of wide plutonic rock complexes outside the schist belts. Furthermore, it is a proved fact that the manner of occurrence of a plutonic body may be different in different parts of the same pluton. The knowledge concerning the tectonics of separate Svecofennidic plutonic bodies is still too meager to allow far-reaching conclusions on the mechanics of their emplacement. The most characteristic structural features of plutonic rock provinces described in this paper are given below.

Granodiorite province. The plutonic rocks of the granodiorite province in southern Finland have been considered as typical representatives of the synkinematic plutonic rocks. They form concordant plutons in the Svecofennidic schist belt. The structures (foliation and lineation) of plutonic bodies coincide very well with those in the wall rock. Gneissose varieties occur especially in the boundary zones of the plutonic bodies.

Steep foliation and steep lineation are characteristic of the granodiorite province in the Loimaa—Hämeenlinna zone (cf. Fig. 1), where an isoclinal folding with a steep axial plane is typical in the Svecofennidic supracrustal rocks. Contacts of the granodiorite bodies are steep. Some small granodiorite bodies in the present section of the ancient mountain chain are surrounded by a coherent schist belt, but more characteristic is the feature that the metamorphic schists »swim» in the coherent plutonic rock area. The geological map of the Loimaa—Hämeenlinna zone gives the impression that the Svecofennidic schists form a roof of a wide and coherent plutonic body with a batholithic character.

The manner of occurrence of the granodiorite in the Orijärvi area has been discussed in many papers, and the opinions expressed by the different authors deviate remarkably. Eskola (1914, 1950 a) has pointed out that the granodiorite body of Orijärvi is a synkinematic anticlinal batholith, and a diapire-like upward movement of the pluton during its intrusion had caused an upward bending of the folds. The Orijärvi pluton is surrounded by Svecofennidic schists and according to Eskola (1950 a) it is »accordant rather than concordant pluton according to terminology of H. Cloos (1928), although an obvious conformity with the surrounding strata is observable». Tuominen and Mikkola (1950) have pointed out that the synorogenic oligoclase granite of Orijärvi is closely connected with general folding in the area and it occurs as a concordant phacolith within a large recumbent fold. Later on, Tuominen (1951) stressed the flat concordant shape of the Orijärvi granite body folded around an axis plunging gently to the east, although he is no longer »very convinced of the existence of the recumbent fold». Tuominen (1951) concludes that »in general, the oligoclase granites occur along planes or zones of high tension and dilation due to folding». In his recent paper dealing with the structure of the Orijärvi area, Tuominen (1957) does not especially mention the tectonic control of folding in the structural position of the plutonic bodies, but on the other hand he stresses the connection of plutonic rocks with brecciated fault zones and says that »in these cases the direction of the foliation and lineation is that of the faults and not of the general folding». On the basis of afore-mentioned diverse opinions it is difficult to decide what are the most important processes controlling the tectonic position of the plutonic bodies in the Orijärvi area.

The granodiorite bodies in the coastal area follow the structural features of the Svecofennidic rock crust and Härme (1958) has shown that the secondary granitization of granodiorites is more common than was known earlier.

Trondhjemite province. The structural elements of the trondhjemite province have been described thoroughly by Anna Hietanen (1943). The linear flow structures of the trondhjemites are parallel with the gently pitching fold axes in the surrounding Svecofennidic gneisses, and the platy flow structure is parallel with the schistosity of the gneisses. Similar movement pictures of the trondhjemites and gneisses have been observed also by means of petrofabric analyses. The structural features show that the trondhjemites are synkinematic plutonic rocks, whose emplacement has taken place parallel with the schistosity during folding of the Svecofennidic rock crust.

Charnockite province. The plutonic rocks of the charnockite province in southern Finland form concordant plutonic bodies in the highly metamorphic Svecofennidic gneisses (cf. Fig. 13). The foliation parallels the schistosity of the wall rocks and the linear structures parallel the lineation of surrounding gneisses. The manner of occurrence of the charnockitic bodies is clearly synkinematic.

Granite province. The plutonic rocks of the granite province in the Tampere schist belt form both long concordant projections into the schists and roundish ovoidal bodies surrounded by the schists. The same plutonic body may be concordant in some places and accordant in other places. The plutonic rocks are slightly foliated, especially along the boundaries, and this foliation usually runs parallel to the steep schistosity of the wall rock. The linear structure of plutonic rocks is steep, as is also the case with the schists of the area.

