NORGES GEOLOGISKE UNDERSØKELSE NR. 237

PETROLOGICAL STUDIES OF THE NEIDEN GRANITE COMPLEX

By

VIGGO H. WIIK

OSLO 1966
UNIVERSITETSFORLAGET

Editor for the Publications
of the Geological Survey of Norway:

State geologist
Fredrik Hagemann.

NIKOLAI OLSENS BOKTRYKKERI - OSLO

CONTENTS

ABSTRACT

The Neiden granite complex fits well into Raguin's group of «anatectic granites with suites of migmatites». In this area, supracrustals of the Bjørnevatn group have, together with their gneissgranitic basement, been subjected to ultrametamorphism. The resulting rocks are classified as gneissgranite, granodiorite and quartz monzonite, these granitoids being separated from the surrounding gneiss by a zone of transition migmatites. Certain features of this zone are best explained by assuming partial anatexis. The totality of observed phenomena can not be accounted for by any purely magmatic or purely metasomatic hypothesis alone, and the proposed petrogenetic model is intended as a working hypothesis rather than a final conclusion. In addition to the conventional methods, studies of the geographical areal variation of Fe, K and Na content of the rock and radioactivity in the field were performed for one particular sub-area. The perhaps most interesting result of this variation study is the strong indication that granodiorite did form by some — practically in situ — transformation of rocks of the Bjørnevatn group. Trend surface analysis has been applied to these quantitative data, adding to the gradually accumulating experience with this method in geology.

INTRODUCTION

Granitic rocks have been subject to extensive research through the last decades, and facts and theoretical considerations in vast amounts have been accumulated in the literature. Thus the problems of granite formation have been linked with almost every field of research within the branch of petrology.

A student wanting to get acquainted with the general body of facts, as well as the methods of investigation and the philosophy of modern petrology, would therefore think it advisable to make investigations in an area where granitic rocks are represented.

In Norway considerable works have been done in the study of granite, in field as well as in laboratories, the investigated field areas being, however, mostly confined to the southern part of Norway. About the granitoid rocks of the Precambrian of Northern Norway, little is known, apart from what can be assumed from the works of Finnish and Russian geologists in adjacent regions.

These considerations in mind, the Neiden area was selected by the author as an object of investigation for the present thesis work.

Neiden is situated about 30 km west of Kirkenes in Eastern Finnmark, Norway. South and east of Neiden lies an area of dominantly granitoid character, forming a more or less rounded massif in a group of regional metamorphic gneisses. Its name, The Neiden granite complex, has been given to the massif of granitoid rocks in order to distinguish these rocks from the surrounding gneisses.

The investigated area, with the granite complex as the central and major part, covers an area of abt. 400 sq. km. The area is located between 69°30′ and 69°45′ N Lat. and 18°30′ and 19°10′ Long. On Fig. 1 the location of the area within its geological environment is indicated.

Previous work.

Since the middle of the 19th century, the region to the south of the Varangerfjord is known to consist of Precambrian gneiss and granite. The Sydvaranger region has been visited by several prominent geologists. Keilhau, Dahll, and Reusch were all here before 1902. Since then, J. H. L. Vogt (1910), Gejer (1912), Holtedahl (1918), Hausen (1926), Wegmann (1929) and Sederholm (1930), Føyn (1945) and J. A. W. Bugge (1950) have published observations from this region. The formers mentioned

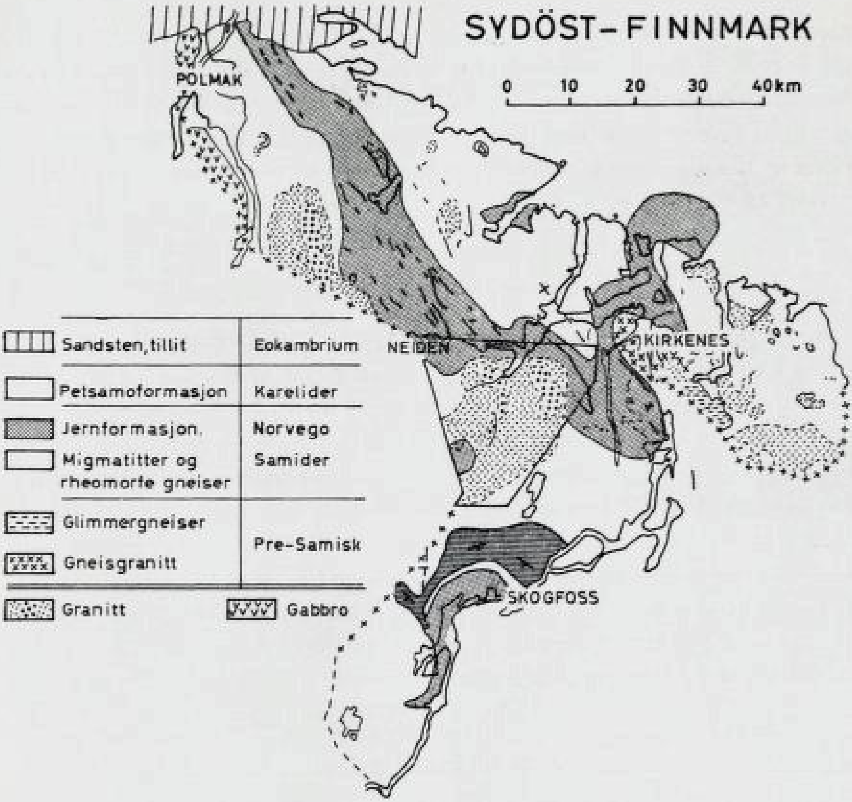


Fig. 1. Precambrian of Finnmark east of the Tana river. The investigated area SE of Neiden is outlined. This map, which was presented by J. A.W. Bugge at the VI. Nordic Geologic Winter Meeting in january 1964, is here reproduced with his kind permission.

here, and also Holtedahl (1918) were mainly concerned with the Eocambrian north of the Varangerfjord, whereas after the discovery of the large iron-ore deposits at Bjørnevatn south of Kirkenes in 1902, the geological investigations were almost entirely concentrated on the area between Langfjorden west of Bjørnevatn and the present Russian border. Only recently has the region west and northwest of Langfjorden been subject to geological mapping, see Current mapping project. This mapping has shown that, contrary to earlier views, the iron ore formation of the Bjørnevatn series extends NW-wards from the Bjørnevatn area and can be traced as more or less continuous zones within the gneiss all the way to the Eocambrian west of the Varangerfjord. (J. A.W. Bugge, — information given at the VI. Nordic Geologic Winter Meeting, Trondheim, Jan. 1964, see Fig. 1. — short notice in N. G. T. No 45, p. 137). As this gneiss series which contains the zones of quartz-banded iron ore constitutes the geological environment for the Neiden granite complex, the earlier investigations in the Bjørnevatn area aquire relevance to the present work, and a review of the geology of that area is presented under Geologic setting.

Current mapping project.

Some years ago, the mining company A/S Sydvaranger started a mapping project covering the whole Precambrian area east of the Tana river. The aim of this work is to produce a geological map of the area at the scale of 1 : 20.000. The leader of the project is professor J. A. W. Bugge, the field survey being carried out by him in cooperation with the mining geologist A. Skordal and several geologists and assistants attached for the field seasons. In the first years the geologists H. Lien and O. Jøsang worked on the project, in the years 1962 and 1963 R. Kvien, O. Inkiinen and J. Paakola have been the field geologists. The geological map by J. A. W. Bugge here presented as Fig. 1, shows the main features of the region as disclosed by this regional mapping project.

Present investigation.

The present work is based on a 3½ month's field exploration, carried out during the summer 1963 and September 1964. The field work was done in close cooperation with the A/S Sydvaranger team and under the guidance of Professor J. A. W. Bugge, who also directed the regional mapping project.

The main purpose of this study is to disclose the origin and mode of formation of the granite complex. For that, detailed structural as well as petrographic maps of the granite complex and its surroundings would be wanted. Within the space of time at disposal this could, however, not be achieved, and it was decided to start with a large scale surveying (mapping) of the whole granite complex and its adjacent gneiss areas, thus locating the critical areas, the detailed investigation of which would give information relevant and essential to the genetic problems. From this initial work the major features of the granite complex emerged, and by aid of photo-geology and aeromagnetic maps, the main geological map was constructed.

In the next stage, the subareas and localities which seemed to display features of particular interest were investigated in detail. The methods applied were chosen according to the particular problem, including detail mapping, structural analysis, profile sampling and grid sampling for chemical and mineralogical analysis, ground magnetometry and radioactivity measurements.

Acknowledgements.

The present study was carried out at the Geological Institute of the Technical University of Norway, under the guidance of Professor J. A.W. Bugge. The writer is greatly indebted to him, and to Professor Chr. Oftedahl of the same institution for their skilled assistance and helpful discussions.

A/S Sydvaranger granted financial support and placed maps, instruments and additional material at the writers disposal. The A/S Sydvaranger team of geologists, and in particular siv. ing. R. Kvien and stud. real. G. Grammeltvedt receive thanks for their friendly cooperation during the field season 1963. It should be pointed out that in the geological map of the Neiden granite complex, Fig. 2, observations made by the A/S Sydvaranger geologists have been incorporated. This applies particularely to the areas north and northeast of the granite complex.

Obliquity of the K-feldspars was determined from X-ray powder diagrams taken on a Guinier-de Wolff camera which was kindly placed at the authors disposal during a visit to the Geological Museum in Oslo.

Chemical analyses were carried out by siv. ing. R. Stokland and Mrs. A. K. Sele of the Geological institute, N. T. H. Miss L. Undersaker and Mrs. M. Frøseth of the same institution typed the manuscript, and Miss B. Hemming and Mrs. L. Nergaard, N. G. U. drafted the maps and figures. To these persons, as well as to my collegues at N. T. H. and N. G. U., from whom this work has in many ways benefited, my sincere thanks are expressed.

The electronic computer work was carried out partly during training on the CDC 3600 of KIRA and partly on the GIER at Regnesentret, N. T. H. The program for regression analysis used in the trend surface computations was written by siv. ing. Arnt Otto Østlie of the last named institution.

Geologic setting.

As indicated by Fig. 1, the regional mapping has shown the Neiden granite complex to be surrounded to the west, north and east by the so called «Jernformasjon». In the terminology maintained throughout the present work, this corresponds to the Bjørnevatn group, a sequence of sediments and vulcanogenic desposits to which also belongs the quartz-banded iron ore developed by A/S Sydvaranger at Bjørnevatn.

For the eastern part of eastern Finnmark, J. A.W. Bugge describes for the Bjørnevatn group the following lithology, Bugge (1960):

Upper.
Plagioclase-hornblende gneiss (sediments and andesitic effusives).
Quartz-banded iron ore.
Bjørnevann gneiss (Quartzites and mica schists with a few horizons of meta-rhyolites).
Bjørnevann conglomerate.
Lower.

The quartz-banded iron ore of the Bjørnevatn group is of particular significance as an easily recognizable and mapable unit in the western, high-metamorphic and migmatitic part of the region, and it is in this work referred to as the «iron formation».

J. H. L. Vogt (1910) considered the iron-formation to be of magmatic origin and described the adjacent gneisses as «pressed granite». Gejer (1912) demonstrated the sedimentary origin of the iron ore. He gives petrographic descriptions, dividing the rock sequence in: I. The gneiss, II. The border zone, III. The ore-bearing formation, mentioned in the order one meets them when going southwards from Kirkenes. The gneiss is described as consisting of two components, a grey biotite gneiss, constituting the major part, and a feldspar-quartz rock of white or pinkish colour, forming streaks and irregular veins with which the whole gneiss mass is interwoven. He states that the rock has been subject to deepseated metamorphism, and he interprets the salic masses as segregations originated within the gneiss itself. The feldspar of the grey gneiss is a fresh oligoclase, together with an insignificant amount of microline. Microcline and quartz are the main constituents of the salic masses. Southwards the gneiss gradually assumes another aspect, becoming like a grey, foliated granite with instrusive-like salic bands. This gneiss is found to consist mainly of plagioclase, quartz and biotite. The plagioclase is a rather basic oligoclase, and there is but very little microcline. Minor constituents are apatite, zircon, titanite and orthite.

The border zone represents a zone of cataclasis, where the gneiss has been granulated and transformed into schistose and very finegrained rocks.

The ore-bearing formation is characterized as a group of leptitic rocks. Gejer did not succeed in establishing the relation between the border zone and the ore-bearing formation.

Sederholm (1930) disagreed with Gejer concerning the origin of the salic component in the grey gneiss. He doubted whether the original content of potassium in the gneiss was high enough, and he pointed out that similar salic streaks and veins also occur within the ore-formation, where they must have been intruded. He notes that the boulders found in the Bjørnevatn conglomerate are identical with the last metamorphozed varieties of the «gneissgranite» (Gejer's gneiss), only that the gneissgranite in the boulders is not penetrated by veins or streaks of the salic material. He therefore assumes that the salic component has been introduced after the deposition of the ore-bearing formation. Sederholm also describes boulders of granite in the Neverskrukk conglomerate, indicating the appearence of granite younger than the ore-bearing formation, but older than the Petsamontunturit formation.

Wegmann (1929) describes the Bjørnevatn-conglomerate in his tectonic analysis of the northernmost Fennoscandia. The Bjørnevatn conglomerate contains numerous pieces of an older gneiss. The embedding mass is micaschist-like, and mica schist also makes up a great part of the area. The mica schist passes over into gneiss and leptite-like rocks, and into quartzite. In this sedimentary zone, the iron ore lies as a member of the sequence. After deposition, the schist- and iron-quartzite-series were intensely deformed through overthrusting movement from ENE. Towards the end of the deformation, the younger granites are thought to intrude, altering the mobility in the deformation process, and bending and modifying the older structures in complicated ways.

J. A.W. Bugge (1960) characterizes the Bjørnevatn formation (elsewhere in this work referred to as the «Bjørnevatn group») as a series of supracrustal rocks. The Bjørnevatn conglomerate is found only west of the main ore deposits, where it forms an anticline with a SE-plunging fold axis. The conglomerate has probably been deformed by two separate tectonic phases, the first one stretching the pebbles into rods in connection with a W-ward thrust. During a subsequent phase, the rods have been bent and folded. Bugge points to the marked difference in mineralogical and chemical composition between the rocks underlying the beds of iron ore and those being intercalated and overlying. Whereas the former are mainly quartzites and mica schists the quartzites with 75—85 % SiO_2, the latter are quartz-biotite-hornblende gneisses with SiO_2 lower than 60 %. These are interpreted as meta-andesites. Their main constituents are plagioclase (An 30—40), hornblende, biotite, epidote and quartz.

The iron sediments are interpreted as exhalative-sedimentary deposits. Their main constituents are magnetite, quartz, green hornblende, grünerite, some epidote and biotite, and occasionally traces of hematite.

The Bjørnevatn formation is cut by dikes of granite and granite pegmatite.

As mentioned earlier, the regional mapping has shown the gneisses surrounding the Neiden granite complex to belong to the Bjørnevatn group. My investigations indicate that the granite complex is formed, to a large extend, through an in situ transformation of the area. In so far as the rock series of the Bjørnevatn area constitutes the «raw material» for most of the rocks encountered in the Neiden granite complex, the reviewed literature is of great value for the present work. It should be noted, however, that the Neiden area is separated from the Bjørnevatn area by a pronounced fault-zone running along Langfjorden. So far, the character and extent of dislocation has not been established, thus preventing any application of the details from Bjørnevatn to the area west of Langfjorden.

PETROGRAPHY

Introduction.

Primarily a distinction is made between the granite complex and the surrounding group of gneiss and amphibolite which covers the major part of the region south of Varangerfjord. This broad group of *regional gneiss* is subdivided into *gneiss, amphibolite* and the *iron formation.*

Within the granite complex a distinction is made between the granodiorite and the gneissgranite group. The majority of granitoid rocks belongs to either of these. Minor intrusive bodies of quartz monzonite might be closely related to the granodiorite, but will here be treated separately. The granitoid dike rocks of the mapped area make up a rather heterogenous group, some being related to the late stages of the evolution of the Neiden granite complex, whereas others seem to be of a more regional occurrence, appearently having no relation to this particular granite complex. Also genetically unrelated to the granite complex are the numerous dikes of gabbroic composition encountered within the mapped area. One single intrusion of ultrabasic rock is described from the granite complex.

Because of the heterogenuity of many of the rock types and the complex interrelationship between them, they are not easily described. The problem is sought solved by first presenting descriptions of the various rock types, emphasizing their general characteristics and average properties. This will produce an idealized picture, which will later be sought modified by bringing additional information on local deviations within the different rock types, and on details of the interrelations among various rock types. Fig. 3 is a simplified geological map, showing distribution of the major rock groups. The shown partition of the area into rectangles 9D, 9E, will be used as a frame of reference.

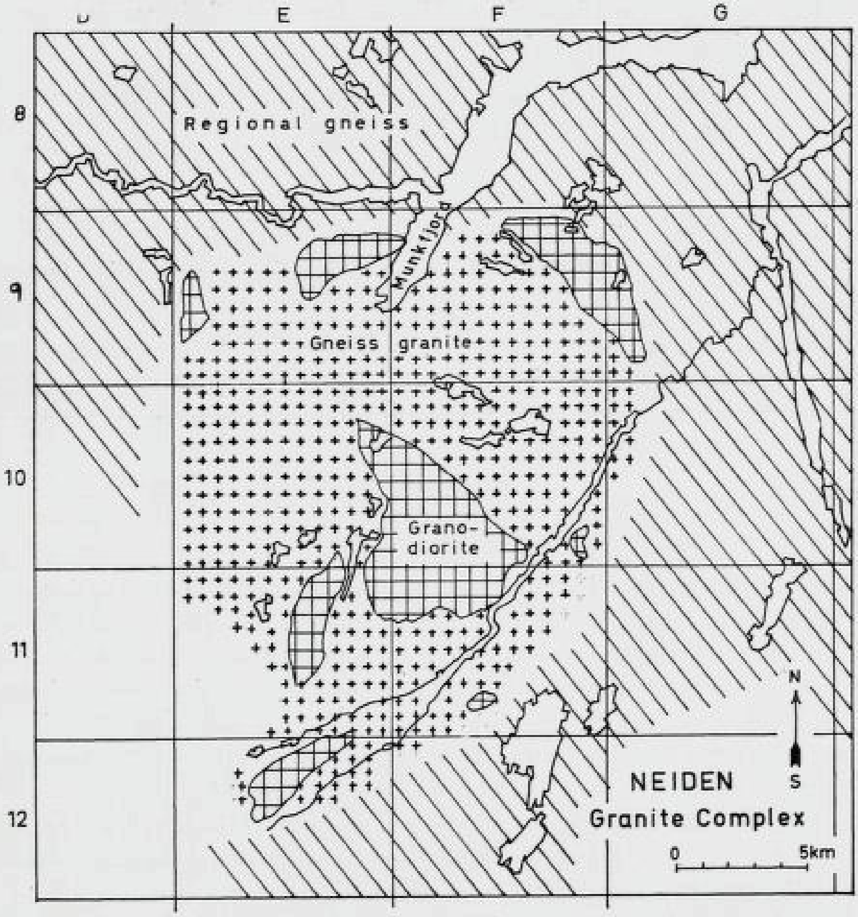


Fig. 3. Distribution of the major rock groups of the mapped area. Frame of reference superimposed.

Terminology.

The geological terms used in this work are generally in accordance with the A. G. I. Dictionary of geological terms, New York, 1962.

Special terms are taken from «Symposium on migmatite nomenclature», Copenhagen 1961.

Smithson (1963b) og Sylvester (1964) stress the fact that many common petrographic terms have genetic implications which make them unsuited for the pure description of rocks. Whenever such terms are used in this report, the descriptive aspect only is intended.

Because of the considerable ambiguity attending their current use, some particular terms are defined below:

Augen — adjective used to indicate that a rock contains megacrysts, nothing being stated about their origin.

Foliation — All types of mesoscopically recognizable s-surfaces of metamorphic origin. Lithologic layering, preferred dimensional orientation of mineral grains, and surfaces of physical discontinuity and fissility may all contribute to foliation of different kinds. (Turner and Weiss, 1963, p. 97).

Granitoid — adjective used in a very wide sence for any granitelike rock with or without foliation.

Granite — Phaneritic rock lacking directional structures, in which quartz and feldspar predominate.

Analytical methods.

Most of the quantitative mineralogical data presented have been achieved through thin section microscopy. Modal analyses were made by point-counting unstained thin sections. Only homogenous medium to fine-grained rocks were analyzed in this way, and by counting 1000 points over an area of 6—8 cm^2, the counting error is kept insignificant relative to the assumed sampling error (Smithson, 1963b, p. 13). Accurate determinations of the An content of plagioclase were made by measurements on an universal stage, applying the «zone method» (Rittmann, 1929). Obliquity ($\triangle$ — value) of K-feldspar was determined by measuring the separation of the 131 and the $1\bar{3}1$ reflections on X-ray powder photograph taken with a Guinier-Nonius quadruple camera (Smithson 1963b, p. 137).

Disposition and petrography of rock types.

The gneiss group.

The granite complex is surrounded by rocks of the gneiss group to the west, north and east. The southern area is extensively covered by glacial deposits, and here the situation of the border zone can only be assumed from the distribution of transition rock types and from structural observations within the granite complex itself. Aeromagnetic anomaly trends are also in support of a southern limitation of the granite complex as indicated on the map, Fig. 2.

It is thus a fair assumption that the gneiss group represents the geological milieu in which the granite complex is situated. To the west, northeast and east, the gneiss strikes parallel to the outline of the granite complex, thus indicating a concordant situation of the granite complex within the gneiss. To the north, the gneiss structures are very complex.

On a regional scale, the gneiss group represents a rather homogenous geological unit, striking NW with a moderate to steep dip towards NE. On a mesoscopic scale, however, considerable heterogenity prevails particularly in the proximity of the granite complex. Within the gneiss group, three rock types can be recognized; quartz-dioritic gneiss, amphibolite and the iron formation.

The quartz-dioritic gneiss is the dominant type. Within the sequence of quartz-dioritic gneiss, concordant zones of amphibolite occur, their thickness varying from a few meters to hundreds of meters

Amphibole gneisses, containing substancial amounts of hornblende and some garnet, are also encountered. These represent transitions between normal gneiss and amphibolite.

The iron formation is normally easily recognized by its typical, finely banded structure of alternating quartz and magnetite plus amphibole minerals. In some cases the rock acquires, due to the presence of more ferromagnesian minerals, an amphibolite-like appearance. The iron formation is in most cases associated with zones of amphibolite.

The gneiss.

As mentioned already, no stratigraphic sequence has been established for the gneiss group in the investigated area. All rocks within the gneiss group not being classified as amphibolite or iron formation, are referred to as gneiss. As a formation, the gneiss therefore is quite heterogenous, displaying considerable variations, from quartzitic to dioritic and granitic gneiss.

The typical variety in the northeastern area is a quartzdioritic gneiss with quartz and plagioclase (oligoclase-andesine) as main minerals. The dark constituent is biotite. Zircons from this rock show healed euhedral outlines around a rounded, anhedral nucleus. Both quartz and plagioclase exhibit signs of slight mechanical strain. The plagioclase is only slightly sericitized. To the northwest of the granite complex, a darker variety of the gneiss predominates in alternation with zones of amphibolite and the iron formation. This gneiss has, in addition to the main minerals quartz and plagioclase (oligoclase, partly sericitized), also biotite, common hornblende and garnet. Apatite is a common accessorium.

Since it is evident already by field inspection that the relative amounts of the minerals vary considerably and irregularly, no representive quantitative data are presented for the mineral composition of the gneiss group rocks.

The rocks are normally medium grained.

In cases where fine grained zones occur, microscopical investigation reveals these as being intensely tectonized and granulated. Generally these zones also have a considerable content of fresh microcline, which has obviously been introduced in connection with tectonization. The plagioclase of these gneiss zones is strongly sericitized.

Also in many thin sections of the normal medium-grained gneiss, a mortar structure is seen, indicating tectonization at late stages. Field impressions indicate that introduction of microcline accompanied this late tectonization, producing granitic gneiss in some zones and leaving others unaltered, all being controlled by the relative increase in permeability produced by the tectonization.

In many areas, a variety of veins, schlieren and dikes of granitic to quartz-dioritic composition and varying in grain size from aplitic to pegmatitic, are intruded into the gneiss. The time sequence of these late intrusives has been established by J. A.W. Bugge (1960).

Whereas in the Bjørnevatn area a distinction is made between the gneiss-granitic basement and the Bjørnevatn group (earlier named the Bjørnevatn formation), no such relation could be established for the Neiden area. Nowhere is rock observed which could be interpreted as the Bjørnevatn- conglomerate, and no stratigraphic sequence like the one described from the Bjørnevatn area has so far been established. It is not possible, therefore, to say whether the rocks forming the gneiss group in the Neiden area are made up entirely of material corresponding to the Bjørnevatn group, or there is a mixture or an alternation of rocks of this group with infolded zones of the gneiss-granite basement.

Due to lack of sensitive rock compositions, the exact position of these rocks in the metamorphic facies series is not determined. The general impression is that the rocks of the gneiss group are regionally metamorphozed in the medium to high amphibolite facies, under estimated medium hydrostatic pressure corresponding to about 20—25 km in the earths crust. There is evidence of a retrograde metamorphism, at least in the proximity of the granite complex.

The amphibolite.

Amphibolite forms concordant zones of varying thickness within the gneiss. Also within this cathegory, there is some variation. The grain size ranges from fine to medium grained, and the mineralogical composition might deviate from that of normal amphibolite in the direction of amphibole gneiss or by gradual transition into the iron formation.

The normal amphibolite has about equal amounts of plagioclase (An 40—60) and common hornblende. Biotite is normally present in subordinate amounts. Common accessories are magnetite, sphene and apatite, the magnetite content being highly variable. The texture is granoblastic, the tendency towards parallel-orientation of hornblende or biotite not being very pronounced. In one specimen, most plagioclase was replaced by epidote, and in another specimen, collected near the western boundary of the granite complex, all biotite had been transformed to prochlorite. Red garnet is present in some varieties of the amphibolite.

The iron formation.

From the Bjørnevatn area, Sederholm (1930) describes the iron formation as consisting of magnetite layers, often mixed with small grains of hornblede, alternating in thousands of repetitions with quartzite layers, sometimes even with layers rich in epidote or garnet. In the Neiden area the typical quartz-banded type is frequently found, but darker, more homogenous types are also encountered. The common association of iron formation with zones of amphibolite, and the gradual transitions between the two rock types, are features worthy of notice, although there are exceptions to such rules.

The main constituents of the iron formation are quartz and magnetite. Ferromagnesia silicates are usually present; in some cases common hornblende together with an amphibole of the cummingtonite-grünerite series, in other cases a diopsidic pyroxene with cummingtonite-grünerite. To the north of the Neiden area, the paragenesis quartz, magnetite, diopside-salite and hyperstene is observed in samples from the iron formation.

Agmatitic fragments of the iron formation within the border zone of the granite complex contain an unusual monoclinic amphibole with a small 2 V. The same amphibole is also found in thin sections from the massive granodiorite.

Granodiorite.

Description of rock type.

This is the only rock type of regional extension having a real granite-like appearance. It occurs in larger and smaller elongated bodies, located near the border zones and in the central part of the granite complex. Its harmonious relationship to the surrounding rocks does not, however, give any indications of intrusive behaviour, and the term autochtonous granodiorite (Read, 1957) seems to give a good characterization of this rock.

From the granodiorite bodies on rectangles 9E and 9F, there is a gradual transition via a zone of various migmatic rocks, into the regional-metamorphic gneiss outside the granite complex. Towards the central part of the granite complex, one passes with no abrupt changes from the granodiorite into porphyroblastic gneissgranite. In this transition zone, schlieren of more fine-grained gneissic rocks are seen. Generally the granodiorite becomes increasingly schistous, and porphyroblasts of K-feldspar start to occur on the approach of gneissgranite areas.

The largest massif of granodiorite is situated in the central part of the granite complex. In association with this, as well as with all the other massives of granodiorite, a typical «transition migmatite» is found. This transition rock is characterized by chaotic flow-fold structures indicative of complex movements of a plastic medium.

Apart from the described transition zones, the granodiorite appears very homogenous, although colour index and grain size might vary to some extent on a regional scale.

The normal, homogeneous granodiorite is a grey, mediumgrained rock with hypidiomorphic to xenomorphic granular texture. The mineralogical composition is plagioclase, quartz, microcline and biotite, with opaque minerals, sphene, apatite, orthite and zircon as common accessories. In a number of thin sections, minor amounts of a bluishgreen, monoclinic amphibole with a small 2 V are observed.

The composition of the plagioclase, as determined by U-stage and refractive index methods, varies within the single specimen or thin section, in the range oligoclase-andesine. The plagioclase occurs in sub-anhedral grains, 1—3 mm wide. The majority of grains are strongly and irregularly corroded, whereas some plagioclase grains are practically free of such inclusions. Zoning is observed in a number of large grains. Twinning is well developed, the albite-, pericline- and carlsbad-laws all being represented. Bent twin lamellae are occasionally seen. Rims or patches of myrmekite are frequently formed where plagioclase lies in contact with microcline, and the myrmekite is particularly abundant in parts of plagioclase grains which protrude into microcline.

Quartz forms anhedral, generally equidimentional grains, 1/4 to 1/2 mm wide, showing a moderate undulatory extinction.

Microcline occurs as anhedral grains and irregular, intergranular masses. Grid twinning is common, and film perthite is present in a majority of the grains. The grain size of microcline is generally intermediate between those of quartz and plagioclase, but larger grains may occur. Inclusions of sericitized plagioclase are frequently found within grains of microcline.

Biotite (Z, Y = dark brown, X = tan) is seen as laths and flakes of size ½ to 2 mm. Bending of some biotite grains is observed. Modal analyses of granodiorite are presented in Table I.

Table I.

Modal analyses of granodiorite specimens.

Spec.nr.	Plag.	Quartz.	Microcl.	Biotite	Eest.	Counrs
9E/102c	35,5	28.—	14.—	19.5	3.—	1200
9E/103	40.—	28.—	18.—	12.—	2.—	1100
9E/152I	29.—	33.—	15.—	18.5	4.5	1000
9/E/152II	34.—	25.—	22.5	16.—	2.5	1000
9E/152A	29.—	28.—	18.—	21.—	4.—	1000
9E/152C	38.—	24.—	19.—	15.—	4.—	1200
9E/151x	39.—	19,5	23.—	12.5	6.—	1000
9E/152E	35.—	24.—	27.—	10.—	4.—	1100

Relation to surrounding rocks.

As already pointed out, the normal granodiorite of the massifs is separated from surrounding gneiss or gneissgranite by zones of transition. Whereas the transition from granodiorite to gneissgranite takes the form of a gradual change in properties, over a distance of 10 to 50 meters from those of normal granodiorite to normal gneissgranite, the «transition migmatite» separating granodiorite from the regional gneiss is characterized by features which are distinctly different from both those of normal gneiss and those of granodiorite. This «transition migmatite» represents an important key to the understanding of the granodiorite, and it must therefore be considered in some more detail.

«Transition migmatite». As a group of rocks, the «transition migmatite» is by far the most heterogeneous one encountered in the present area. The reason for making one group out of such a variety of rocks being in many respects widely different, is their structure on a mesoscopic scale. However different these structures may be, they are united by the fact that they can only be explained assuming a rock system that was at the time of deformation in a partly solid, partly fluid state. Through this assumption their structural comlexity is accounted for, as pointed out aready by Sederholm (1907). The variety of flow folded gneisses and agmatitic breccias are now satisfactorily explained in light of experiments on anatexis of rock materials of various composition. (Winkler, 1965).

In order better to describe the structures of the various types of «transition migmatite», reference will be made to the structural classification proposed by Berthelsen (1961), see Fig. 4.

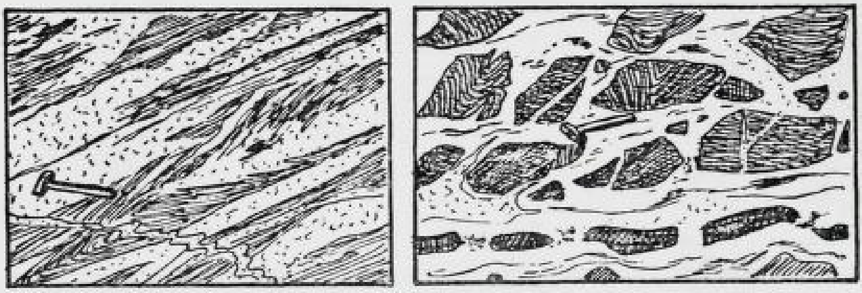
In spite of their complexity of structure and mineralogical composition, most of the «transition migmatite» rocks can be classified as either *agmatite* or *flow folded gneiss*. On the geological map, distinction is made between these two rock types.

As seen from the map, the flow-folded gneiss has a widespread occurence, whereas agmatite or agmatitic gneiss, although being represented in all parts of the border zone of the granite complex, has a more restricted occurrence.

Agmatite has in most cases an appearance very similar to the agmatitic gneiss of Berthelsen, see Fig. 4. Smaller and bigger fragments of dark, amphibolitic rocks with foliation and frequently with fold structures lie embedded in a light, aplitic or granitic mass, which is normally without directional structures. Sometimes only zones, or schlieren of amphibole-rich material and (more rarely) similar schlieren of magnetite, are found in an aplite-like matrix. In addition to the planar structure produced by these darker components, a hardly discernible foliation is sometimes also present in the light material, this effect problably being produced by parallel orientation of minute flakes of mica. Both kinds of agmatite

BANDED GNEISS

STREAKY GNEISS



VEINED GNEISS

AGMATITIC GNEISS

WAVY GNEISS

HOMOGENEOUS GNEISS

SMALLFOLDED GNEISS

NEBULITIC GNEISS

Fig. 4. Structural criteria as basis for classification of gneisses and migmatites. Berthelsen (1961).

mentioned above are associated with migmatitic gneiss of the flow folded gneiss type, or of varieties more similar to the regional gneiss type. Another variant of agmatite differs from the former mentioned types through a lack of foliation in the dark, xenolithic fragments. In these cases, the matrix medium is granitic, rather than aplitic. The included fragments strikingly resemble those meta-dolerites frequently encountered outside the granite complex as dikes.

Flow folded gneiss. This rock type constitutes a transition from grey, banded gneiss of the regional gneiss group, into normal granodiorite. This transition is a gradual one, and correspondingly, the properties of this «flow folded gneiss» are continuously changing across the border zone. This transition is observed in several places within the mapped area. Along the northern boundary of the Munkefjord—Sandnes granodiorite, good, continous exposures permit detail study of the phenomenon. On approaching the granodiorite from the regionally dominant, grey, banded gneiss, one passes into a zone where the gneiss is intensely folded. Berthelsens illustration of smallfolded gneiss, Fig. 4, gives a good impression of the mesoscopic appearance of this zone. Closer to the granodiorite, the folding is more smooth and at the same time more chaotic. This is the typical flow folded gneiss.

In Fig. 5 are plotted measurements of fold axes from this type of tran-

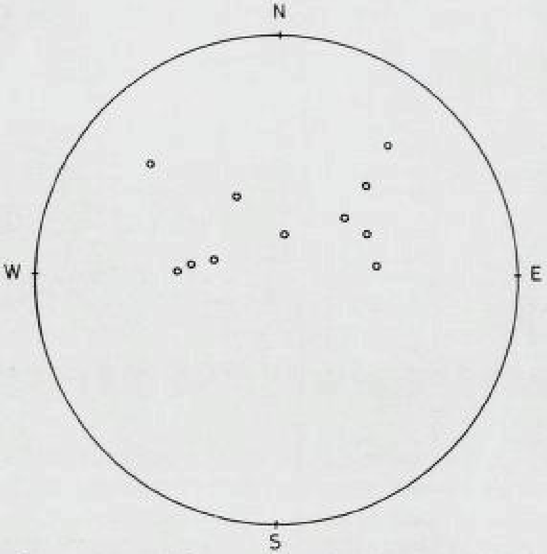


Fig. 5. Fold axis measurements in «transition migmatite» near Skoltefoss Nedre Neiden, Wulff net lower hemisphere.

sition migmatite. Measurements taken only meters apart are widely different, and no significant pattern emerge from the stereonet plot.

At this stage, the rock conforms with the definition of migmatite. Schlieren and lenses of coarsegrained quartzofeldspatic material, both concordant and cross-cutting, occur in multitude within the folded gneiss. In other places it seems as if the mineral grains of the gneiss have locally been rearranged to form homogeneous, mediumgrained, greyish, granite-like masses, into which the fold structures are fading. This homogenization of the banded and folded gneissic rock becomes stronger as the massive granodiorite is approached. It seems as though some kind of granoblastesis has blurred out the banding and fold structures and has transformed the gneiss into practically homogeneous, grey grandiorite. Berthelsen's term nebulitic gneiss corresponds to the rock of this zone. From here onward to granodiorite free of any relict or nebulitic structures, the transition is very gradual, and no boundary can be drawn between what was apparently a paragneiss and the wholly igneous-like granodiorite.

The width of this transition zone, as cut by the present surface of the lithosphere, might vary from about one kilometer down to less than one hundred meters. Locally, and particularly where the transition takes place over a short distance, microcline porphyroblasts have developed in the folded gneiss as well as in the massive granodiorite.

The gneissgranite group.

The variety of different rock types put together as gneissgranite make up a very heterogeneous group. The reasons for grouping together rocks of such unmatched appearance as a medium grained gneissgranite and a locally intrusive augengranite, e.g., are not at all obvious. Let it therefore be stated at the outset, that the gneissgranite group as a whole conforms to the picture of a series of gneissic rocks which have been subject to granitization. The mineralogical and structural heterogenities of such a material, overlapped by the irregular distribution patterns of tectonization and metasomatism during a granitization process, might well, it is assumed, account for the observed petrographical variations within the gneissgranite group.

By this statement subjectivity is introduced already at the stage of petrographic description. Whatever the true genetic explanations might be, it is felt, however, that in the actual case, a more correct picture of what is actually observed in the field is conveyed to the reader by the above statement, than by the apparently more scientific description of isolated rock types and their interrelations. Actually, the concept of «rock type» is not easily applied to the rocks of the gneissgranite group. The various rocks represent aspects of a complex unity; when applied to mapping and description of such a system, the rock types become artificial constructions which might inflict a considerable distortion on the observed reality.

As one group, the gneissgranite is covering more than half the area of the granite complex. The dominant variety is a red-spotted, medium to finegrained, granite-like rock with a more or less pronounced foliation. Incipient porphyroblats of microcline are normally present, but their size only slightly exceeds the matrix grain size. Colour index, degree of foliation, grain size and other properties vary rather irregularely. When more specific data are to be presented, these will therefore be given with reference to certain localities or certain specimens, rather than as representative for larger units.

Specimen 9E/170a is taken from a gneissgranite area in the middle of the 9E rectangle. The rock is medium-grained and has a foliation imparted by anhedral, lense shaped concentrations, 2—5 mm thick and 10—20 mm long, of mainly reddish feldspar. These lenses have parallel orientation and together with the subparallel orientation of dark micaceous minerals, they give the rock a distinct gneissic structure. The lenses have apparently grown in the largely solid rock, and seem by their growth partly to have destroyed an older planar structure outlined by the oriented mica. In some cases, the lenses consist of a single large microcline crystal, but more frequently a granular aggregate of microcline and quartz is found to make up such lenses. There is a tendency that the quartz-feldspar aggregates form the more elongate and concordant lenses. The larger the microcline porphyroblast, the more equidimentional its shape. Euhedral microcline porphyroblasts are not observed. In thin section the texture is normally granoblastic, but there are textural signs of paragenetic instability. The rock is chiefly composed of plagioclase, (oligoclase-andesine), quartz, microcline and biotite in a state of transformation to chlorite. Accessories are sphene, opaque minerals and apatite.

Plagioclase grains are sub-anhedral, the width being ½—1 mm. Where bordering on microcline, myrmekite has developed in the plagioclase. *Microcline* occours as equant, anhedral, granoblastic grains and as porphyroblasts, 2 to 5 mm wide, with inclusions of sericitized plagioclase and flakes of biotite. The biotite inclusions in microcline and quartz are generally fresh, as opposed to the majority of the biotite in the thin section. Grid twinning and perthite are common in the microcline, and although this is no strict rule, there seems to be a general tendency towards absence of grid twinning in the perthitic grains or parts of grains, and vise versa. The perthites are of the film- and flame-perthite types.

Quartz occurs in anhedral, equant grains or interstitial to the other minerals. Its extinction is to some extend undulatory. Notice should be paid to the fact that nearly all grains of equigranular microcline show some undulation of extinction, as opposed to the larger microcline porphyroblasts, none of which exhibit this feature.

Textural features leave the impression of a younger quartz — microcline paragenesis breaking the former texture of plagioclase and sub-parallel oriented biotite. Tectonic movements probably outlasted the crystallization of the equigranular microcline, whereas the porphyroblasts were formed after this stage. The biotite-chlorite transformation is also a late feature. Modal analysis of this specimen is presented in Table II.

Specimen 9E/227 represents a dark reddish, medium-fine grained gneiss-granite in the Sisivatn — Vegskillevatn area, western part of 9E. The orientation of dark minerals, and their concentration along lines separated by 1 to 2 mm thick zones of quartzofeldspatic material, imparts to the rock a distinct lineation or foliation which is easily observed in most outcrops. For certain orientations of the section, however, the rock appears as a red, granoblastic and completely structureless granite. The tendency towards formation of microcline porphyroblasts is much less than in the case of 9E/170a.

In thin section, corroded plagioclase and irregular flaky grains of chlorite (prochlorite) seem to be floating in a granoblastic mass of quartz and microcline. Epidote is often found in aggregates with chlorite.

Plagioclase (An30—35) occurs in anhedral grains, bearing signs of thorough tectonization in the form of twinned crystals which are bent and broken. The grain size distribution of the plagioclase, from 0.2 to 3 mm, might also be explained as an effect of partial granulation.

Microcline occurs in anhedral, equigranular grains, 0.3—0.8 mm wide. Flame perthite is present in nearly all grains, grid twinning is rarely seen. A few porphyroblasts, ca. 3 mm wide, are seen in thin section. In one case, an anhedral, apparently porphyroblastic grain of plagioclase is observed.

Contrary to the other plagioclase grains, this one shows no twinning, it engulfs or embeds others plagioclase grains, and it contains numerous small inclusions of epidote and sericite.

Quartz forms anhedral grains of variable size and shape, often occurring as intergranular fillings between other minerals. Except for small rounded quartz inclusions in microcline and elsewhere, the quartz shows very undulatory extinction.

The *chlorite* is strongly pleocroitic (neutral- dark green), and has anomal violet interference coulours. It is identified as a prochlorite on optical criteria. In a few grains, remnant layers of biotite are seen, indicating a formation of the chlorite from original biotite. In other instances, epidote seems to grow within chlorite grains. Most chlorite grains show signs of tectonization. The larger grains commonly display fold-structures within a single grain. In addition to epidote, sphene, opaque minerals and apatite are accessories.

The mode of this thin section is presented in Table II. Study of thin sections of gneissgranite from other areas shows some variation in the relative amounts of the main constituents, but the mineralogical composition is largely the same as described for the specimens 9E/170A and 9E/227. There is the general impression of an older plagioclase-quartz-biotite paragenesis being «diluted» by introduced quartz-microcline in connection with thorough tectonization. The biotite is transformed to prochlorite, some epidote is normally formed, and plagioclase is to some extend resorbed by microcline. Fluorite is observed as accessorium in a number of thin sections.