A type example of the plutonic bodies in the Tampere schist belt is the granodiorite body of Värmälä, whose structural geology has been described by Härme and Seitsaari (1950). This body has structural features showing both concordant and accordant modes of occurrence. Its emplacement is due to an upward rise of the plutonic body tilted to the north. The rise of the body has pushed the surrounding schists in its closest vicinity, indicating a forceful injection.

Steep foliation and steep linear structures are also characteristic of the plutonic rocks of Central Finland, adjoining the Tampere schist belt. These structural elements are especially common in quartz diorites and granodiorites, but many granites are rather massive with very slightly developed flow structures. As a general remark concerning the plutonic rocks of the Tampere area, we may state that the planar and linear structures are not so well developed as in the synkinematic plutonic rocks of southern Finland. A sharp separation of plutonic rocks into synkinematic and late-kinematic groups is difficult, because many transitional varieties, ranging from gneissose, synkinematic types to massive, late-kinematic types, occur.

A characteristic feature of many quartz diorite and granodiorite plutons in Middle East Bothnia is that the margins are rimmed by gabbroidic rocks. Different types of these plutons are connected with each other by gradual transitions suggesting magmatic differentiation (cf. Mäkinen, 1916). Bodies of basic and intermediate plutonic rocks are concordant with the surrounding schists. Granodiorites occur both as elongated and ovoidal masses, and intrusive breccias related to their emplacement are common. Granites penetrate the schists and other plutonic rocks of the area. According to Salli (1956) the synkinematic phase of plutonism is represented by gabbros, quartz diorites, and granodiorites and the late-kinematic phase by granites. It should be mentioned, however, that transitional forms occur between different phases.

Microcline granites. Microcline granites in southern Finland are the youngest plutonic rocks related to the Svecofennidic orogeny. Their emplacement has taken place at a late-kinematic phase of the Svecofennidic orogeny after synkinematic plutons of the granodiorite, trondhjemite, and charnockite provinces. It should be mentioned that the synkinematic and late-kinematic deformation phases of the Svecofennidic orogeny in the coastal area of southern Finland are distinctly separated by a tectonically quiet intra-orogenic phase characterized by the intrusion of amphibolite dikes. These basic hypabyssal dikes, described by various authors (Sederholm, 1907; Wegmann, 1931; Kranck, 1933; Edelman, 1949 a), penetrate synkinematic granodiorites, but they are older than the microcline granites and the granitization. Microcline granites often form concordant bodies and they show relic structures of the folded supracrustal formations or synkinematic plutons. This manner of occurrence is caused by metasomatic granitization that had taken place quietly along the schistosity planes of the folded Svecofennidic rock crust.

Many migmatites formed by microcline granites show, however, structures indicating high plasticity. Furthermore, migmatitic and granitized masses of the microcline granites have caused a violent folding in their surroundings owing to a diapiric rise and updoming of the microcline granite masses. These movements, connected with the emplacement of microcline granite, are late-kinematic in relation to the tectonics of the Svecofennidic orogeny. New, detailed investigations of the structural geology of the microcline granites in southern Finland have been carried out, especially by Edelman (1949) and Härme (1954 b).

Metasomatic granitization creates as an end product massive, homogeneous, igneous-looking microcline granites, in which relic structures of the pre-granitized rocks are almost totally lacking. Some microcline granites behave structurally as true igneous rocks. They form intrusive breccias and penetrate the surrounding rocks as sharply cutting dikes. It is probable that granite melts have occurred in conjunction with the granitization.

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METAMORPHISM AND PLUTONISM

Svecofennidic crystalline schists, penetrated by the plutonic rocks, are typical representatives of regional metamorphism. Increase of the grain size in the rock series phyllite → mica schist → mica gneiss and different mineral assemblages of the schists show variations in the grade of metamorphism. An attempt will be made to describe briefly the relations between metamorphism and plutonism.

The lowest grade of metamorphism has been found in the schists of the Tampere field. Primary sedimentary structures and textures are well preserved in the folded and deformed strata. Argillaceous sediments are represented by slates without porphyroblasts of aluminous silicate minerals. No bodies or veins of plutonic rocks occur in the best preserved parts of the low-grade schists. At the margins of plutonic bodies the slates have, however, been recrystallized and metamorphozed into mica schists containing porphyroblasts of aluminous silicate minerals. It seems credible that the low-grade metamorphism of the slates in the Tampere area is due to the fact that plutonic bodies have not been near enough in every place to bring about to necessary thermal conditions for metamorphism characterized by mica schists.