In the field small amounts of molybdenite are found as flaky crystals, 3—8 mm wide, in medium to coarse-grained gneissgranite around the south end of Munkefjord.

Table II.

Specimen No.	Plag.	Quartz	Micr.	Bi/Chl.	Epidot	Rest	Counts
9E/170A	32.—	29,5	27.—	10.—	0	1.5	1000
9E/227	37.5	23.—	22.5	14.5	1	1.5	1000

From the just described dominant variety of gneissgranite, there is departure of properties in opposite directions. One direction is represented by rocks of the augen-gneissgranite type, where the original gneiss-foliation is enhanced by the planar orientation of the K-feldspar porphyroblasts. Contrary to this accentuation of the foliation there has been, in some areas within the gneissgranite, a tendency towards granoblastesis and destruction of all directional structures, producing a quite massive and homogeneous medium-grained, red granite, shown on the map as microcline granite. Only by observing the successive change in properties from those of normal gneissgranite through the gradual destruction of the gneissgranite foliation, is it possible to interprete this granite as a member of the gneissgranite group. It is interesting to note that there is also in the augen-gneissgranite line of evolution a locally developed, final stage implying the destruction of planar structure. The resulting augen-granite displays clearly intrusive behaviour in some cases. In order to express in the geological map the described variations within the gneissgranite group, distinction is made between:

Normal reddish gneissgranite
Augen-gneissgranite
Mediumgrained red granite — Microcline granite
Intrusive augen-granite.

It should be stressed again, that many of the rocks belonging to the gneissgranite group have properties intermediate between those of the named rock types, whereas others again represent transitional links towards the regional gneiss or the massive granodiorite.

Associated with granodiorite bodies in the southern and central parts of the granite complex are found some peculiar rocks, which are best described as hybrids between migmatitic gneiss and microcline granite. The name: Flaggy granitegneiss, is given to these rocks, and on structural criteria, a distinction is made between two types.

Type one has a strictly planar foliation while the second type has been intensely flow folded, closely resembling the flow folded gneiss of the previously described zone of transition between regional gneiss and granodiorite. Both types of flaggy granite-gneiss differ from the migmatitic gneiss by being more coarse-grained and having a higher content of potassium feldspar. They are flaggy in the sence that they possess a foliation imparted by alternating mica-rich laminae of thickness ca. 1 mm, and 5—10 mm thick bands of light, reddish quartzofeldspatic material.

These rocks are interpreted as «roof pendants» to the granodiorite bodies, representing an overlying migmatite zone, which in these central parts of the granite complex have suffered granitization. Through their position as more or less isolated flakes, floating on the granodiorite, they have been protected from granular flow and hence transformation to normal gneissgranite.

Intrusive quartz monzonite.

Apart from various dike rocks and local variants of the augen-granite, the quartz monzonite is the only rock within the granite complex which has an obviously intrusive character. Bodies of quartz monzonite are found, so far, only in three areas: Two bodies in the central part of 9E, intruding an augen-gneissgranite, one body southwest on 9G, cutting through rocks of the gneiss group and having xenoliths of the iron formation, and in the northern 12E area a quartz monzonite body is found, cutting a granite pegmatite which in its turn sets through a granoblastic granite of the gneissgranite group. Due to overburden, the boundary has nowhere been traced all around such bodies. They appear, however, to be irregular bodies, mainly elogated in the strike direction of the surrounding rock. In addition to xenolithic fragments of surrounding rock found in the quartz monzonite and its sharp, crosscutting boundaries, its fine-grained marginal zones point to a thermal difference between the quartz monzonitic material and its environment during crystallization.

The rock appears fine to medium grained, its colour might vary from light grey to light reddish. Porphyric microcline grains of 5—10 mm, are occasionally seen in the rock. In thin section the main constituents are plagioclase, microcline, quartz and biotite. Opaque minerals, sphene, apatite, fluorite and chlorite occur in accessory amounts. The texture is granular or sometimes granoblastic.

Plagioclase (oligoclase-andesine) occurs in anhedral to subhedral grains, twinned according to albite- and carlsbad laws. The grain size varies between 0.5 mm and 1.5 mm. Some of the larger grains are zoned. Most plagioclase grains are moderately sericitized. Myrmekite has sometimes formed against adjacent microcline.

Microcline occurs in anhedral grains, 0.3 to 2.0 mm wide. Perthite is common. Grid twinning is present only in about half of the microcline grain population. Distinction might be made between one type of microcline grains, being equigranular and forming a granular texture with quartz and plagioclase grains of similar size, — and the microcline of a few, larger grains of granoblastic character. Quartz forms anhedral grains from ½ to 4 mm wide, which have undulatory extinction. Biotite occurs in relatively small, subhedral laths, a few grains showing signs of transformation into chlorite. Sphene is commonly associated with opaque minerals.

Modal analyses of four specimens of quartz monzonite are presented in Table III.

Table III.

Specimen No.	Plag.	Quartz	Microcl.	Biotite	Rest	Counts
9E/190	34.5	24.5	32.5	6	4.5	1000
9E/176B	35.—	22.5	34.5	6	2.—	524
9E/170B	39.5	22.5	31.5	4.5	2.—	1000
9E/170Bx	33.—	28.—	31.5	5.5	2.—	1000

Chemical analysis of specimen 9E/190 appears in Table IV.

Chemical composition.

The procedure of analysing a «representative» specimen as a means of finding the mean composition of a granite of regional extension, is no longer generally approved of. As indicated through the work of Whitten (1961), a large number of analyses are required in order adequately to describe the mean composition and the variability of such a rock. In the present investigation, no effort has been made to fulfill such statistical requirements for the data gained from modal and chemical analyses. These results should therefore be treated as mere indications of the general composition of the rocks. Three complete silicate analyses have been made, one from each of the three most homogenous rock types within the granite complex; the granodiorite, the quartz monsonite and a locally intrusive augen-granite. Results are presented in Table IV. The analyses have been recalculated in the catanorm and the mesonorm (Barth, 1959, 1962). For computing the cation-percentages and the catanorm-values, the electronic computer, GIER, og Regnesenteret, NTH, was used. The results are presented in Tables V and VI. Although earlier presented, the modes of the sp. 9E/103 and 9E/190 are repeated in Table VII. Because of its porphyric texture, no modal analysis have been made of Sp. 9E/282^{II}. The mode of Sp. 9E/170^{A}, which is a normal gneissgranite, has been included for comparison.

Table IV.

Chemical analyses of rocks of the granite complex. Results in weight %.

	Sp 9E/103	Sp. 9E/190	Sp 9E/282II
SiO_2	63.72	68.62	71.66
TiO_2	1.02	0.42	0.48
Al_2O_3	14.66	15.05	13.54
Fe_2O_3	1.36	1.51	1.06
FeO	4.85	1.40	1.90
MnO	0.15	0.04	0.09
MgO	2.10	0.90	0.71
CaO	3.46	1.28	1.59
BaO	0.07	0.17	0.05
Na_2O	3.15	4.13	3.19
K_2O	3.83	5.08	4.96
P_2O_5	0.37	0.20	0.13
H_2O^+	1.19	0.94	0.75
H_2O^-	0.03	0.10	0.04
S	0.06	0.04	0.03

Sp 9E/103	Normal granodiorite. Near main road, 1½ km east of Neiden.
Sp 9E/190	Fine-grained quartz monzonite. Central part of 9E.
Sp 9E/282^{II}	Intrusive augen-granite. Near northern border of the Neiden-Munkefjord granodiorite.

Table V.

Cation-%	Sp 9E/103	Sp 9E/190	Sp 9E/282II	
Si		60,57	64.40	67.69
Ti		0.73	0.30	0.34
Al		16.40	16.62	15.05
Fe'''		0.97	1.06	0.75
Fe''		3.96	1.13	1.57
Mn		0.00	0.00	0.00
Mg		2.99	1.27	1.01
Ca		3.60	1.46	1.66
Na		5.80	7.50	5.83
K		4.65	6.09	5.98
P		0.30	0.16	0.10

Table VI.

Mineral	Catanorm			Mesonorm		
	9E/103	9E/190	9E/282II	9E/103	9E/190	9E/282II
Q	17.45	19.70	27.43	23.76	21.55	29.64
Or	23.24	30.43	29.91	12.50	27.33	26.24
Ab	28.98	37.51	29.16	29.00	37.50	29.15
An	14.88	5.97	7.43	11.85	4.45	5.70
C	0.00	0.64	0.26	1.21	1.25	0.96
Bi	—	—	—	17.22	4.99	5.86
En	6.00	2.53	2.01	—	—	—
Fe	5.44	0.57	1.68	—	—	—
Mt	1.45	1.59	1.13	1.45	1.59	1.13
Ap	0.79	0.42	0.28	0.80	0.43	0.28
Il	1.45	0.59	0.58	—	—	—
Ti	—	—	—	2.19	0.90	1.02

Toble VII.

Modal analyses. Data taken from tables I, II and III.

Minerals	Sp 9E/103	Sp 9E/190	Sp 9E/170A
Quartz	28.—	24.5	29.5
Microcline	18.—	32.5	27.—
Plagioclase	40.—	34.5	32.—
Biotite	12.—	6.—	10.—
Rest	2.—	4.5	1.5
Number of counts	1100	1000	1000

The general agreement between norms and mode is not very good. The catanorm gives a wrong paragenesis, and even if the mesonorm yields a correct mineralogical composition, there are considerable discrepancies. The generally higher modal than mesonormal K-feldspar values may be due to the perthitic inclusions being counted as microcline. Sericitization of plagioclase, which was observed in all the rocks, would account for the normative corundum. The discrepancies, particularely those in Biotite and Quartz-values, are not easily interpreted as errors of identification during the point counting operation, and it must be questioned whether the thin sections have been representative for the analysed material.

In Fig. 6 the analyses are plotted in the granite system. The mesonormal compositions of all three rocks are seen to fall within the low-temperature trough of petrogeny's «residual system» (Barth, 1962, pp. 121) and reasonably near to the line AB, which is the locus of the minimum melting compositions at P_{H_2O} between 500 and 4000 bars. As stressed by several authors on granite petrology, this is, however, no proof that these rocks are derivatives of a basalt magna.

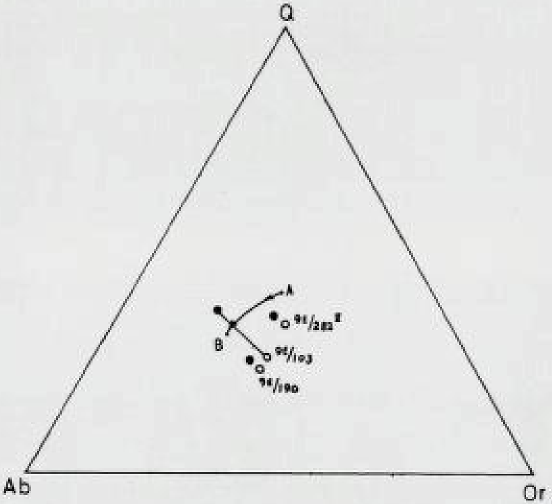


Fig. 6. Chemical analyses plottet in the granite system. Open circles represent catanorm, black dots represent mesonorm.

Granitoid dike rocks.

Various types of aplitic, granitic and pegmatitic dikes and veins are encountered in all parts of the granite complex. These are evidently late- to post-kinematic, and there are evidences of several generations of such dike rocks. Since the aim of the present investigation was to outline the major synkinematic processes, about which the granitic dikes can give little or no information, special attention has not been paid to the dike rocks. It is noted as a general tendency that, on passing away from the granite complex northeastwards on rectangle 9G, the granitic and aplitic dikes or veins become less abundant, hydrothermal quartz veins taking their place.

An unusual type of dike rock has been observed in the northern and western parts of the granite complex. The rock is light greyish to dark grey, very fine grained, sometimes with a distinct planar structure outlined by tiny flakes of biotite. In thin section, the rock has a fresh, granoblastic texture of equidimentional grains, 0.1 to 0.5 mm wide. The main minerals are microcline, quartz, plagioclase (oligoclase-andesine), biotite, chlorite and occasionally a green, monoclinic amphibole with a small 2 V. Sphene, apatite, epidote and opaque minerals occur in minor amounts.

Gabbroid dike rocks.

Like in the rest of the Precambrian region south of Varangerfjord, gabbroic dike rocks are also encountered within the granite complex. Observations from this area leave no doubt that there are several generations of such dike-intrusions, some of which are older than the granite complex. Fragments of doleritic or meta-doleritic material are found as xenoliths in augen-granite and quartz monzonite. In a number of cases, granitic dikes and pegmatites are observed cutting doleritic dikes, however, the opposite situation is also frequently encountered. Although an important and promising project which might add valuable information about the development of the granite complex, the thorough study of the relations between different types of gabbroid intrusions and the rocks of the granite complex has not been undertaken in the present work. Føyn (1945) has studied the dike rocks in Sørvaranger, and when this important contribution is supplied with results from the current regional field investigations carried out by the A/S Sydvaranger team, there will emerge a foundation for the interpretation of the observations of gabbroic and meta-gabbroic dike rocks in the granite complex.

Ultrabasic dike.

Of particular interest is an ultrabasic dike, running in a N—S direction in the central part of the granite complex. It causes a marked anomaly on the aeromagnetic map and corresponds on the aerial photographs to a marked linear feature extending for more than 5 km, most part of which is a long, narrow lake. Only isolated outcrops are found in the field, these being all situated along the same zone, which is also enhanced by different and more dense vegetation than that of the surrounding gneissgranite.

A constinuous dike is assumed, of which only isolated outcrops are left uncovered by water and glacial material. Block streams of ultrabasic boulders are found in several places, only within or quite near the zone, however, thus indicating very little glacial transport in this part of the Neiden area. Towards its northern end the dike turns west- and then southwards, forming a foldlike body, the western limb of which quickly narrows and disappears. The strike of the surrounding gneissgranite is cut by the dike. Cross-sections drawn from aeromagnetic data indicate that the dike is practically vertical, Fig. 7. In one place the boundary between metaperidotite and gneissgranite is observed. It is quite sharp, and the dike rock is fine grained near the border.

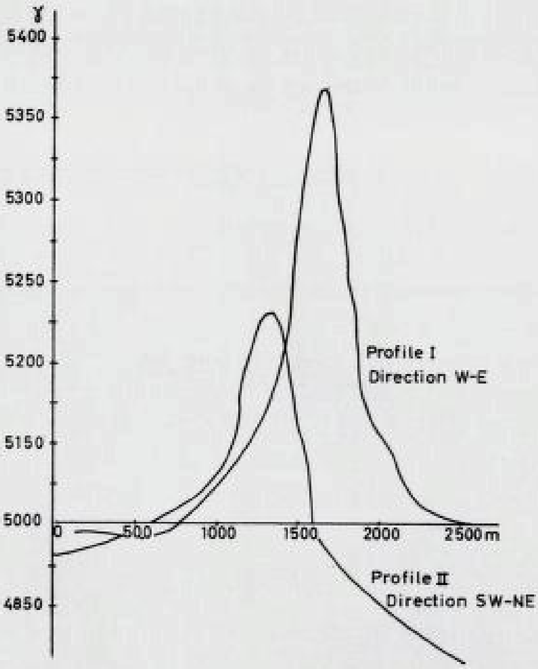


Fig. 7. Magnetometric profiles across ultrabasic dike along Brandvann. Data taken from aeromagnetic map.

Two thin sections have been examined from this peridotic dike. One specimen, collected near the northern end of the dike, is found to contain numerous armoured relicts of olivine, surrounded by a hysterogenic mass of serpentine, chlorite, phlogopite and large quantities of a light brownish, monoclinic amphibole which is commonly clouded with inclusions of opaque minerals. The other specimen, which is from the southern end of the dike, is also in a state of paragenetical disequilibrium. About 75 % of the rock consist of a light brownish monoclinic amphibole with a distinct pleochroism. It forms sub- anhedral grains, 1 to 5 mm wide. The mineral is evidently undergoing transformation, the optical properties varying within the single grains. Measurements in unaltered grains give the following results: $2\ V = 80 \pm 5°$, optically negative, $Z/c = 21°$, X = neutral, $Y = Z$ = brownish (green patches in some grains).

Frequently, the brownish amphibole is replaced by an aggregate of small, colourless needles of cummingtonite.

Additional to the two amphiboles mentioned, biotite occurs in irregular flakes evenly distributed in the thin section, and clouds of magnetite dust are scattered around. No olivine is seen in this thin section.

The iron oxide is associated with the aggregates of fine grained amphibole and has probably been formed by exsolution from ironrich olivine during metamorphism. A «condensation» has seemingly taken place in some of the clouds, leading to fewer and bigger grains of magnetite. There can be no doubt that the high content of magnetite in the meta-peridotite is responsible for the aeromagnetic anomaly associated with this ultrabasic dike.

Supplementary mapping in detail.

On the general geological map of the area, in scale 1 : 50 000, minor-scale features could not be recorded. Some of these are very interesting and should not be left out of consideration in an attempt to explain the genetic evolution of the granite complex. In order to collect such data, mapping in scale 1 : 10 000 was performed, of the easily accessible and detail-rich northwestern quadrant of rectangle 9 E, and along a zone of iron formation east of Munkefjord. At one place near Nedre Neiden, where iron formation occurs in the proximity of massive granodiorite, a map has been made in scale 1 : 4000.

The Neiden-Munkefjord subarea.

As indicated by the map, Fig. 8, the gneiss-group rocks adjacent to the granite complex deviate from the regional trends with respect to strike, structures and petrographic characteristics. Remarkable are the smaller

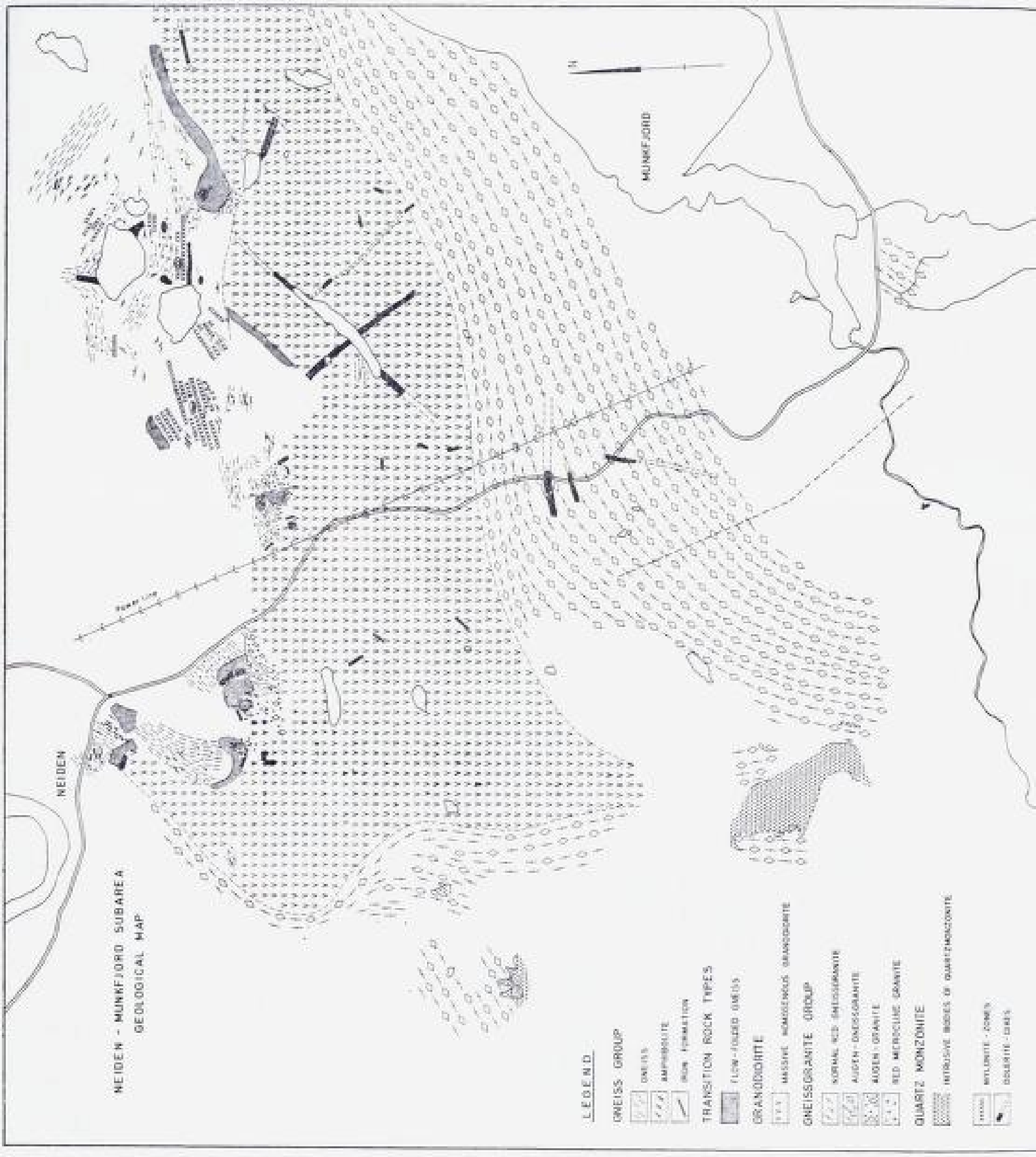


Fig. 8. Geological map of the Neiden — Munkefjord subarea.
Scale ca. 1 : 35 000.

and bigger, isolated occurrences of iron formation (quartz-banded iron ore), distributed according to no apparent system within the gneissic rocks which here display more or less pronounced migmatic character. Along the borders of the granodiorite, flow-folded gneiss is found, and agmatitic schlieren and fragments of amphibolite embedded in aplitic material occur locally within the gneiss even at considerable distance away from the granodiorite boundary.

A phenomenen observed in this sub-area is homogeneous augengranite. This rock has locally intruded as a mobile, probably semi-solid crystal mash, cutting into and incorporating xenoliths of the adjacent gneiss. The intrusive granite has a massive appearance, but a gradual transition is observed from such massive augen-granite over augen-gneissgranite to more or less porphyroblastic gneiss which obviously belongs to the regional gneiss series. Presence of amphibolitic zones in the gneis is a common feature in those areas where augen-granite locally exhibit intrusive behaviour. Bergstrøm (1963) reports augen-granite under similar conditions, and he suggests that mobile granites were formed where the tectonical conditions were favourable for «trapping» the ascending solutions. In his Tjørn area, augen-granite thus is formed locally under impervious greenstones.

In the northwestern part of the Neiden-Munkefjord sub-area, zones of intense cataclasis set through the gneiss just north of the border of the granite complex. Mylonite zones, up to several hundred meters in thickness, run in an E—W direction. It is assumed that these are late features, being formed after the consolidation of the granite complex.

Relation of iron formation to granite complex.

Because the iron formation represents primary strata in the gneiss series which can still be recognized when all other primary features of the gneiss group have vanished, particular attention was paid to occurrences of the iron formation near the granite complex boundary. It was hoped that by detailed investigation, these localities would reveal significant relations between the regional gneiss and the rocks of the granite complex. Of two such localities a detail mapping was performed.

Locality 9F/109, sand and gravel quarry by main road Neiden—Kirkenes, about 5 km from the end of Munkefjord, on east side of the fjord. The iron formation occurs in a ridge ascending to the east of the quarternary deposits and extending eastwards for more than 1 km. Fig. 9 shows a map in scale 1 : 10 000, covering this ridge. To the south of the mapped area, rocks of the gneiss-granite group occur, whereas northeastwards the migmatitic gneiss passes gradually into normal, regional gneiss. The quartz-banded iron ore is associated with amphibolite and, seen on a large scale, this unit forms a continuous zone within the migmatitic gneiss.

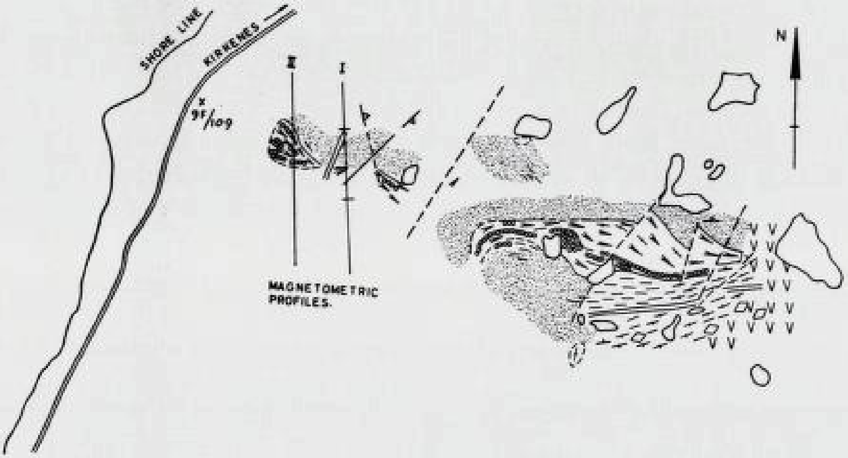


Fig. 9. Map showing behaviour of the iron formation in migmatitic gneiss near western end of the Munkefjord — Sandnes granodiorite. Scale 1 : 20 000.

In detail, however, the zone is not strictly continuous, having, as shown by the map, a rather irregular distribution. Along two sections running N—S over the western part of the zone, magnetometer readings and geology were recorded, see Fig. 10. The sections are separated by 150 m. These data corroborate the impression given by the map, that the zone, which on a larger scale appears continuous and uniform, in reality has a very complex detail structure. Fig. 11 a and b shows details from folded iron formation in the eastern part of the mapped zone. It is remarkable how, although locally irregular, these separate parts line up to form a narrow and largely continuous zone within the migmatitic gneiss.

At *locality 9E/101*, about 1 km eastwards along the road from the Nedre Neiden village, there is a geological situation similar to the one just described from 9F/109. Greyish, quartz-dioritic gneiss here strikes SW into massive granodiorite. The gneiss has in many places migmatitic character,

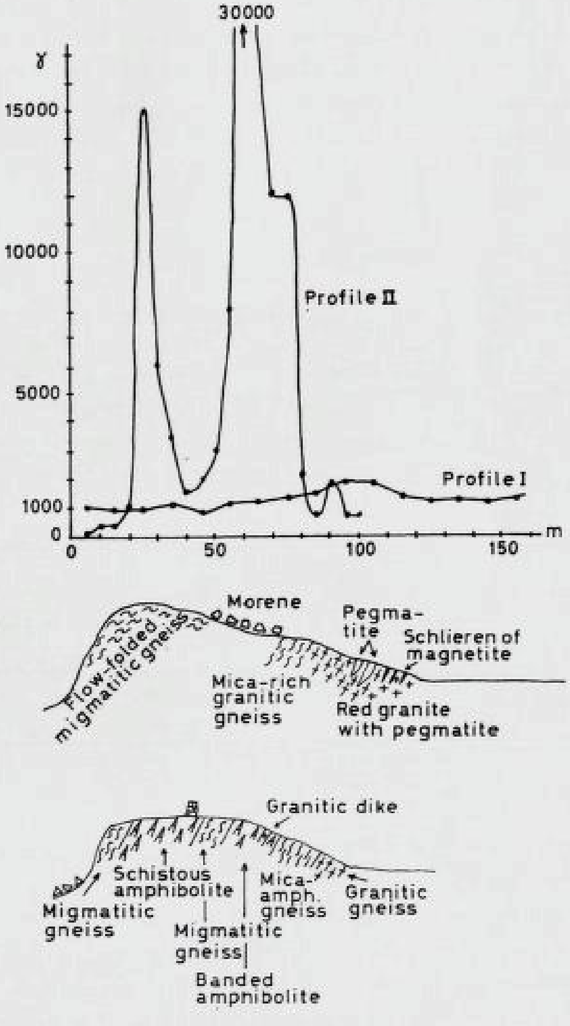


Fig. 10. Geological and magnetometric sections across the zone of iron formation. Location of sections shown in Fig. 9.

with light aplitic material surrounding schlieren and bands of femic rock. Prevailing is a normal, foliated gneiss, which sporadically contains porphyroblasts of white microcline. Flow folded gneiss is found bordering the massive granodiorite. In these gneissic rocks, bodies of the iron formation are distributed. A map in scale 1 : 4000 was made over this particular part of the Neiden-Munkefjord sub-area, see Fig. 12.

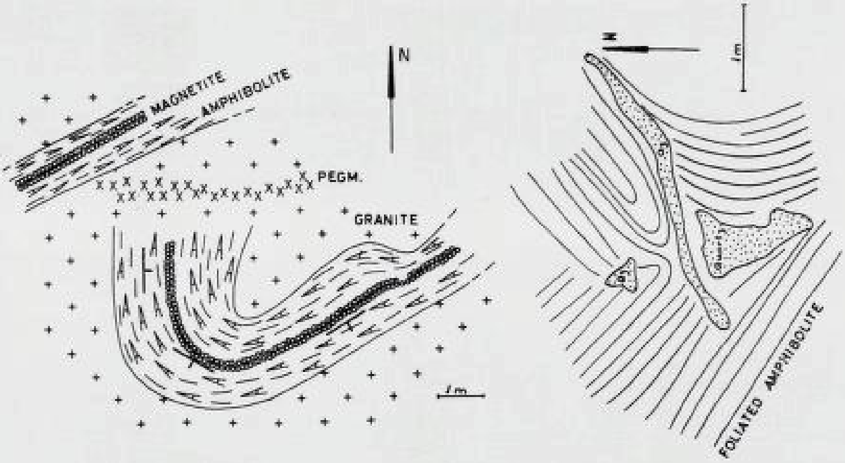


Fig. 11. Details from eastern part of the amphibolite iron formation-zone of Fig. 9.

Although separate, the bodies of quartz-banded iron ore and associated amphibolite line up in zones parallel to the strike of the gneiss. From the map, the excistence of at least two parallel zones is suggested. On approaching the granodiorite, the magnetitic rock disappears, only some schlieren of amphibolite are found more or less in the continuation of the iron formation. A magnetometer profile normal to the strike of the gneiss about 150 m away from granodiorite boundary gave no anomalies, supporting the observed depletion of magnetite rock in the gneiss on approaching the granodiorite boundary. Because a 20 m wide dolerite intrusion occurs along the boundary between granodiorite and gneiss, this locality is not ideal for the study of granodiorite/gneiss borderrelations. Southeast on the mapped area, however, outcrops show a gradual transition from gneiss to massive granodiorite. Along a section marked on the map, specimens were taken for the determination of alkali content. Results are shown in

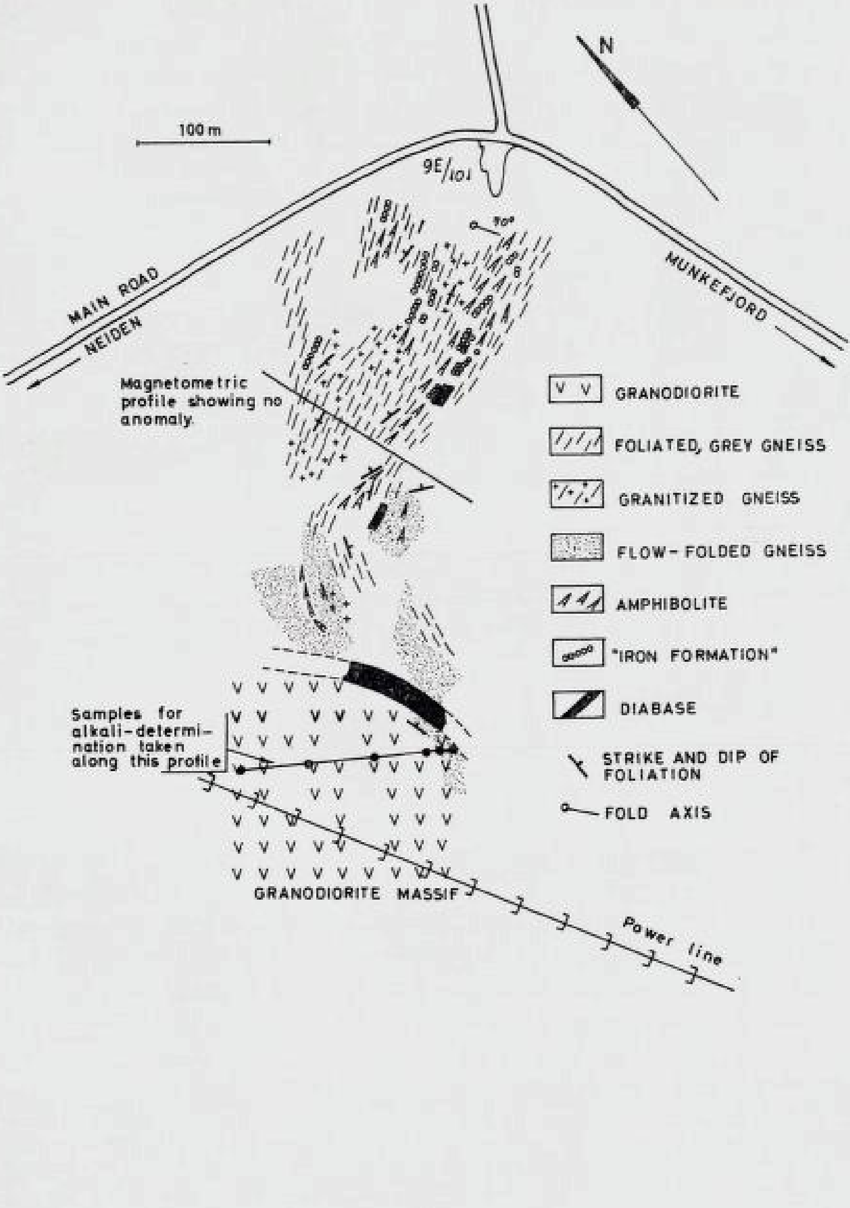


Fig. 12. Occurrences of iron formation in migmatitic gneiss near granodiorite border. Loc. 9E/101 about 1 km east of Nedre Neiden along road to Kirkenes.

Fig. 13. The granodiorite is considerably higher in K_2O than the gneiss. The curve indicates an enrichment of potassium in the border zone, whereby the granodiorite near the border has been drained of some of its K_2O. The sodium content is markedly higher in the gneiss than in the granodiorite but is not subject to fluctuation near the border.

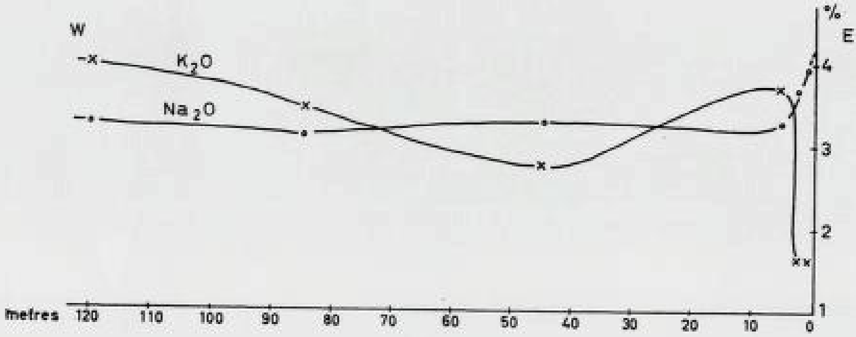


Fig. 13. Alkali distribution along a section normal to the granodiorite/gneiss boundary near 9E/101. The location of specimens indicated on Fig. 12.

From the investigations at 9E/109 and 9E/101, it is evident that the iron formation, although far more resistant than the gneiss, has suffered mechanical deformation and destruction during the evolution of the granite complex. The quartzbanded iron ore and the amphibolite no doubt represent originally continuous zones in the gneiss sequence. As a result of the rising temperature, the gneiss must have reached a state of rheomorphism, loosing its mechanical strength, whereas the amphibolite and iron formation still retained their stiffness. Given such a situation, it is possible to imagine how these stiff layers would break up and become embedded in the viscously flowing gneiss. The general alignment of the femic rock fragments suggests a state of only limited relative movement within the mobilized gneiss.

Apart from the mechanical deformation of the iron formation, certain features of the situation at 9E/101 indicate that the iron formation has also suffered more radical transformation during the culminating stages of migmatization. In the southeastern zone of iron formation, the fine, alternating bands of quartz and magnetite are still preserved, leaving no doubt that this rock is identical to the iron ore at Bjørnevatn. In some of the bodies, beautiful fold-structures are seen, whereas elsewhere strictly planar foliation or banding obtains. In contrast to this zone, the occurrences further nortwest and west on Fig. 12, seem to be in a state of mineralogical transformation. In what appears to be the highest state of transformation, pure magnetite is concentrated in schlieren or continuous bands, bordered by a rim of mafic silicates and embedded in a light, fine-grained gneiss of aplite-like character. Fig. 14 shows these magnetite schlieren. At other places, magnetite is enriched in irregular aggregates, more or less continuous along the strike direction. The surrounding material is a dark green amphibolite. In Fig. 15, which shows this, the magnetite appears light relative to the amphibolite on weathered surface.

The question of what happens to magnetite bearing rocks, like the present iron formation, under conditions of migmatization and partial anatexis is of considerable interest to economic geology. Although locality 9E/101 represents a geological situation where a detail study of such processes could be made, this has been concidered outside the scope of the present work.

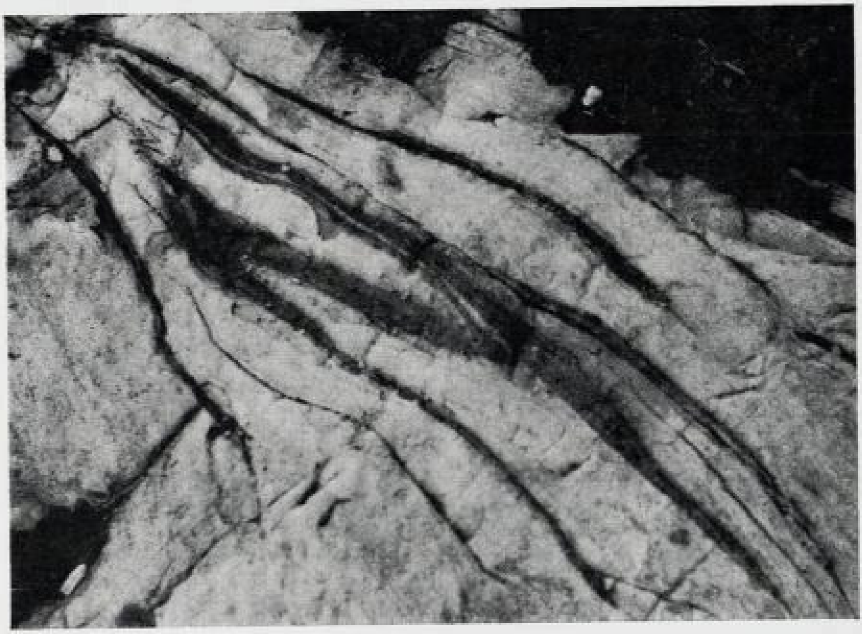


Fig. 14. Schlieren of magnetite in aplitic gneiss. Loc. 9E/101. Scale as in Fig. 15.

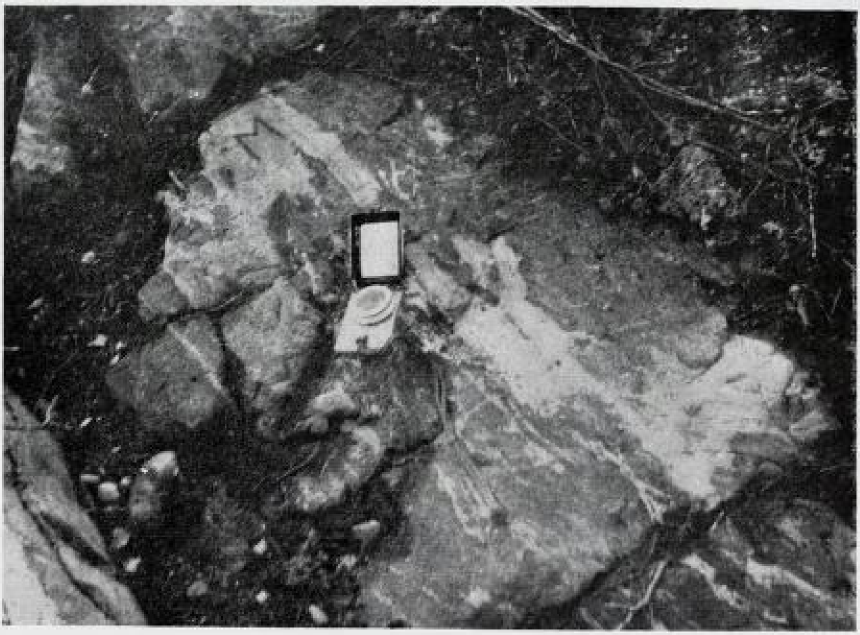


Fig. 15. Concentrations of magnetite in amphibolite.
Loc. 9E/101. M for magnetite.

Local features of particular interest.

The description of rocks given in the preceding chapters has mainly emphasized the general and average characteristics of the rocks of the Neiden granite complex. In addition to this kind of facts, obtained by generalizing observations from numerous outcrops, very important information may also be achieved by paying attention to the «uniqueness» of the single outcrop. A number of localities now being described, do all possess particular features which might throw light on the genesis of various rocks of the granite complex and their interrelationship.

Locality 9D/101. Outcrop by footpath along western side of Gråfjellvatn. Interesting relationship between regional gneiss and augen-gneiss-granite/augen-granite. Regional gneiss strikes S to SE-wards, and becomes more and more migmatitic in this direction. Further south it passes over into rocks of the gneissgranite group. At the locality, a minor body of augen-granite has a concordant situation within grey, banded gneiss. Zones of porphyroblastesis in the gneiss, running parallel to the foliation and parallel to the somewhat indistinct boundary between gneiss and augen-granite. Fig. 16 shows the situation.

The thickness of the porphyroblastic zones, and the extend of porphyroblastesis vary considerably. There is no doubt that K-feldspar porphyroblasts have started to grow preferably along certain zones in the gneiss. These zones might represent primary bands, the composition of which facilitated the porphyroblastesis of K-feldspar during regional granitization. The zones could also be conditioned by tectonization, representing zones of higher permeability than the remaining homoeogranular gneiss at the time of porphyroblastesis. Only to a very limited extend do porphyroblastic zones cross the foliation of the gneiss. Due to lack of outcrop, the shape of the body of augen-granite seen to the left in Fig. 16, could not mapped out, nor could its contact relations towards the gneiss be observed for more than a couple of meters. Signs of forceful intrusion were not seen, and the occurrence of faint s-surfaces and ghost-like, darker zones in the augen-granite, paralleling the foliation plane of the adjacent gneiss,

Fig. 16. Body of augen-granite and concordant zones of K-feldspar porphyroblastesis in adjacent quartz-dioritic gneiss.