Metamorphic rocks of the amphibolite facies are characteristic of the Svecofennidic schist belt penetrated abundantly by plutonic rocks. Argillaceous sediments are represented by mica schists, containing porphyroblasts of cordierite and andalusite, or by coarse-grained, garnet- and cordierite-bearing mica gneisses (kinzigites). Mica schists occur in the areas penetrated by the plutonic rocks of the granodiorite and granite provinces, whereas mica gneisses are typical of the areas penetrated by the trondhjemites and migmatite-forming microcline granites.

The highest grade of metamorphism in the Svecofennidic rock is represented by the gneisses of the granulite facies described recently by Parras (1958). These high-metamorphic gneisses occur in the area characterized by an abundance of plutonic rocks of the charnockite province.

The afore-mentioned examples suggest that the grade of metamorphism is controlled by the type of plutonism. Studies on the evolution of the Svecofennidic rock crust in southern Finland (cf. Wegmann and Kranck, 1931; Simonen, 1948 b; Edelman, 1949) have pointed out that the deformation and metamorphism of the supracrustal strata have taken place in close connection with the emplacement of synkinematic plutonic rocks. Thermal conditions favouring regional metamorphism have been caused by the emplacement of the plutonic rocks in the root zone of the ancient mountain chain.

Furthermore, two different phases of metamorphism occur in the coastal area of southern Finland. The older phase connected with the intrusion of the synkinematic plutonic rocks is characterized by pure regional metamorphism without radical changes of chemical composition in the metamorphosed rocks, while the younger phase of metamorphism is connected with the emplacement of microcline granites and is characterized by metasomatic metamorphism.

Regional metamorphism of the Svecofennides, connected with deformation and synkinematic plutonism, is isochemical in character, because the primary chemical composition of the Svecofennidic schists has not undergone any great change.

The chemical compositions of the Svecofennidic phyllites, mica schists, and mica gneisses are for example similar to the geosynclinal graywacke-slates of younger age; and they are very similar to each other (cf. Simonen, 1953), if one considers the specimens of regionally metamorphozed rocks, not influenced by later metasomatic metamorphism. This supports the view that pure regional metamorphism has taken place without essential metasomatic alteration. No gradual change in chemical composition has been observed in the rock series phyllite → mica schist → mica gneiss with an increasing grade of metamorphism. This evidence does not support the ideas of modern transformists (cf. Read, 1948; Lapadu—Hargues, 1945) on the serial transfer of material and on the development of compositional series during regional metamorphism. No evidence for »the passage of waves or fronts of metasomatizing solutions out from the central granitization core about which arise the zones of metamorphism», suggested by Read (1948), have been found.

Metasomatic metamorphism characterized by granitization is younger than pure regional metamorphism in the Svecofennidic rock crust. It belongs to the late-kinematic phase in relation to the Svecofennidic orogeny and is independent of regional metamorphism in time. Migmatization and granitization are connected with the emplacement of the late-kinematic microcline granites.

Metasomatic metamorphism has caused serial changes of chemical composition in regionally metamorphosed rocks. All the rocks, regardless of their primary chemical composition, tend to change towards the chemical composition of microcline granite. Compositional series ranging from the primary composition of the supracrustal rock to microcline granites have developed. Mention must be made of the fact that in the granitized rock crust there occur remains of regionally metamorphozed rocks which do not show appreciable signs of metasomatic alteration. This suggests that pure regional metamorphism has been older than granitization which has not influenced the whole Svecofennidic rock crust. The metasomatic metamorphism is characterized by potash metasomatism and by retrogressive alterations of mineral assemblages of regionally metamorphosed rocks.

ORIGIN

The origin of plutonic rocks, especially granitoids, is continuously under lively discussion and nowadays most petrologists agree that granitic rocks may originate in more than one way. Two principal extreme ways are magmatic and metasomatic. Indisputable evidence bearing on the problem of the magmatic versus metasomatic origin of granitic rocks is, however, difficult to find, because considerable data previously regarded as indicating only a magmatic origin may be applied also to metasomatic and metamorphic rocks. To determine the most probable origin of a plutonic body, a group of principal geological, mineralogical, and chemical features must be collected in order to draw safe and reasonable conclusions. An attempt will be made to discuss briefly the origin of the Svecofennidic plutonic rocks by geological, mineralogical, and chemical data presented in this paper.