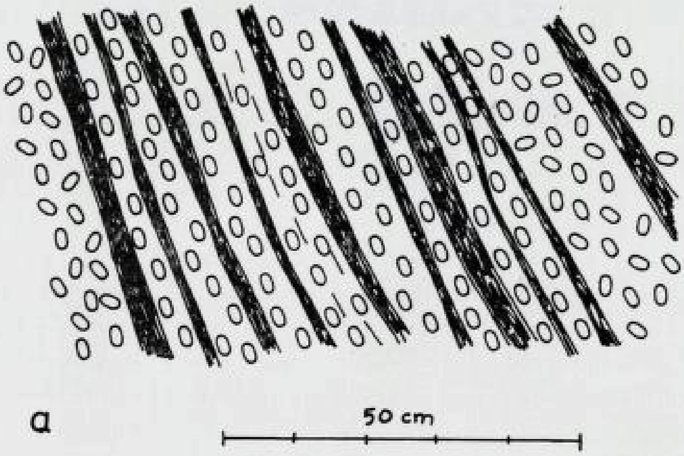


Fig. 17a. Relict amphibolitic bands in augen-gneissgranite.

are regarded as strong indications of a metasomatic origin of the augengranite.

Locality 9D/128, west of Veiskilvann, is situated in an area where rapid changes prevail between migmatitic gneis and augengneissgranite. The last mentioned rock type predominates, but within this red, porphyroblastic granite-like rock, bands and fragments of dark rock are frequently seen. These are interpreted as relics of amphibolitic bands in a preexcisting banded gneiss. Figs. 17 a and b show such relics. Provided the amphibolite relics of Fig. 17 b are remnants of a concordant band in an original

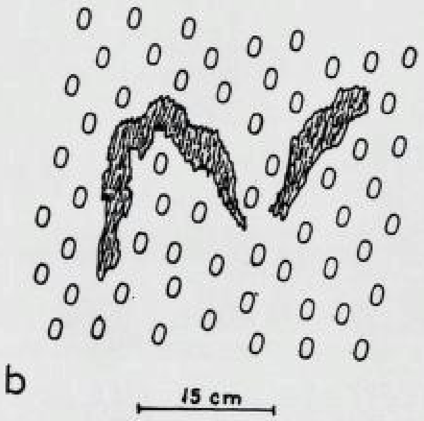


Fig. 17 b. Amphibolitic »ghosts» in augen-gneissgranite.

gneiss sequence (as corroborated by Fig. 17 a), it is worthy of notice that the porphyroblasts outline an s-surface of the augen-gneissgranite which runs practically parallell to the axial plane of the folded amphibolite band.

Locality 9E/104, at the northern end of Veiskilvann, lies in an area where nearly all rock types of the granite complex are represented, their interrelationship being rather irregular. Fig. 18 shows part of an irregular transition-zone from normal quartz-dioritic gneiss with bands of amphibolite, through augen-gneissgranite to augen-granite. The relict amphibolitic bands are more or less preserved, visible even in the augen-granite. A pegmatite dike cutting at right angle to the strike, is younger and clearly without relation to the process of porphyroblastesis. One of the amphibolite schlieren within the gneissgranite has a high magnetite content.

Fig. 18. Transition zone with migmatitic gneiss (right) and augen-granite with amphibolitic relic. A granite pegmatite cuts the strike.

Only 20 metres southeast of the outcrop of Fig. 18, the banded and foliated gneiss passes over into a massive grey, medium-grained granitoid rock. Disregarding its distinct foliation, outlined by dark micaceous minerals, this rock strikingly resemble the granodiorite. The same rock type is described from locality 9E/213.

At this locality problems are met with, which are essential to the whole of the granite complex. From what at the outset probably was a quartzdioritic gneiss with bands of amphibolite, there seems to have been two possible lines of evolution. One of these implies K-feldspar-porphyroblastesis most likely in connection with granitization. Of the various stages in this evolution, several are found, from gneiss with some porphyroblastrich zones, over augen-gneissgranite to augen-granite with no discernible foliation. The other line of evolution implies a gradual homogenization of the gneiss, leading to a grey, granodioritic rock with more or less distinct foliation.

Which were the critical factors determining the course of evolution? Are the processes separated in time, or are primary compositional differences within the gneiss series responsible for the development to take the one course or the other during the granite complex evolution? At this stage, no definitive answer can be given.

Locality 9E/239. Near the previously described locality 9E/204, fragments of banded, amphibolitic gneiss are found in a matrix of white, quartzofeldspatic material. This matrix is fine to medium grained and has in some places a recognizable planar structure. The structures displaid by the amphibolitic fragments indicate plastic deformation, and their structural interrelationship cannot be interpreted by assuming metasomatic processes only. The biggest fragment exhibits features indicative of a selective corrosion preferably attacking the darker bands in the amphibolitic gneiss.

Locality 9E/213. In this area, 1—2 km E of Veiskilvann, the dominant rock is a grey, medium to finegrained granitoid, which in places might exhibit a faint planar structure. Gradual transitions between this rock and both augen-gneissgranite and foliated gneiss are frequently observed. Within this rather massive «grey granite», lense-shaped, ghost-like inclusions of darker, amphibolitic rock are not scarce. Fig. 20 shows a situation where, in addition to such an amphibolitic relict, elongate inclusions of a light, fine-grained material are present. The shape of the amphibolitic inclusions points to their possible origin as boudins from amphibolitic bands in a preexcisting gneiss. Their present irregular distribution makes it necessary then, to assume considerable relative movement in the rock system at one stage of the transformation to the present state. The light,

Fig. 19. Agmatitic fragments of banded, amphibolitic rock in white, quartzofeldspathic matrix. Locality 9E/239.

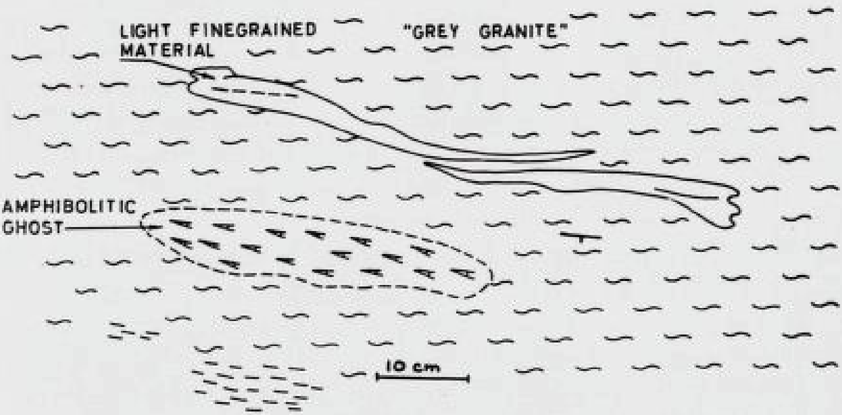


Fig. 20. Inclusions in homogeneous vaguely foliated «grey granite».

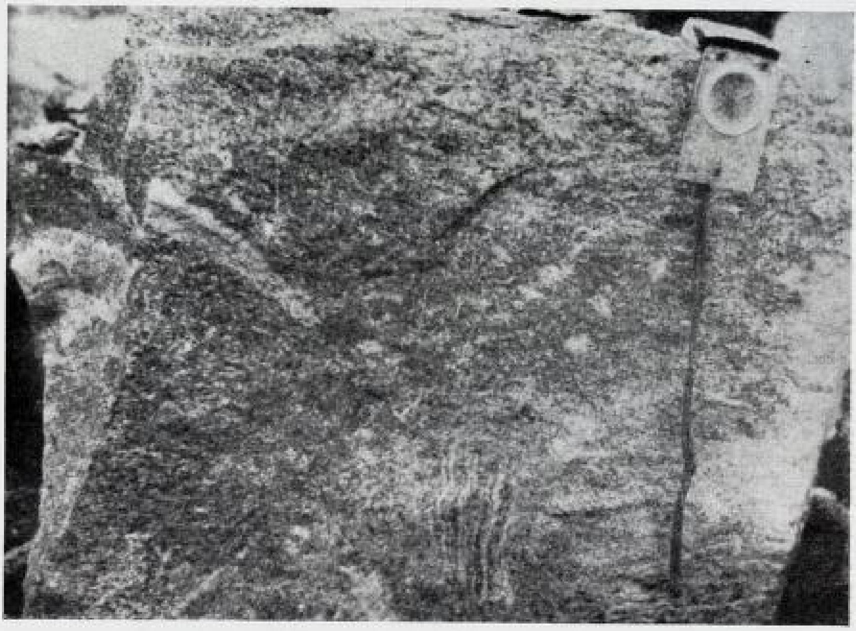


Fig. 21 a. Rotated gneiss fragments in granodiorite.

finegrained bodies in Fig. 20 might be interpreted as remnants of a very finegrained dike or vein, which, because of its denseness and low permeability, have escaped the transformation into «grey granite».

Locality 9E/103. This is a quarry in granodiorite, located by the main road about 2 km southwest of Nedre Neiden. Thanks to the excavations, it is here possible to study numerous fresh sections in the granodiorite. The rock is massive and homogeneous and has a medium to coarse grain-size and a greyish colour. Occasionally, however, local heterogeneous patches are encountered, which look like more or less diffuse relics of foliated or flaggy gneissic rock. Sometimes fragments with non-aligned orientation are seen, Fig. 21 a. Fig. 21 b shows gradual transition from flowfolded migmatitic gneiss into massive granodiorite at the same locality.

Keeping in mind the observed general rule of gneiss passing gradually into migmatite, which again indistinctly grades into granodiorite, it seems beyond doubt that the structures shown in Fig.s 21 a and b are inherited from older gneissic rock, parts of which have not been completely transformed to, or assimilated by massive granodiorite. It is difficult to imagine a process whereby the observed structures could develop during the crystallization of homogenous granodioritic magma. On the other hand, the rotated fragments of Fig. 21 a indicate that magma-like conditions obtained during one stage of the granodiorite genesis.

Locality 9F/147. In the western part of the Munkefjord-Sandnes granodiorite. relics of rather fine-grained, gneissic rock are sometimes seen in the homogeneous, medium-grained, grey granodiorite. Fig. 22 shows a horizontal exposed surface at the above mentioned locality, where almost angular pieces of fine-grained, granitic gneiss lie embedded in homogeneous granodiorite. Worthy of notice is the fact that the three apparently non-connected gneiss-inclusions have parallel alignment of the foliation, the strike being NW to W and in concordance with that of the regional gneiss north of the granodiorite boundary.

Locality 9E/259. In a small granite dike cutting the biotiterich augen-gneissgranite to the west of Munkefjord, some interesting helicitic structures are observed. The dike has finegrained border zones, but no really

Fig. 21 b. Relict gneiss-lamination in granodiorite.

clear-cut boundary against the augen-gneissgranite. In one place in the medium to coarsegrained central zone of the dike, faint planar structures are seen. The structures seem to be in geometrical continuity with the schistousity of the surrounding gneiss-granite, expressing a weak flexure in the central portion of the dike. Also visible on Fig. 23 is a quartz-filled gash which illustrates difference in mechanical properties of granite and gneiss-granite during late tectonization.

Locality 9G/112 is situated to the southeast of the Munkefjord-Sandnes granodiorite, in an area where the regional gneiss, with associated amphibolite zones and iron formation, is intruded by a minor body of quartz monzonite. The gneiss group rocks are here irregularely folded, having in some places a migmatitelike appearance. The average strike direction is N-S, with dip towards E. The emplacement of the quartz monzonite has produced a breaking-up of the surrounding gneiss, and fragments of the regional rocks are found as xenoliths in the homogeneous, fine to medium-grained intrusive. Fig. 24 shows a situation near the eastern

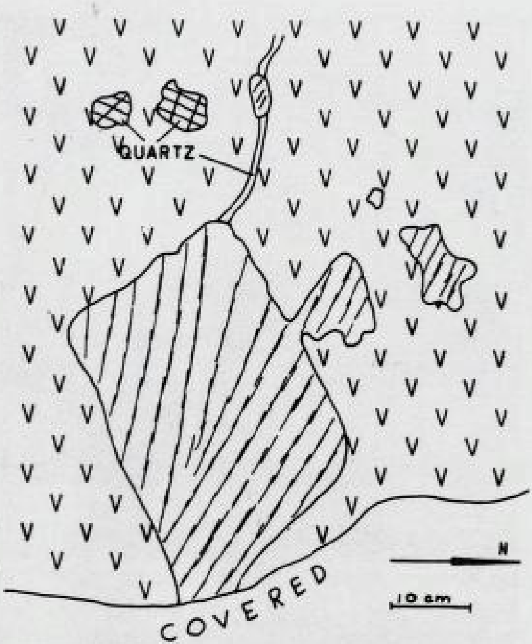


Fig. 22. Ghost-like inclusions of gneiss in homogeneous granodiorite.

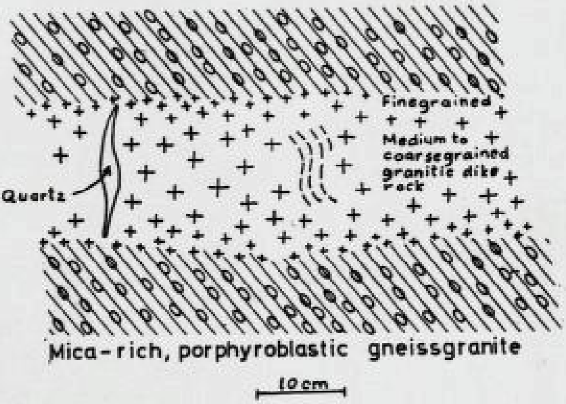


Fig. 23. Helicitic foliation structures in central part of small granitic dike which intersects gneiss-granite.

border of the intrusive body, where migmatitic gneiss is broken up and intruded by quartz monzonite. Quartz fillings and local porphyroblastesis may relate to earlier epochs. The xenolith of mica-rich, dark amphibole rock is considered to stem from dolerite dike which must have been present

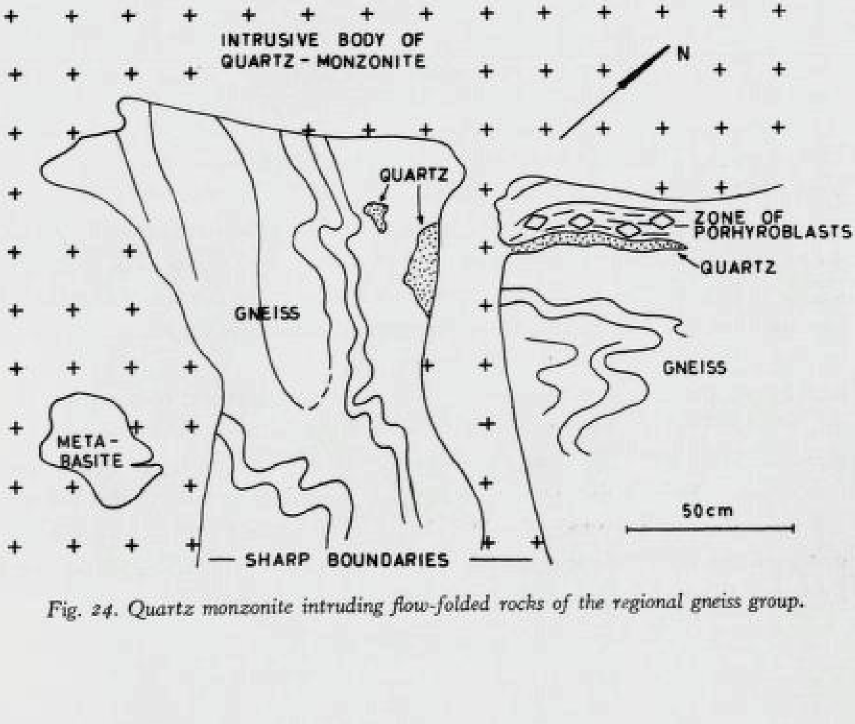


Fig. 24. Quartz monzonite intruding flow-folded rocks of the regional gneiss group.

Fig. 25. Patch of granite in flow-folded migmatitic gneiss.

in the gneiss prior to the quartz monzonite intrusion. A local zoning is seen in the quartz monzonite parallel to the outline of this basic fragment.

Locality 9G/144 is situated in the zone of transition migmatite, about 5 km west of Sandnes. Good outcrops in a river bed show dark and light banded, flow-folded gneiss. The rock is medium to coarse-grained, and has in places a more homogeneous, granodiorite-like appearance. What makes this locality particularely interesting is the appearance of smaller and larger patches of fine-grained, homogeneous granitic rock within the migmatitic gneiss. This granitic rock has the same grey colour as the migmatitic gneiss. By close examination it is seen to form discordant boundaries against the gneiss, but no impression is left of the granite representing foreign material which has been intruded into the migmatitic gneiss from some distant source. Fig. 25 shows the relation between folded gneiss and homogeneous, more fine-grained granite.

Specimens were collected from either side of the boundary drawn in Fig. 25, and examination of thin sections showed that whereas the «gneiss» has a quartz-dioritic composition, the «granite» is a real granite by composition. Although not very accurate (due to small counting areas), the results of modal analyses of the two rock types, presented in Table IIX, express this marked difference in mineralogical composition.

Table IIX.

Modal analyses of «gneiss»-A, and «granite»-B, at 9G/144.

Specimen No.	Plag.	Quartz	Microcline	Biotite	Rest	Counts.
9G/144A	53	36	6	4	1	600
9G/144B	24	30	39	3	4	700

The «gneiss» has a heteroblastic texture where bigger grains of quartz and plagioclase, 1—3 mm wide, are surrounded by distinctly smaller grains of the same minerals. Biotite shows sub-parallel orientation. Microcline occours in small patches within some plagioclase grains and is occasionally found as anhedral grains, intergranular between quartz and plagioclase. Most of the plagioclase grains show no distinct twinning. Some sericite is present. Zircon, sphene, and epidote are accessories. The «granite» has a granoblastic texture, the grain boundaries frequently being sutured. Microcline shows grid twinning and is sometimes perthitic. In this fine-grained mass, some bigger plagioclase grains are embedded. These are, as a rule, full of inclusions of muscovite. Accessories are scarce.

Plagioclase composition was determined for both rock types. A number of grains were measures in each thin section.

9G/144^A: 20—25, 25—30, 25±, 25—30, % An in plagioclase.
9G/144^B: 25±, 35±, 25—30, 25, 25—30 « « «

The results do no indicate any marked difference in plagioclase composition between the two rock types.

The patchy and irregular occurence of «granite» within migmatitic gneiss which display all signs of having at one time been under near anatectic conditions, leads to the assumption that the «granite» represents metasome which was squeezed out of the flowing anatectic gneiss and formed local accumulations within its actual milieu of formation. To some extent, solid crystals of plagioclase and biotite contaminated the mobile metasome. It is possible that the locality 9G/144 in fact represents an embryonal state in the development of granodiorite and quartz monzonite.

Red colouring of Rocks along fissures.

A conspicuous feature encountered in all parts of the mapped area is the strong red colour associated with many joints and larger zones of fracture. Small fissures of 1 mm width, filled with chlorite, epidote, etc., are often accompanied by a band, 5—10 mm wide, of red coloured rock, running symmetrically along the fissure. Major zones of late tectonization are often characterized by patches, several meters wide, of equigranular quartzofeldspatic rock of a strong red colour. The rock adjacent to these zones are also coloured red, the intensity decreasing uniformly on passing away from the zone. This phenomen seems to occur regardless of the fractured rock being gneiss, gneiss-granite or granodiorite.

Microscopic examination of thin section and rock powder of a red coloured gneissgranite, sp. 9E/106^x, shows that the red colour arises from a clouding of the plagioclase of the rock. The plagioclase grains are full of tiny, brownish inclusions which, as a rule, are evenly distributed throughout the grain, although a certain tendency towards concentration along (010) planes is evident in some grains. The inclusions are reddish brown, anisotropic, of irregular shape and less than 0.05 mm wide. The nature of these inclusions has not been proved, but hematite is suggested as the more probable mineral. Puzzling is the fact that microcline, which occurs in considerable amounts as fresh, anhedral grains, interstitial to the other minerals, are completely devoid of these inclusions.

In an experiment the clouded plagioclase of sp. 9E/106^x was heated for 4 days at 1000 °C. No effect could be observed with regard to the inclusions.

Presence of hematite inclusions in feldspar has been explained in two ways:

1. Exsolution of iron incorporated in the feldspar lattice during crystal growth, brought about by aluminium metasomatism or partial removal of alkalis (Rosenqvist, 1951).
2. Secondary introduction of the clouding substance from some source outside the feldspar grains. (Polderwaart and Gilkey, 1954).

Neither of these two explanations permits an immediate disregard of the phenomen observed in the Neiden area as irrelevant to the genesis of the granite complex.

If the clouding substance was introduced along fractures during the late tectonization, it is difficult to understand why the microcline has not been clouded in the same way as the plagioclase. There are no indications of the microcline in the redcoloured zone being any different from that of the gneissgranite further away from the fissure, and, as it is difficult to imagine a mechanism whereby introduction of the clouding substance into solid plagioclase would leave the microcline entirely unaltered, this hypothesis implies that the granitization leading to the present gneissgranite took place *after* the fissure-formation. This would mean that the granodiorite was consolidated and capable of fracturing long before the gneissgranite was granitized. On these grounds the hypothesis must be rejected.

The first mentioned origin of the inclusions seems to be more plausible. It is possible to imagine how local metasomatic processes took place along the newly formed fractures, causing a precipitation of the iron which was previously held in solid solution in the plagioclase lattice. If the microcline had no iron in solid solution, there is no reason why it should be influenced by this process. It is not readily understood, however, how be it that the plagioclase of the gneiss, as well as that of the gneissgranite and the granodiorite do all have the same high content of iron in solid solution. If this is really so, there is still another indication that the different rocks of the granite complex are of common origin, and that the processes of transformation which are responsible for their present individuality have not really been very radical. Another implication is that microcline must have crystallized under conditions different from those under which plagioclase formed.

REMARKS ON STRUCTURAL GEOLOGY

From investigation in the Bjørnevatn area, Wegmann (1929) and Bugge (1960) concluded that, in detail, the structure is very complex. In the present area this will be even more so, and in this work no attempt has been made of applying structural analysis to the problems of the development of the granite complex. On the other hand, as no clear petrographic difference could be recognized between many of the rocks within the mapped area, their structural properties on a mesoscopic and on a regional scale were emphasized as a means of distinguishing between them. For drawing conclusions concerning the development of the granite complex, the major structural features of the area and information on the structural relationship between the various rock types, are to be considered.

Primary structures.

Apart from the dike forms, no obviously primary structures are met with in the granite complex. It is assumed, however, that the quartz-banded iron ore, which on a regional scale forms continuous zones, often accompanied by amphibolite, in the gneiss outside the granite complex, represents one stratum-or several strata — in a primary, sedimentary-volcanogenic sequence. As no other stratigraphic entities are recognizable in the gneiss series, this «iron formation» becomes of great importance as a leading horizon, outlining the structural state of the primary gneiss series.

Also within the granite complex, the iron formation or its transformed equivalents are highly valuable as a means of tracing the continuation of the regional gneiss series and for it recognition as raw material for the present granitoid rocks.

Secondary structures.

The multitude of structures on a mesoscopic scale. which are encountered within the mapped area, are obviously secondary, being imprinted during the regional metamorphism and the evolution of the granite complex.

The s-surfaces of the gneiss are best understood as an axialplane foliation, formed during the regional folding about an axis NV-SE. This structure was imprinted prior to the formation of the granite complex.

The rheomorphic folds of the migmatite were formed contemporaneously with the coming into excistence of the granodiorite. This very complicated structural pattern represents a transitional stage between normal, foliated regional metamorphic gneiss, and massive granodiorite where practically all directional structures have been annihilated.

The s-surfaces of the gneissgranite may be a feature inherited from the regional gneiss, or it may have developed through flow-movements of gneissgranite during the formation of the granite complex. Observations of relict amphibolite bands in foliated gneissgranite indicate that also these s-surfaces represent an axial-plane foliation.

One very interesting structural feature is produced by the ultrabasic dike which intrudes the gneissgranite in the central part of the granite complex. The dike has a fold-like shape, and the strike of the surrounding gneissgranite is parallel to the axial plane of this fold. It is interpreted as an intrusion of ultrabasic magma into a tension-fissure, formed normal to the strike of the gneissgranite as this moved viscously during the period of formation of the granite complex. This assumed granular flow of the gneissgranite towards north, must have continued after the intrusion of the peridotitic magma, thus moulding the dike into its present shape. Such a flow along an anti-clockwise curving flow-line, as expressed by the strike of the gneissgranite in this area, would also account for the observed narrowing off of the westerly limb of the fold-shaped dike.

The strike of the gneissgranite group continues through the granite complex, its track having the shape of an S, tilted towards east. This general trend is modified by the presence of the central granodiorite massif and other local deviations, particularely in east and southeast. In the east-southeast area the strike seems to turn SW-wards, paralleling the assumed boundary of the granite complex. What are now gneissgranite group rocks must have lost connection with the regional gneiss through the development of completely mobile granodiorite bodies along the northern border zone, and it seems as if these disconnected gneissic rocks were subjected to a kind of laminar or granular flow within the granite complex. Attention is drawn to the geological map, where massive granite or augen-granite variants of the gneissgranite occur in the areas of compression with regard to the S-shaped fold structure.

What is said above should not distract attention from the fact that the structural relations are very complicated, and that much more work must be done in order that the history of deformation of the granite complex may be reconstructed.

PETROGENETIC CONSIDERATIONS

In the previous chapters, field observations have been presented with a supplement of results from standard thin section examination and some chemical analyses. Through modern granite research, numerous methods and lines of investigation are available for the further accumulation of relevant data, but, so far, no particular procedures have pointed themselves out as definitely superior in all cases. The next step in this study should be, therefore, to select those lines of investigation which are likely to yield results of maximum significance for this particular geological situation, and to perform investigations along those lines.

For this purpose of choosing the appropriate methods of further investigation, it might be wise at the present stage to review the knowledge already accumulated, of the Neiden granite complex. If, from this excisting information, a set of hypothetical genetic models could be developed, the subsequent problem would be the rather tangible one of seeking the more probable hypothesis among a set of possible hypotheses.

The Neiden granite complex is a highly heterogenous rock unit. A remarkable, unifying feature is the harmonious relationship among the granitoid rocks themselves as well as towards the country rock. Gradual transitions predominate, and only locally do the granitoids exhibit intrusive behaviour. In some parts of the migmatite-zone, and occasionally in the granitoids, do «T»-intersection of foliation in adjacent inclusions indicate relative displacement in a highly mobile medium. The occurrence of aligned inclusions and dark, biotite-rich shadows in the granodiorite and the gneissgranite indicate that substantial amounts of regional gneiss material have been incorparated in these rocks through assimilation or metasomatic transformation.

The gradual transition: country rock — migmatite — granodiorite or granite has been characterized by Read (1948) as «without doubt one of the most firmly established facts». As pointed out by him, this fact might be interpreted in two ways. Either it shows a relatively unimportant migmatized and an feldspathized zone between the country rock and an intrusive magmatic granite, — or it shows the production of granite from country-rock by the completion of those granitization processes which are seen in a half-way stage in the intermediate migmatite zone.

The metamorphic environment of the granite complex is that of high amphibolite facies. Presence of hyperstene in gneiss outside the mapped area points to even higher metamorphic conditions. This fact, together with the mentioned harmonious relationship between granitoids and country roks, is in support of the view that the granite complex was formed in situ through transformation of pre-excisting regional gneiss rocks. In the opinion of the writer, the phenomena observed in the zone of transition migmatite can only be explained by assuming ultrametamorphic conditions and partial anatexis. As concerns the granodiorite, Read's second interpretation is favoured, picturing a formation through the process of anatexis of gneissic material. Any satisfactory hypothesis should be capable of accounting also for the observed distribution of granodiorite bodies within the complex.

The gneissgranite group is different from the granodiorite by its mode of occurrence, its macroscopic and mesoscopic structure, colour and relation to the country rock. In the border zones of the granite complex a close relationship obtains between gneissgranite and porphyroblastic gneiss. These zones of porphyroblastic gneiss must have originated from common, regional gneiss by some process in the solid state, implying the addition or local enrichment of potassium. The manifestation of such processes in the investigated area forwards the assumption that the gneissgranite group rocks represent only more advanced stages of metasomatic transformation of pre-existing gneiss group rocks. Remnant bands and patches of micaceous amphibolite within gneissgranite corroborate this theory.

The intrusive bodies of quartz monzonite leave no doubt as to their mode of emplacement. Sharp boundaries with chilled margins, apophyses and included fragments of country rock make clear that this rock have ascended to its present niveau as a magmatic melt or a highly mobile silicate/melt mixture. Although plotting near the minimum melting curve in the granite system, the quartz monzonite does not conform texturally with normal two-feldspar granite. The concept of the quartz-monzonite magma as a mash of solid plagioclase and biotite grains in a juice of granitic melt, is favoured by the writer, because in this way field observations as well as certain textural peculiarities get their simple and natural explanation.

As distinct from the dolerite dikes, the occurrence of the ultrabasic dike in the central part of the granite complex seems to be in some way related to the evolution of the granite complex. Provided the interpretation previously given to the structural relations between the dike and the surrounding gneissgranite (p. 59) is correct, the dike must have intruded at a late stage of the granite complex development, but certainly before the laminar or granular flow of the gneissgranite came to and end. Maintaining that partial anatexis played a part in the development of the granite complex, it is an interesting proposition that the ultrabasic material of this dike represents the paleosome remaining after the rising to higher levels of the granitic metasome. It is conceivable that this mafic residuum ultimately aquired sufficient mobility to enable it to flow into an opening tension fissure.

It is the writer's opinion that neither a purely magmatic nor a purely metasomatic model can be made to account for the totality of features of the granite complex. Rather than indulging in the development of mutually exclusive hypotheses based on magmatic and metasomatic principles respectively, it is proposed here to search for one single, compromising model for the genesis and evolution of the Neiden granite complex.

Although it is evident that, at the present stage, the genesis of the Neiden granite complex cannot be fully understood, the following model is suggested as a working hypothesis.

A genetic model.

In a geosynclinal phase, sediments and volcanics of the Bjørnevatn group were deposited on an older basement of granitic gneisses. The orogenic development led to regional metamorphism of the supracrustals in the amphibolite facies. Through regional folding about an axis NW-SE and subsequent folding about the direction WSW/ENE, culminations were created, where the granitoid basement beneath the Bjørnevatn group was raised to relatively high positions. In Fig. 26 the supposed anticlines of the two directions of folding are indicated. Culminations of the granitoid basement are expected at the intersections of the lines.

The development of the granite complex cannot be explained without assuming a higher influx of thermal energy to the granite complex area than to the surrounding areas. A «heat dome» is therefore postulated, its center being situated in the central part of what is now the Neiden granite complex. Hypothetical isotherms are shown in Fig. 26. Through recent geophysical measurements, the existence of such local anomalies in the distribution of thermal energy in the earths crust seems to be an established fact (Boldizar, 1964, in Winkler, 1965).

The introduction of thermal energy was sufficient to rise the temperature above the minimum melting temperature at the deeper levels of the granite complex area, causing a partial melting of the granitoid basement underlying the Bjørnevatn group. Those basement-culminations which were properly located within the «heat dome» would be the loci of initial melting at their high level, and due to the increased mobility in a crystal/melt system in comparison to a wholly solid system, the thermal energy was preferably led upwards around these loci. The preferencial supply of thermal energy to these areas had as its consequence a partial melting of the overlying Bjørnevatn material. As seen from Fig. 26, the distribution of granodiorite bodies are accounted for. The size of the bodies would be a function of the supply of thermal energy, it is therefore expected to find the larger bodies in the central parts of the »heat dome».

By occurrence of a certain amount of anatectic melt the gneisses were transformed into a completely mobile mash of crystals and liquid, in which homogenization of the primary gneiss structures was easily accomplished through short-range relative movement of the individual crystals. In the transition zone, only small amounts of intergranular melt was formed,

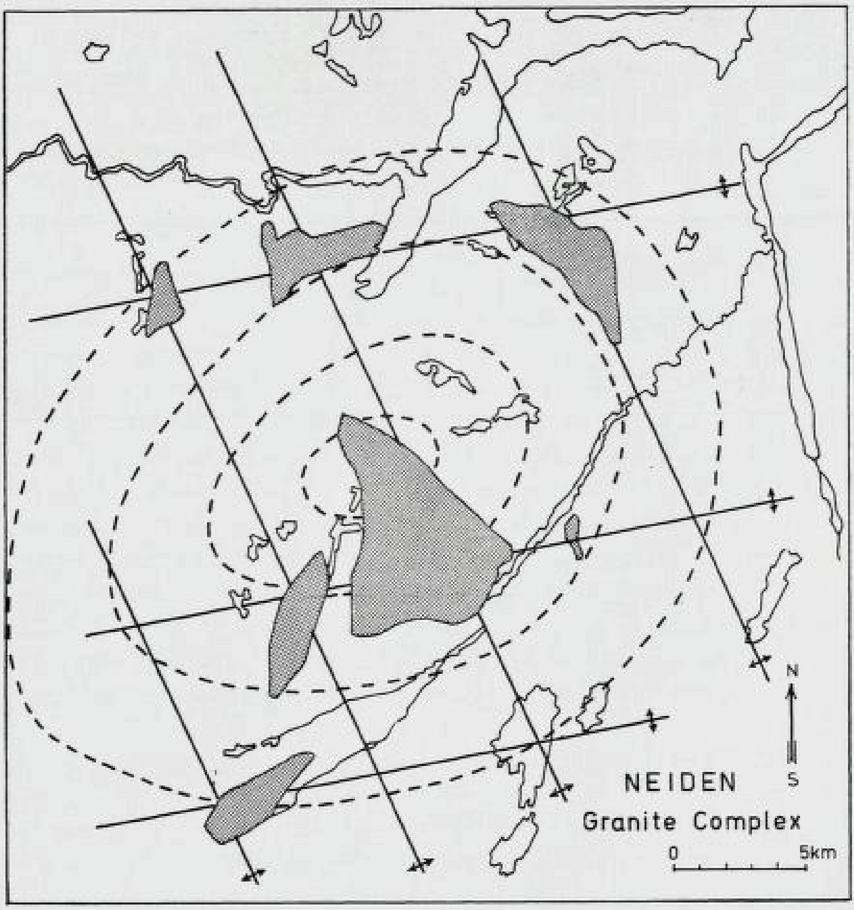


Fig. 26. Schematic superposition of «heat dome» on a system of two fold phases, an attempt to explain the distribution of granodiorite bodies (gray) within the Neiden granite complex.

sufficient to give the rock plastic properties but at the same time insufficient to permit homogenization of all primary structures.

The introduction of heat probably had the character of an invasion of emanations or highly mobile phases, which apart from thermal energy also carried potassium and other highly mobile constituents from the deeper levels. Observations recorded in the preceeding indicate that such a potassium-rich mobile phase has been active in the border zones of the granodiorite, provoking microcline porphyroblastesis in the country rock as well as in the adjacent granodiorite.

As a result of the development of granodiorite bodies along the boundary of the present granite complex, large areas of Bjørnevatn group rocks were more or less cut off from the gneiss outside the granite complex. These rocks were still in a solid state, but having lost their regional connection, they yielded more easily to local tectonic forces, and through the combined effects of granular flow and pervasion of ascending emanations from the underlying, remelted granitoids these rocks gradually became homogenized and were transformed to the various members of the gneissgranite group.

Towards the end of the flowing movement of the gneissgranite, a tension fracture did form, normal to the direction of flow, in an area to the west of the central granodiorite body. At this late stage of the evolution of the granite complex, the metasome had already ascended from the level of anatexis, causing a granitization of the overlying rocks, while the mafic paleosome was left behind. A portion of this somewhat mobile paleosome was squeezed into the opening fissure in the gneissgranite, producing the present ultrabasic dike. Through continued viscous flow of the gneissgranite, the ultrabasic dike was deformed into its present shape.

As a consequence of the moderate tectonic movement accompanying the development of the granite complex (manifested in the flow folding of the migmatitic gneiss and in the granular or laminar flow of the gneissgranite), squeezing out and local concentration of granitic melt took place in the migmatitic gneiss; and where considerable quantities of melt accumulated, it was capable of ascending as a magma or a highly mobile silicate/melt mixture. This magma intruded the overlying gneissgranite as a late feature in the development of the granite complex, producing the intrusive bodies of quartz monzonite. In the final stages of its evolution, the granite complex suffered irregular retrograde metamorphism, with epidote formation and partial transformation of biotite to chlorite.

FURTHER INVESTIGATIONS

The proposed genetic model serves the purpose of a working hypothesis rather than being a final conclusion. It immediate function is to provide a frame of reference for the further investigations, which may now be focused on the cruxial points of the model. Essential to the proposed genetic model are the following questions: 1) Can the presence of regional gneissmaterial in the granite complex rocks be proved or disproved? 2) Are such processes possible which would bring about the assumed transformations (including metasomatic changes) of the regional gneiss rocks into the rock types of the granite complex, and what is the nature of these processes?

Concerning the first question, search for mineraliogical and chemical relics from an earlier gneiss stage in the different granitoids might yield conclusive evidence. Studies of the morphology of zircons, and of the spatial variability of quantitative, petrographic and chemical variables are considered to be among the most forceful tools for the handling of such problems.

When it comes to the second question, the situation is far more confused. Although important experimental data are accumulating (e. g. Tuttle and Bowen (1958), Orville (1962), Winkler (1965)), there is apparently a long way to go before the true nature of the complex crustal metabolism under ultrametamorphic conditions is fully understood. Because of the ambiguity inherent of nearly all observed facts, it is no easy task to devise methods of further investigation, which are likely to lead to conclusive statements concerning the genesis of the rock types of the granite complex.

It is generally realized that the feldspars represent an important source of information about the mode of formation and subsequent development of the rock in which they occur. An expression of this was the Advanced Study Institute of Feldspar, Oslo 1962; this authoritative meating leaving, however, a rather strong impression of the study of feldspars not yet being readily applicable to the solution of petrogenetic problems.

Similarely, the textural features of granitoid rocks obviously have considerable bearing on the rock-forming processes, but neither can this field of study offer much unambiguous, factual information at the present stage.

In the proceeding, an account is given of the results of some tentative investigations along the lines mentioned. The performed studies are highly preliminary, and the potentialities of the methods in question are by no means fully exploited, the intention being merely to discuss the applicability of the methods to the present geological situation.

Zircon studies.

Zircon has a wide distribution as an accessory constituent of many rocks, and because of its high melting point and extreme resistance to both chemical and mechanical attack, it is able to survive most metamorphic processes as solid crystals. The works of Poldervaart (1950), Poldervaart and Eckelmann (1951), Hoppe (1963), Schidlowski (1963), Frasl (1963) and others, have shown that statistical evaluation of the morphological properties of the zircons in heavy mineral concentrates from crushed rock samples permit conclusions to be drawn regarding the origin of the rock material in ultrametamorhic or «pseudo igneous» rocks. Not only does the prevalency of zircons with sedimentary relic-structures prove beyond doubt the sedimentary derivation of the material in question, but secondary overgrowths in the form of a transparent shell of newly added zircon material, and the habitus and length breadth ratio of the crystals might reveal the nature of those processes whereby the rock achieved its present character.

For the genetic problems encountered in the Neiden area, this method appears to be very useful. In the present work, only some introductory investigations were done. Heavy mineral consentrates were obtained from specimens of granodiorite, augengranite, augen-gneissgranite and quartz monzonite. The granodiorite and the quartz monzonite produced very few grains of zircon by the employed, rather crude procedure of crushing and sedimentation in methylene iodide, and nothing can be said about the zircons of these rocks without further investigations. The rocks of the gneiss-granite group yielded heavy mineral consentrates rich in zircon, and, although no statistical work has been done, some of the observed features may be of significance: Most grains are euhedral, many of them being brownish and full of dark impurities. A considerable number of colourless, inclusionfree crystals are also encountered. In some grains, an older clastic zircon-nucleus is overgrown with a thick coating of colourless zircon, producing stubby prisms with bipyramidal terminations. From these fragmentary observations, no conclusions can be drawn. It seems, however, as if the method is well applicable to the present genetic problems, and important information is antecipated from a thorough study of the zircons in the various rocks of the Neiden granite complex.

Geographical areal variation.

The considerable inhomogeniety of the sundry rock types of the Neiden granite complex is evident already by visual inspection, and in light of this, quantitative data from scattered localities within the granite complex cannot be accepted as representative. Even if reliable mean values could be provided and were plotted on e. g. ternary diagrams without reference to geographical location, such information would be not nearly as significant in the present geological situation as information on the spatial variability of the geological variables.

In the last decade there has been a growing interest for methods whereby the spatial variability of quantitative, geological variables may be assessed, see review by Whitten (1963).

In the course of the present investigations, the Munkefjord-Sandnes subarea presented itself as a geological situation where the application

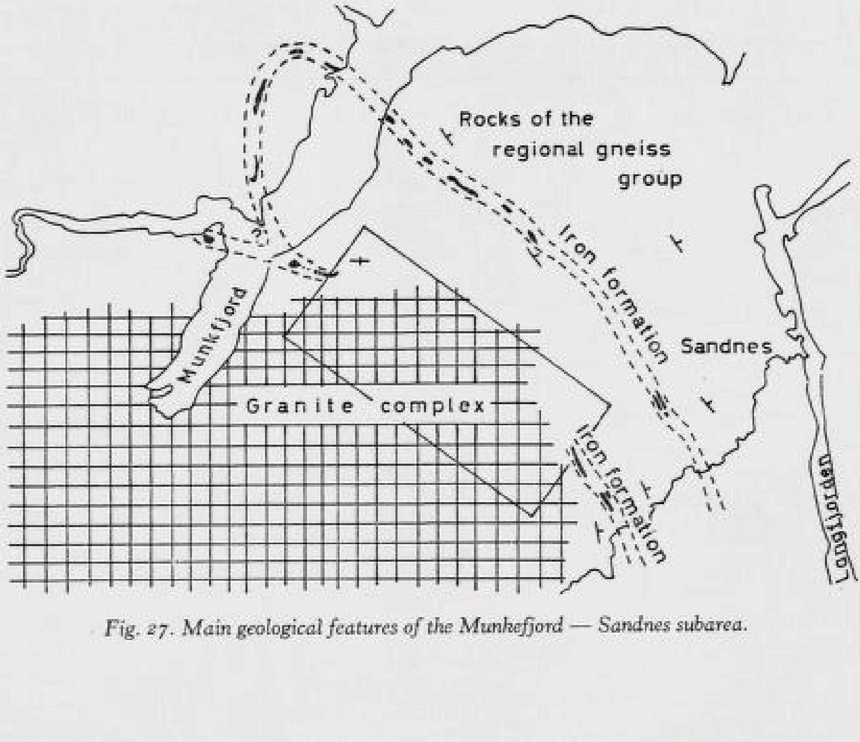


Fig. 27. Main geological features of the Munkefjord — Sandnes subarea.

of such methods seemed particularely promising. Fig. 27 emphasizes the main geological features of this area. Within the regional gneiss series to the northeast of the granite complex, a more or less continuous stratum of iron formation runs in the direction NW-SE. Similarely, both northwest and southeast of the Munkefjord-Sandnes granodiorite, aligned occurrences of iron formation point to the existence of another band or stratum of iron formation, running parallel to the first one and passing through the area which is now occupied by granodiorite. In this situation, an investigation of the areal variability of the iron content in the granodiorite was considered to have significant bearing on the proposed genetic model. This model postulates the formation of the granodiorite by a more or less in situ transformation of regional gneiss. The area marked with a rectangle in Fig. 27 was subjected to an areal variability investigation. The 21 sq. km large area was subdivided into 84 squares, each of the size 1/4 sq.km. and during a field operation in September 1964, one specimen was collected from each square, the specimens being taken as near to the center of the square as possible. The location of a specimen is referred to as a sample point. Additional to the collections of specimens, magnetometer readings were taken and background radioactivity measured at each sample point. A field name was also assigned to the rock at every locality.