Characteristic features of the Svecofennidic plutonic rocks of the granodiorite, trondhjemite, charnockite, and granite provinces are as follows:

- — compositional series with a gradual transition from basic to acid members of the province;
- — relative ages show that a more acid plutonic rock penetrates a more basic rock type of the province;
- — plutons are concordant with the structure of the country rocks;
- — contacts are normally sharp without transitional zones into country rock, and intrusive breccias occur;
- — discontinuous reaction series olivine $\rightarrow$ pyroxene $\rightarrow$ hornblende $\rightarrow$ biotite;
- — continuous plagioclase series, zoned plagioclase with anorthitic core;
- — gradual increase of ratios (FeO) : (MgO) and ($Na_2O + K_2O$) : (CaO) with an increasing silica content of plutonic rocks;
- — an eutectoid granite composition of the most acid members of the granite province.

This group of geological and petrographic features suggests the origin of the granodiorite, trondhjemite, charnockite and granite provinces to be magmatic. The emplacement of the plutonic rocks had taken place in a liquid state by magmatic intrusion, and differentiation a compositional series ranging from basic to acid members to evolve. A magmatic origin of the synkinematic plutonic rocks of the granodiorite, trondhjemite, charnockite, and granite provinces has been suggested by most of the Finnish geologists, but transformistic ideas on the origin have also been advanced.

Chemical study has shown that the rocks of the granodiorite province contain more lime than the corresponding rocks of other provinces; the trondhjemites are characterized by a high content of soda; and a high content of potash is typical of the granite province. Assuming a magmatic origin, the chemical differences between different provinces may be interpreted as being due to slight primary chemical differences between the parent magmas. Compositional differences between the parent magmas, appearing especially in the contents of lime and alkalies, have been principal factors in causing independent plutonic provinces to evolve. The main factor controlling the paths of evolution of the trondhjemite and charnockite provinces, which are chemically closely related, has been, however, different contents of volatile substances in the parent magma. The trondhjemites have been differentiated from a parent magma rich in water, whereas the charnockites have been crystallized from a magma poor in volatile substances. It is probable that the parent magma of the trondhjemite province has received its high water-content from argillaceous sediments of its surroundings. Gradual transitions have been found between silicic members of the trondhjemite and charnockite provinces and, furthermore, evolution in the charnockite province may produce acid end members identical to the acid trondhjemites. This supports the conclusion that the charnockite magma may be enriched in volatile substances then producing trondhjemites.

Special mention must be made of the fact that the chemical differences between the granodiorite, trondhjemite, and granite provinces appear distinctly in the most silicic members, which deviate by a marked compositional break from each other without gradual transitions. This supports the thesis that the paths of evolution of the provinces mentioned have been independent. Plutonic evolution, producing different end members without gradual transitions, is easier to explain as a result of magmatic processes than as a result of regional metasomatism.

Evidence of metasomatic replacement has also been found, especially in the porphyritic granites of the granite province. Large microcline porphyroblasts have developed. In my opinion (cf. p. 48) these are, however, products of autometasomatic replacement caused by a residual granitic magma or by fluids expelled from the last crystallizing portions of the parent magma. Taken as a whole, the origin of the plutonic rocks, ranging from gabbros to acid members, has been controlled principally by magmatic differentiation, but autometasomatic processes have also played a role in the development of the most acid members.

Considering the origin of the parent magmas, we must remember that acid plutonic rocks are predominant in the granodiorite, trondhjemite, charnockite, and granite provinces. Percentage areas occupied by the main petrographic types show that gabbroidic rocks occupy only 5—20 % in the plutonic provinces mentioned. This fact does not support the development of the plutonic rocks as a product of differentiation from a basaltic magma. The great total bulk of acid plutonic rocks in comparison with that of associated basic rocks suggests that the parent magma has been acid, probably quartz dioritic or granodioritic in composition.

Great quantities of acid magma may have formed locally by complete or differential fusion of various rocks in deep levels of the earth's crust. Especially the sial crust of granodioritic bulk composition could produce great masses of acid magmas by anatexis. The abundance of acid plutonic rocks in orogenic zones suggests that conditions favourable to the development of acid magmas prevail in deep parts of mobile orogenic belts, where great masses of sial crust have been depressed into a zone of anatexis. These magmas have been squeezed and intruded upwards as completely or partially liquid masses and their close connection with the original zone of anatexis becomes obscure.