The location of sample points are shown in Fig. 28 a. Due to overburden and numerous small lakes, the desired sample point location was

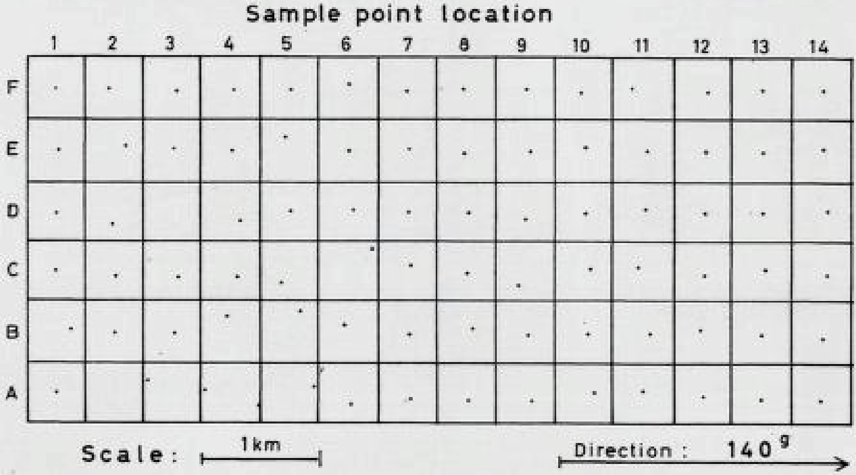


Fig. 28a. Location of sample points in the Munkefjord — Sandnes subarea.

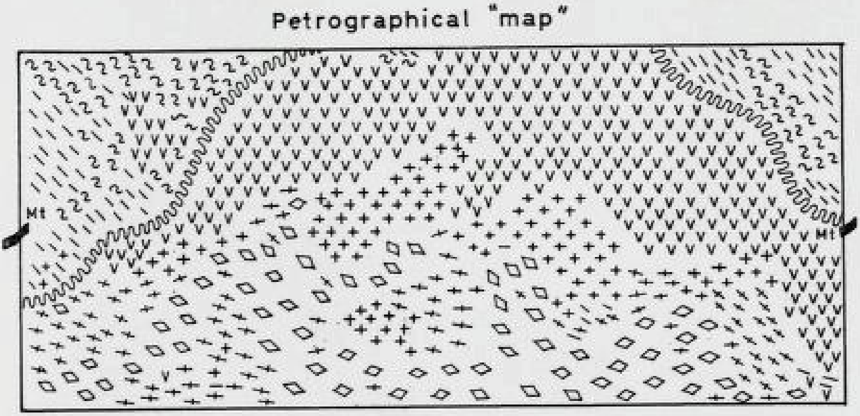


Fig. 28b. Petrographical «map» of the sampled area, constructed from records of rock name at every sample point.

not always achieved, but in general the distribution of the sample points is regarded as quite satisfactory. In the case of square D 3 no specimen could be taken because the entire area was occupied by water and thick glacial covering. Fig 28 b is a petrographic «map» of the investigated area, constructed from the records of rock name from every sample point. Attention should be called to the fact that the specimens collected in this way do not represent a random sample in the strict statictical sence, but could, according to Link and Koch (1962, p. 412) better be called «haphazard» samples. This means that statistical validity cannot be claimed right away for the results of the subsequent trend surface analysis, which presupposes data drawn at random. Before much more experience is accumulated, concerning the application of this kind of methods to geological populations, nothing can be said about the possible influence on the final results of using «haphazard» instead of random samples.

A total of 83 specimens were collected, and in all of them Fe total, K_2O and Na_2O were determined by titration and flame photometry respectively. Table IX presents these results together with the scintillometer readings in the field, for every sample point.

Table IX.

Quantitative geological variables determined for all sample points in the Munkefjord-Sandnes subarea. Coordinates relate to Fig. 28 a.

Sample point	Total Fe %	K_2O %	Na_2O %	Background radioact. mR x 1000
A 1	3,61	5.75	3.52	19
A 2	3,64	5,46	3,24	17
A 3	3,72	5,04	3,29	17
A 4	4,14	5,26	3,29	19
A 5	4,26	5,00	2,94	19
A 6	4,41	5,13	3,24	20
A 7	4,40	5,20	3,27	19
A 8	4,25	5,15	3,10	17
A 9	4,11	5,31	3,10	19
A10	4,18	5,87	3,20	19
A11	3,82	4,95	3,31	21
A12	3,53	5,43	3,16	19
A13	3,57	4,89	3,04	19
A14	3,63	5,33	2,20	19
B 1	3,78	5,31	3,16	18
B 2	3,69	4,79	3,19	18
B 3	3,67	4,83	3,23	21
B 4	3,72	5,14	3,11	19
B 5	3,68	3,07	2,94	24
B 6	3,48	5,48	3,17	18
B 7	4,00	4,89	2,84	19
B 8	3,92	6,04	3,41	19
B 9	6,35	5,12	3,51	18
B10	4,30	5,09	2,65	19
B11	4,20	5,26	4,02	19
B12	5,36	3,65	3,15	14
B13	4,95	4,17	3,18	14
B14	6,37	4,26	3,06	12

Sample point	Total Fe %	K_2O %	Na_2O %	Background radioact. mR x 1000
C 1	3,88	5,20	3,09	17
C 2	6,28	4,07	3,11	15
C 3	3,81	5,51	2,78	17
C 4	3,83	5,04	3,16	23
C 5	4,07	5,18	3,20	22
C 6	4,18	5,22	3,18	18
C 7	3,59	5,48	3,14	22
C 8	3,38	4,82	3,44	18
C 9	5,78	6,67	5,11	21
C10	5,26	4,52	3,12	16½
C11	6,15	4,02	3,11	14
C12	5,26	4,21	3,05	13
C13	6,99	4,06	3,06	13
C14	6,39	4,06	3,10	12
D 1	1,61	1,04	5,57	13
D 2	4,81	4,68	3,16	13
D 3	—	—	—	—
D 4	6,00	3,67	3,20	8
D 5	5,04	4,64	2,98	13
D 6	3,74	5,42	3,02	15
D 7	4,71	5,11	3,00	20
D 8	4,81	4,99	2,96	16
D 9	4,71	4,86	3,27	16
D10	6,13	4,57	3,01	14
D11	6,40	4,22	3,11	13½
D12	6,37	4,43	3,17	13
D13	7,20	3,26	3,05	10
D14	1,94	2,24	5,16	5

Sample point	Total Fe %	K_2O %	Na_2O %	Background radioact. mR x 1000
E 1	3,23	1,34	5,37	9
E 2	2,31	0,89	4,51	7
E 3	3,25	1,21	4,86	5
E 4	6,33	4,19	3,14	12
E 5	6,25	4,37	3,21	12
E 6	6,15	4,07	3,24	15
E 7	5,67	4,57	2,96	14
E 8	6,73	4,15	3,06	18
E 9	6,52	4,09	2,36	13
E10	6,38	4,45	3,11	12
E11	6,60	4,28	3,07	12
E12	6,79	4,12	3,03	12
E13	5,02	4,73	3,17	11
E14	1,13	2,58	4,88	5
F 1	3,57	1,99	4,43	7
F 2	2,58	1,74	4,79	6
F 3	2,55	1,22	4,55	5
F 4	2,76	1,21	4,69	6
F 5	2,25	3,57	3,95	10
F 6	6,18	4,14	3,24	14
F 7	6,28	4,12	3,13	12
F 8	6,30	4,14	3,15	12
F 9	6,26	4,06	3,13	14
F10	6,05	4,22	3,14	12
F11	6,74	4,10	3,13	12
F12	5,09	4,49	3,41	12
F13	0,80	1,27	8,01	5
F14	1,46	1,61	5,22	5

Iron content.

Fig. 29 is a contoured map expressing the areal variability of the percentage of Fe total in the rocks of the investigated subarea. A highly interesting feature of this map is the pronounced, ridge-shaped iron-high anomaly, which forms a continuous zone from the outcrops of iron formation southeast of the subarea and extends towards the zone of iron formation in the gneiss northwest of the sampled area. By comparing the isopleth map of Fig. 29 to Fig. 28 b, it appears that the area which is high in iron (> 5%) in fact correlates nicely to the area which is occupied by granodiorite. It might therefore be argued that the granodiorite as a rock type has a higher content of iron than the migmatitic gneiss and gneiss-granite surrounding it, and that the coincidence of the iron-high feature with the expected position of the hypothetical relict zone of iron formation must be disregarded as more or less accidental.

In opposition to this argument stands, however, the fact that there are concentration grandients *within* the granodiorite area, forming a pronounced ridge which outlines the expected course of the relict iron formation and which cannot be explained assuming an origin of the granodiorite as an intruding, homogenous magma.

The writer is inclined to consider the found areal variability of iron content in the investigated subarea as a very strong indication that Munkefjord-Sandnes granodiorite came into existence through processes implying

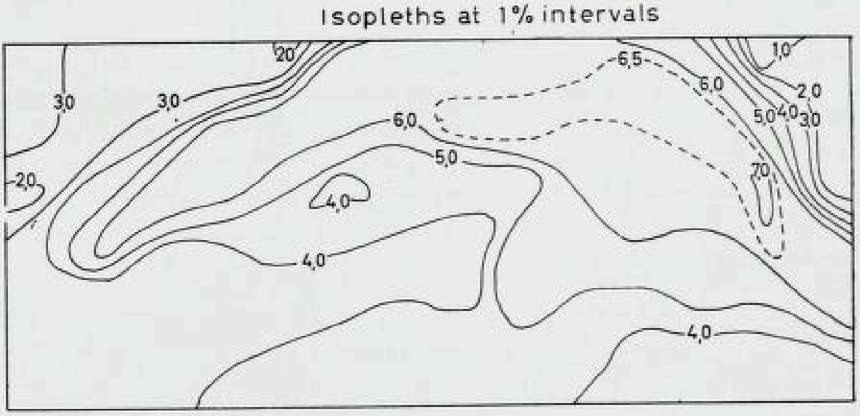


Fig. 29. Contoured map showing areal variability of total iron in the Munkefjord — Sandnes subarea.

partial melting and homogenization, or assimilation, of rocks previously present as members of the regional gneiss group.

Whichever were the actual processes, it seems that large quantities of the preexisting rocks have been incorporated in the present granodiorite.

Potassium content.

Fig. 30 expresses the areal variability of the K_2O content. There are K_2O-low areas to the north and east (the upper left and right hand corners of the rectangular area), corresponding to the areas of regional gneiss and the zone of transition migmatite. Then comes a wide «plain» where the K_2O content lies between 4.00 % and 4.50 % before the next sharp increase, leading onto the soutwestern «plateau» where the K_2O values vary only in the range 5.00 % to 5.50 % over a wide area. Some local irregularities occur, but the general picture is that of sharply delimited, distinct levels corresponding to 1) the regional gneiss, 2) the granodiorite, and 3) the gneissgranite group.

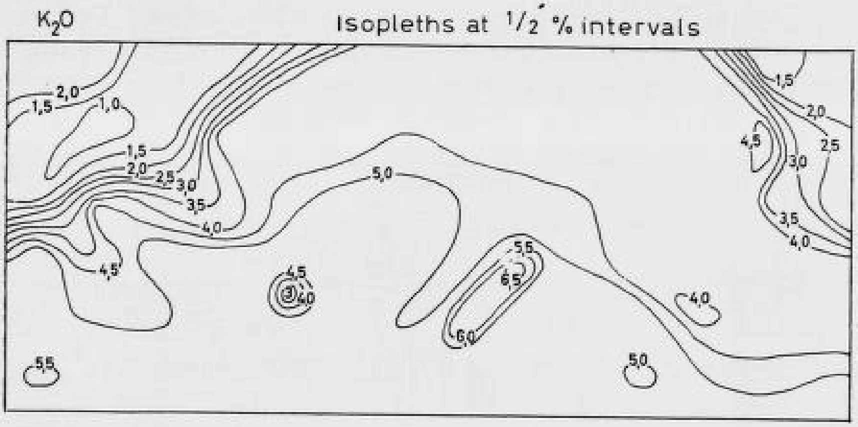


Fig. 30. Contoured K_2O map of the Munkefjord —Sandnes subarea.

Sodium content.

Fig. 31 illustrates the variability of Na_2O content within the investigates subarea. On this contoured map, the gneiss areas protrude as domains of a high and relatively uniform Na_2O content in the upper right

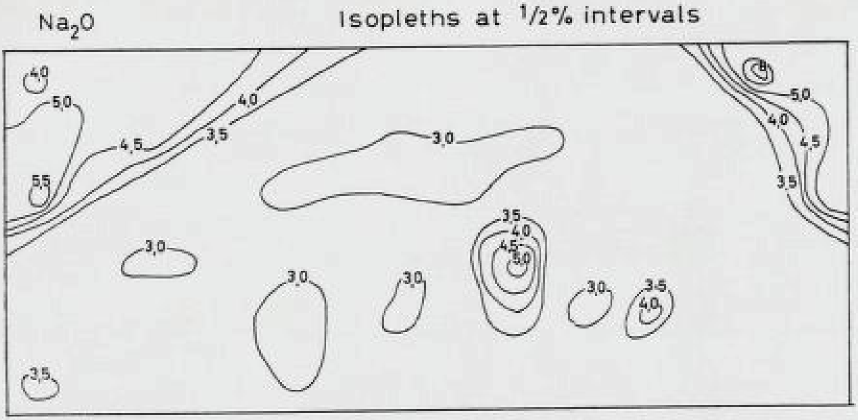


Fig. 31. Contoured Na_2O map of the Munkefjord — Sandnes subarea.

and left hand corners. Here the values vary between 4.50 % and 5.50 %, with local deviations at 4,43 and 8,01 %. From this level, a steep downhill feature, which coincides with the granite complex boundary, leads down into a relatively flat «plain», extending for the remainder of the investigated area. A few extreme values and a shallow, elongated depression, paralleling the strike of the adjacent regional gneiss, are the only irregular features of this 3,00 % $<$ Na_2O $<$ 3.50 % plain, which corresponds to the area occupied by granite complex rocks. The difference between granodiorite and gneissgranite is not reflected by this Na_2O isopleth map.

Background radioactivity.

In Fig. 32 are contoured the values of background radioactivity, measured at each sample point by holding a Precision Scintillator in vertical position, 50 cm above rock surface. All measurement were taken within a period of 14 days, and possible changes in atmospheric radioactivity during this time have been disregarded.

This map exhibits somewhat more irregular variation than do the isopleth maps, and the «topography» is more moderate, lacking the hill and plain-structures of the alkali-isopleth maps. Nevertheless, the 3-level topography of the K_2O-map can be recognized also in the radioactivity map, although very modified. A gradual increase in radioactivity occurs within the granodiorite on the approach of the gneissgranite area. Within the gneissgranite there appears to be a high radioactivity ridge along its border towards granodiorite.

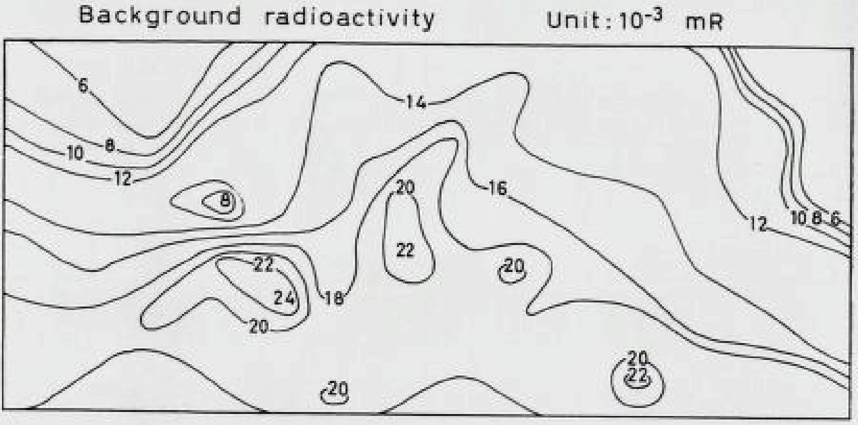


Fig. 32. Contoured background radioactivity map of the Munkefjord — Sandnes subarea. Unit: 10^{-3} mR. Isopleths drawn for every 2½ units.

Taking into consideration the susceptibility of this method of measurement to «noise» of various kinds, the recognizable correlation of gneiss area-low, granodiorite-intermediate, gneissgranite-high radioactitivity must be regarded as an interesting and significant feature.

Trend surface analysis.

The contour maps of the preceding section can be visualized as highly complex surfaces in an U, V, Z, right-angle coordinate system, where U and V are the geographical coordinates and Z represents the dependent geological variable. Several components may contribute to such a surface:

1. A regional trend in the distribution of the variable.
2. Local deviations caused by geological factors.
3. Various kinds of random «noise» in the measured property.

By means of regression analysis, polynominals are fitted to the observed data, and in this way a more or less satisfactory separation of the components 1 and 2 in the above list is achieved. The polynomials correspond to so called trend surfaces, which may be interpreted as more or less correct geometric expressions of a regional trend in the distribution of the investigated variable. Subtraction or the computed trend value from the original value of Z, produces a residual or deviation value, the areal variability of which might express geologically significant features, provided the «noise» level is comparatively low.

Further details concerning the actual computation of trend surfaces of linear, quadratic, cubic and higher degrees by nonorthogonal polynomial analysis are given by Krumbein (1959).

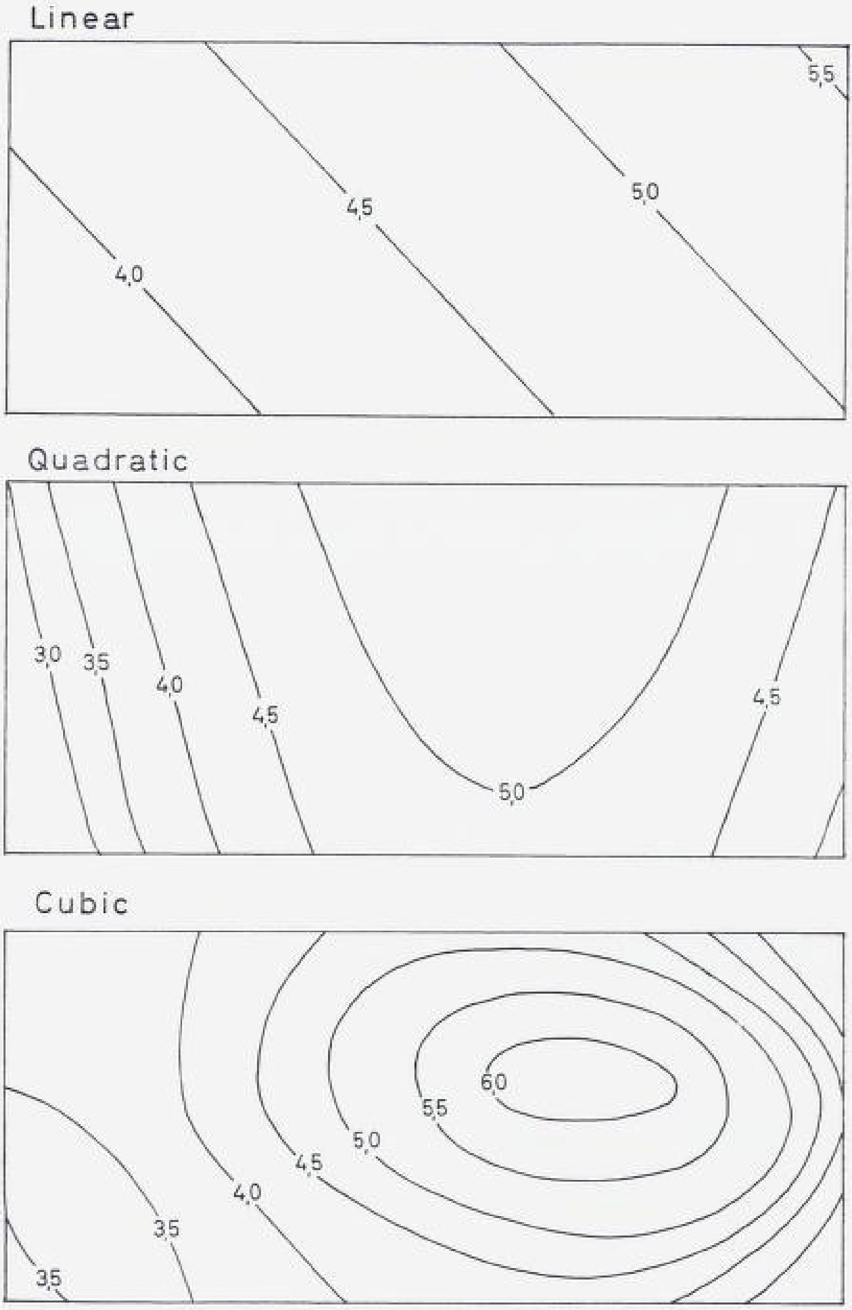
Through the works of E. H. Timothy Whitten (1959, 1960, 1961, 1962 and 1963), and discussions by Link and Koch (1962), and Chayes and Suzuki (1963), the application of trend surface analysis to the study of granitoid masses has received considerable attention. The method represents an interesting approach to the quantitative study of granite massifs, and although several fundamental questions still remain unanswered, the accumulation of «case histories» seems to be desirable at the present stage. It was therefore considered worth while to apply trend surface analysis to the geological data from the Munkefjord-Sandnes subareas.

Fe-data.