In my opinion, mobilized anatectic magmas of slightly varying composition (quartz dioritic-granodioritic) have invaded the Svecofennidic rock complex during orogenic movements. Emplacement of synkinematic plutonic rocks has taken place by intrusions of anatectic magmas, and magmatic crystallization of these independent liquid masses has played an essential role in the development of the granodiorite, trondhjemite, charnockite, and granite provinces. The most valid evidence of the anatectic origin of the magmas is the great total bulk of acid plutonic rocks in comparison with that of associated basic rocks in the Svecofennidic plutonic provinces. Furthermore, mention must be made of the geological fact that the basement for Svecofennian sedimentation is unknown. This supports the view of the regeneration and fusion of the old pre-Svecofennidic basement on a large scale.

The petrographic characteristics of the microcline granites in southern Finland deviate considerably from those of the afore-discussed plutonic rocks. The most characteristic features of the microcline granites are as follows:

— they do not belong as an acid member to a compositional plutonic series grading from basic into acid types;
— relic structures of older solid rocks, consisting of Svecofennidic schists or synkinematic plutonic rocks, are common;
— plutons often show a diapiric updoming;
— contacts are transitional into country rocks;

— associated migmatites are common;
— no reaction series of mafic and salic minerals; zoned plagioclase extremely rare;
— chemical composition does not correspond to an eutectoid granite composition of residual granite magmas, but it contains more potash than eutectoid granites.

The geological and petrographical features of the microcline granites show that metasomatic processes have played an essential role in their origin. Evidence has been offered by various authors that many microcline granite bodies are extreme products of metasomatic granitization that has taken place in solid rocks of various type. All the various rock types, regardless their primary chemical composition, have passed, if they have been entirely granitized, into microcline granite. Especially the granitization of extreme rock types, such as limestones and true quartzites, presupposes that the material introduced, causing the metasomatic granitization, has contained all the elements of the microcline granite. Therefore, it is probable that this introduced material has been a granite melt. The existence of a liquid granite phase in the granitized masses is suggested by associated arteritic migmatites, microcline granite veins with sharp boundaries in non-granitized rocks, and intrusive breccias formed by microcline granite. The occurrence of sharply bounded microcline granite veins, cutting well-preserved country rocks as metabasalts without any signs of granitization, are the most suggestive examples of independent granitic melts, because their origin is difficult to explain as an extreme product of metasomatism of solid rocks. Some large plutons of homogeneous microcline granite (Perniö granite, Nauvo granite, etc.) have been considered also as products of crystallization from a granite magma.

Relic structures common in the microcline granites show, however, that metasomatic processes have played an essential role in the emplacement of the microcline granites. Sometimes metasomatic replacement has taken place without any considerable increase of volume, but large granitized masses have been updomed diapirically. Structural features show that granitized masses have been mobile and highly mobile granitic material has been intruded into a metasomatic environment. Furthermore, a marked difference between the chemical composition of the pre-granitized rock crust and microcline granite presupposes that great quantities of granitic material have moved into a zone of metasomatic granitization.

Microcline granites show evidence of both metasomatism and intrusion. Therefore, it seems probable that the granitization has been effected by a granitic magma. The noneutectoid composition of many microcline granites is thus a product of postmagmatic potash metasomatism at a hydrothermal stage of the granitizing liquid. The granite magma causing metasomatic granitization is probably of anatectic origin, having moved upwards from greater depths.

In the foregoing, I have tried to give a short interpretation of the origin of the Svecofennidic plutonic rocks. This review is based on my field experience in Finnish Archean and on the chemical and mineralogical data presented in this paper. Many facts, fundamental for interpretation, have been already presented by two Finnish masters of the granite problem, Sederholm (1907, 1923, 1926, 1934) and Eskola (1932, 1933, 1950 b, 1956). Furthermore, the discussions and excursions with my colleagues in the Geological Survey have inspired my work. In especial I wish to mention two of my colleagues by name, Edelman (1949 a, 1949 b) and Härme (1954b, 1958, 1959, 1960), whose investigations have added many new facts and suggestive ideas to the knowledge of the Svecofennidic plutonism.

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