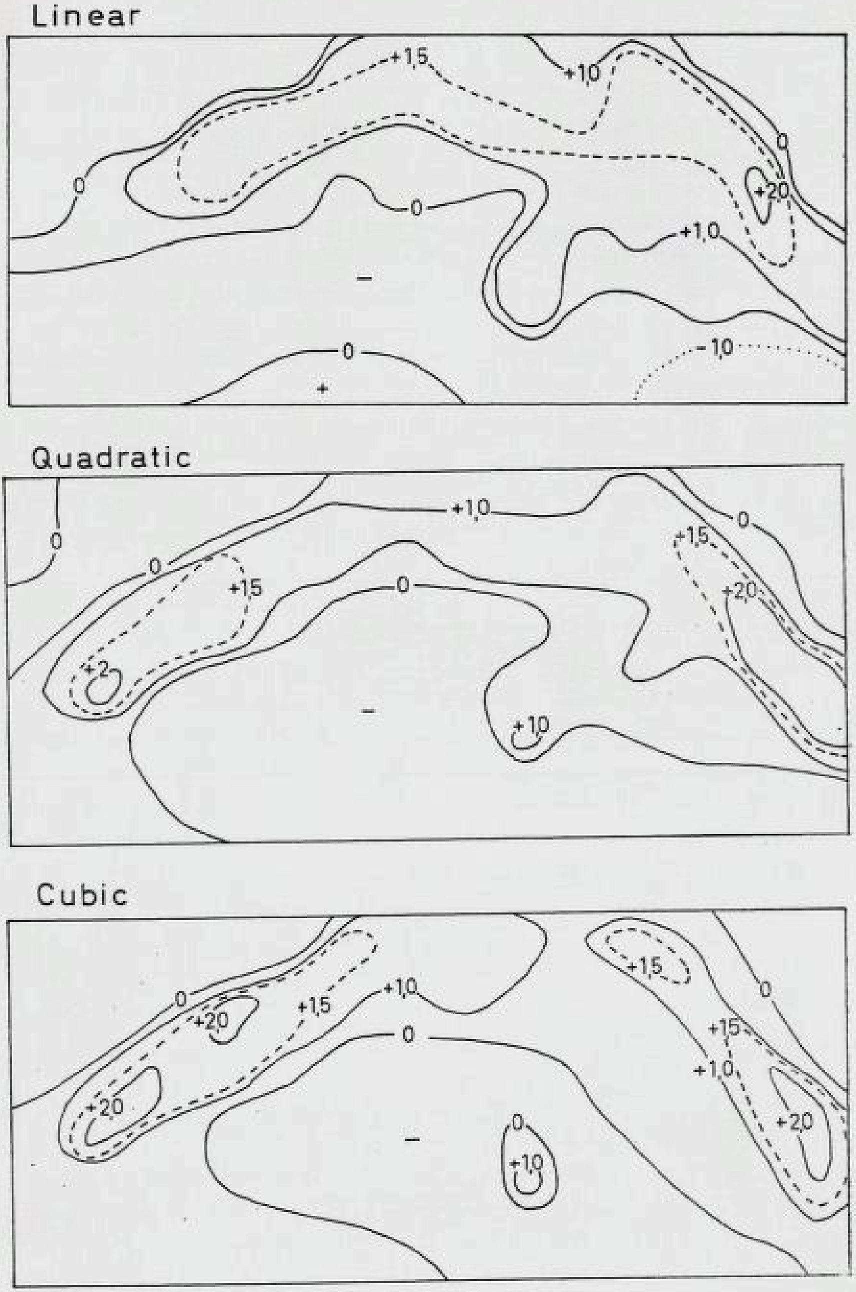
As apparent from the contoured map, Fig. 29. the iron-high anomaly represents a dominant feature of the area under consideration. It is thus to be expected that the computed trend surfaces to a large extend are influenced by this anomaly. This means that in the present case, the trend surfaces cannot be attributed to some significant regional trend in the distribution of iron. In order to find such a trend, the analyzed area would have to be extended, to minimize the effect of the anomaly.

The application of trend surface analysis to such a heterogeneous area, including gneiss, granodiorite and various rock types of the gneissgranite group, might also be objected. Provided that the rocks of the investigated subarea have all evolved from the same regional gneiss series by different processes of transformation, however, there might be reasons to expect that the deviation maps reflect, more or less, the inequalities of the preexisting gneiss group rocks; whereas the trend surfaces tend to express the processes of homogenization and transformation related to the evolution of the granite complex.

In Fig. 33 are presented the linear, linear plus quadratic and linear plus quadratic plus cubic trend surfaces and the corresponding deviation maps for the Fe total data. The iron-high anomaly stands forth on the deviation maps and persists as a significant, positive residual feature even after the cubic trend surface has incorporated a considerable portion of the anomaly. The trend surfaces are clearly influenced by the anomaly, and no regional, geological significance should be attributed to them.



Trends *Fig. 33.*



Linear

Quadratic

Cubic

Fe-data.

Deviations

K_2O-data.

Fig. 34 shows trend surfaces and corresponding deviation maps for first through third degree regression. By comparing the trend surfaces to the geology of the area, it is noted that the trend surfaces express a gradual increase in potassium content of the rocks on passing from the gneiss into the granite complex. The «cubic» surface obviously gives the most correct expression of the regional trend, although there are reasons to believe that the computation of higher degree surfaces might yield even better approximations to the real regional trend. In the deviation maps, no significant features are apparent. The most informative deviation map would be the one that corresponds to the best-fitting trend surface, which in the present case is the one of third degree.

Na_2O-data.

The trend surfaces and deviation maps resulting from the regression analysis of Na_2O-data are presented in Fig. 35. There is a strong negative correlation between the Na_2O trend surfaces and those for K_2O. The strikes of the linear trend surfaces are parallel, the planes dipping in opposite directions. The «cubic» trend surface, which is probably the best expression of the regional trend, differs only little from the «quadratic» surface, both having the shape of a wide trough with steep sides towards the gneiss areas. One remarkable feature, which is hardly discernible in the K_2O trend, is the appearance of an extremum within the investigated area. In the case of Na_2O, there is a shallow domain of minimum values, in the case of K_2O a maximum is indicated, both being located near the middle of the southeastern limitation of the subarea. It is not clear to the writer to which extent these extrema are due to an unfortunate limitation of the investigated area relative to the rock distribution. If, however, these features are geologically real, they do indeed corroborate that part of the proposed genetic model which emphasizes the sites of the granodiorite bodies as centra of major importance in the development of the granite complex.

The deviation maps for Na_2O contain some geologically significant features. The Na_2O-highs corresponding to the gneiss areas are persistant through the regression. The general negative deviation associated with the granodiorite area is an effect due to the very sharp decline in Na_2O

content of the rocks on passing into the granite complex area, and no real difference between granodiorite and gneissgranite is actually recognizable with respect to this variable.

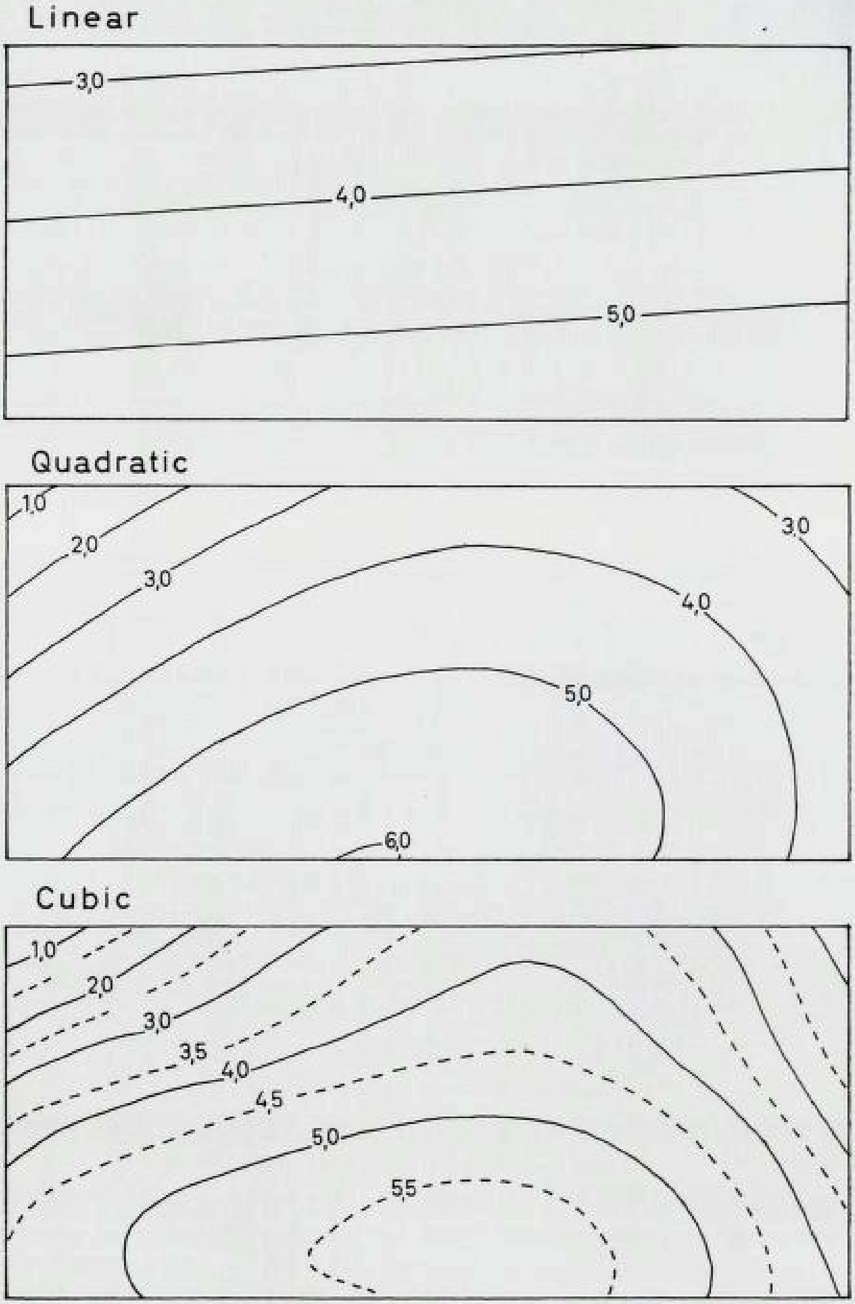
Radioactivity data.

Fig. 36 shows trend surfaces and deviation maps based on the observations of background radioactivity in the field. Surprisingly, the «cubic» trend surface for the radioactivity data is that trend surface which seems to be in best accordance with the expected trend in the process of «granitization», to judge from the geological situation of the subarea. The contours parallel the granite complex boundary, and the elongated shape of the trend surface is in harmony with the foliation of the gneissgranite.

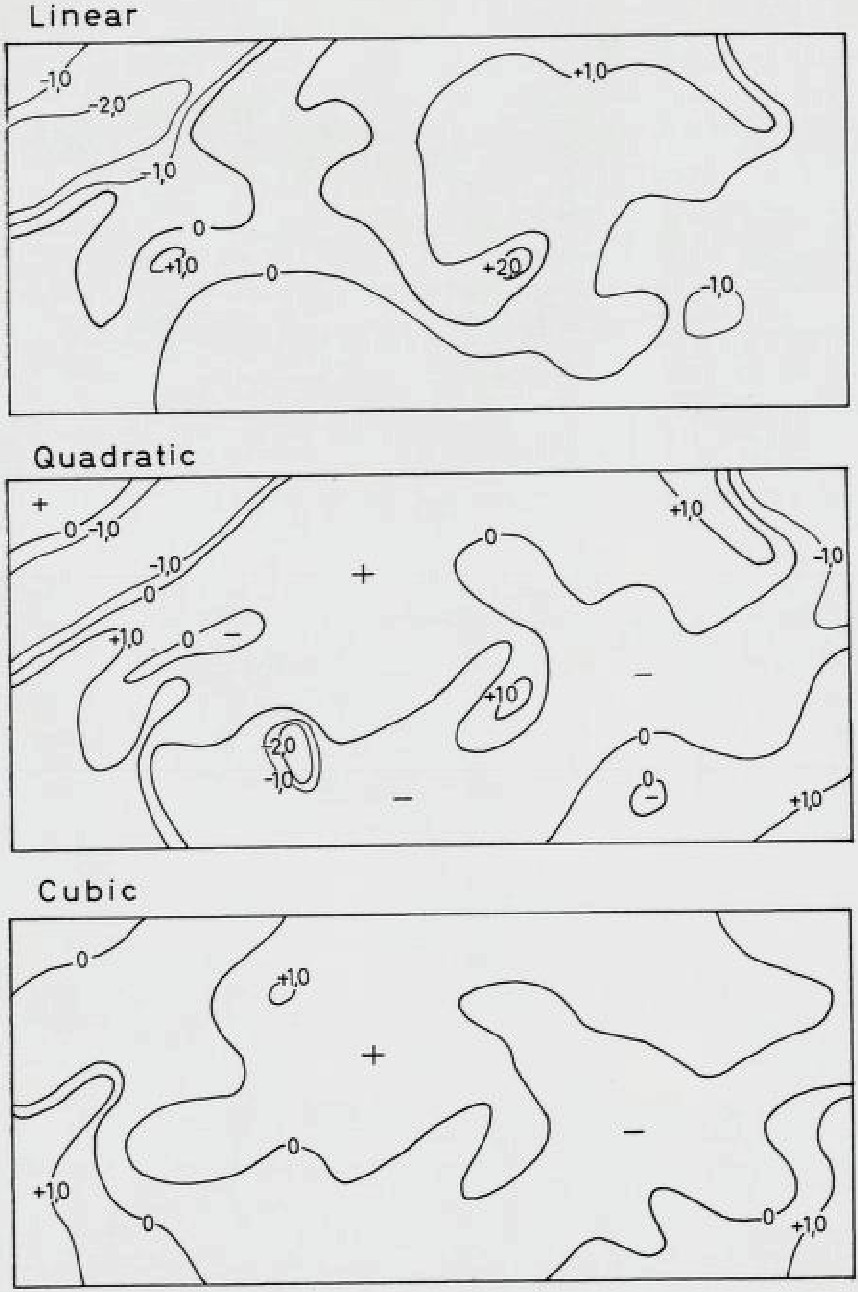
The trend in radioactivity data has many features in common with the K_2O trend, but there is evidently no simple and direct connection between the two variables. This might be explained in several ways. The radioactivity trend might consist of two overlapping patterns, one which stems from the distribution of radioactive minerals in the preexisting gneiss, and another, produced by the radioactive components introduced at the time of formation of the granite complex. If this is so, the younger distribution pattern is apparently dominant, being responsible for the marked similarity with the K_2O distribution. It may also be the case that the distribution pattern expressed by the trend surface is produced entirely by radioactive components introduced during the granite complex formation, only that these components migrated and were precipitated in a way slightly different from that of potassium. The presence of a radioactivity maximum within the investigated area is beyond doubt.

Obliquity of alkali feldspar.

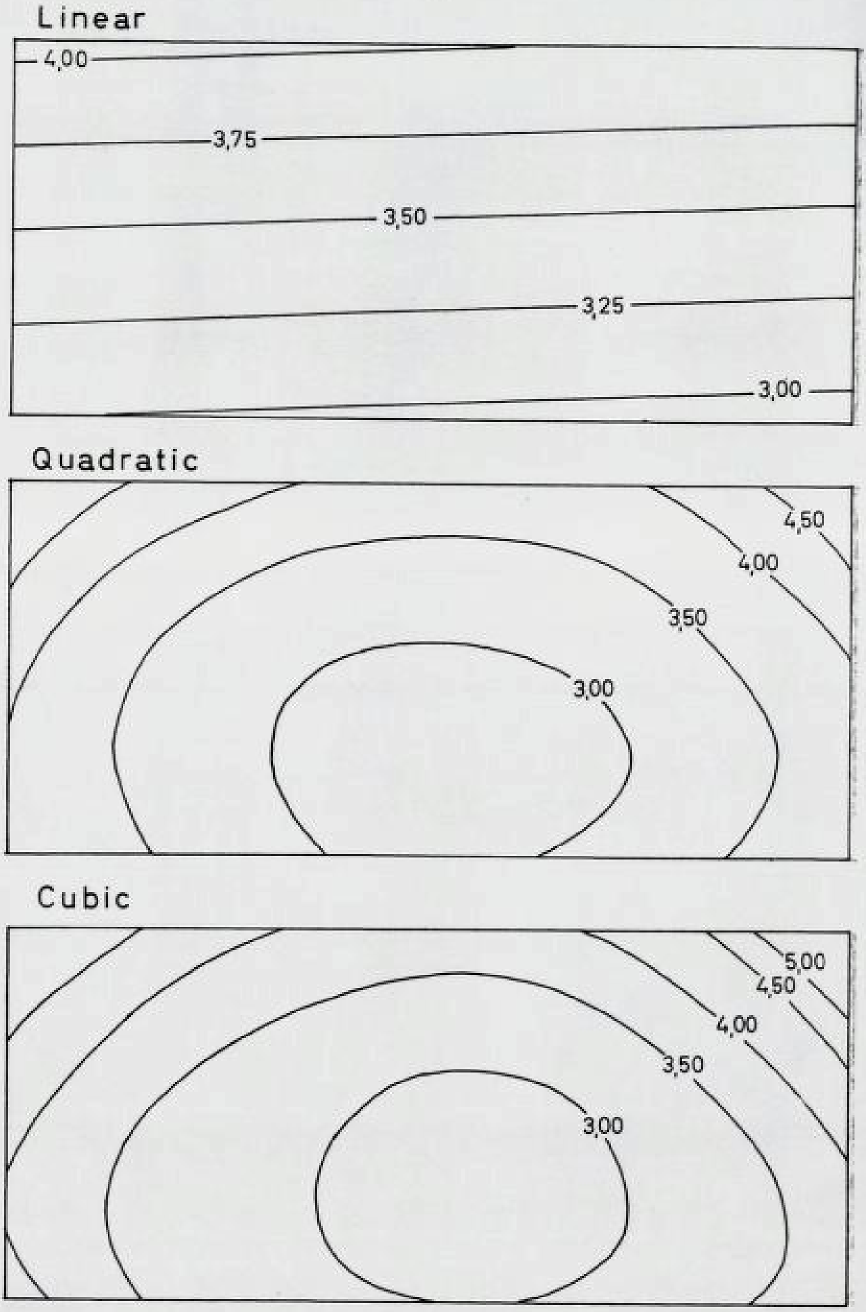
From the collection of hand specimens representing all rock types encountered in the mapped area, 84 specimens were picked out for X-ray investigation of their K-feldspar. This group of specimens include representatives for nearly all granitoid rock types: gneissgranite, granodiorite, quartz monzonite, and also pegmatites, aplites and granitic dike rocks. Specimens of porphyroblastic gneiss from the border zones of the granite complex were also included. The material used for taking powder diagrams was obtained by hand picking, and this has led to a certain preference for rocks with medium to coarse-grained K-feldspar, although a



Trends *Fig. 34.*

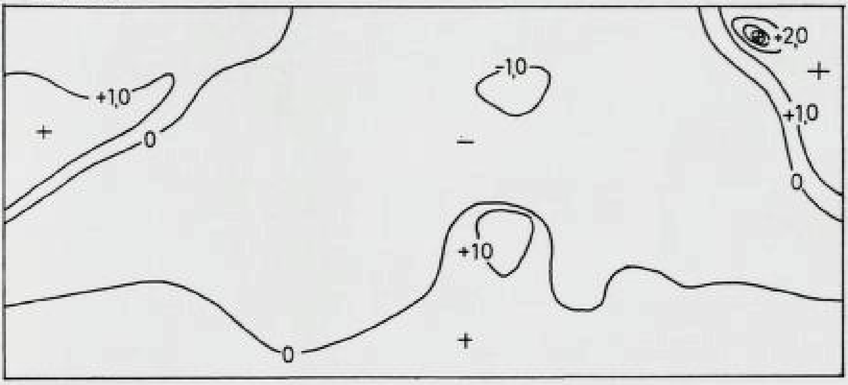


K_2O-data. *Deviations*

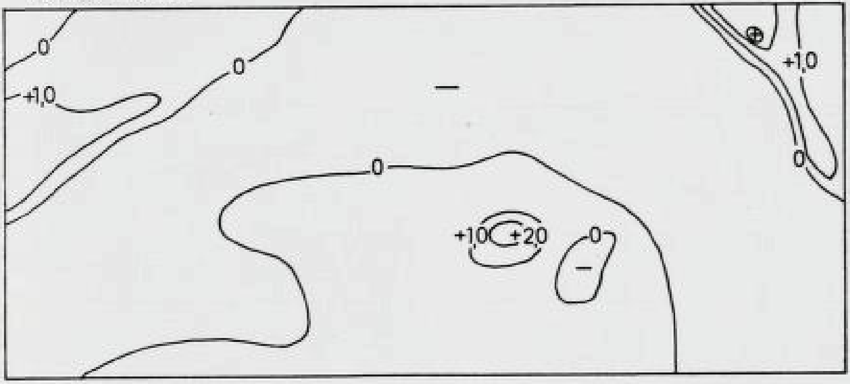


Trends *Fig. 35.*

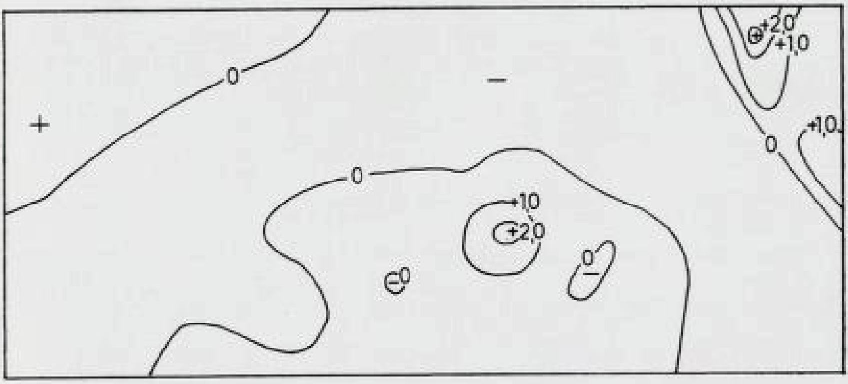
Linear



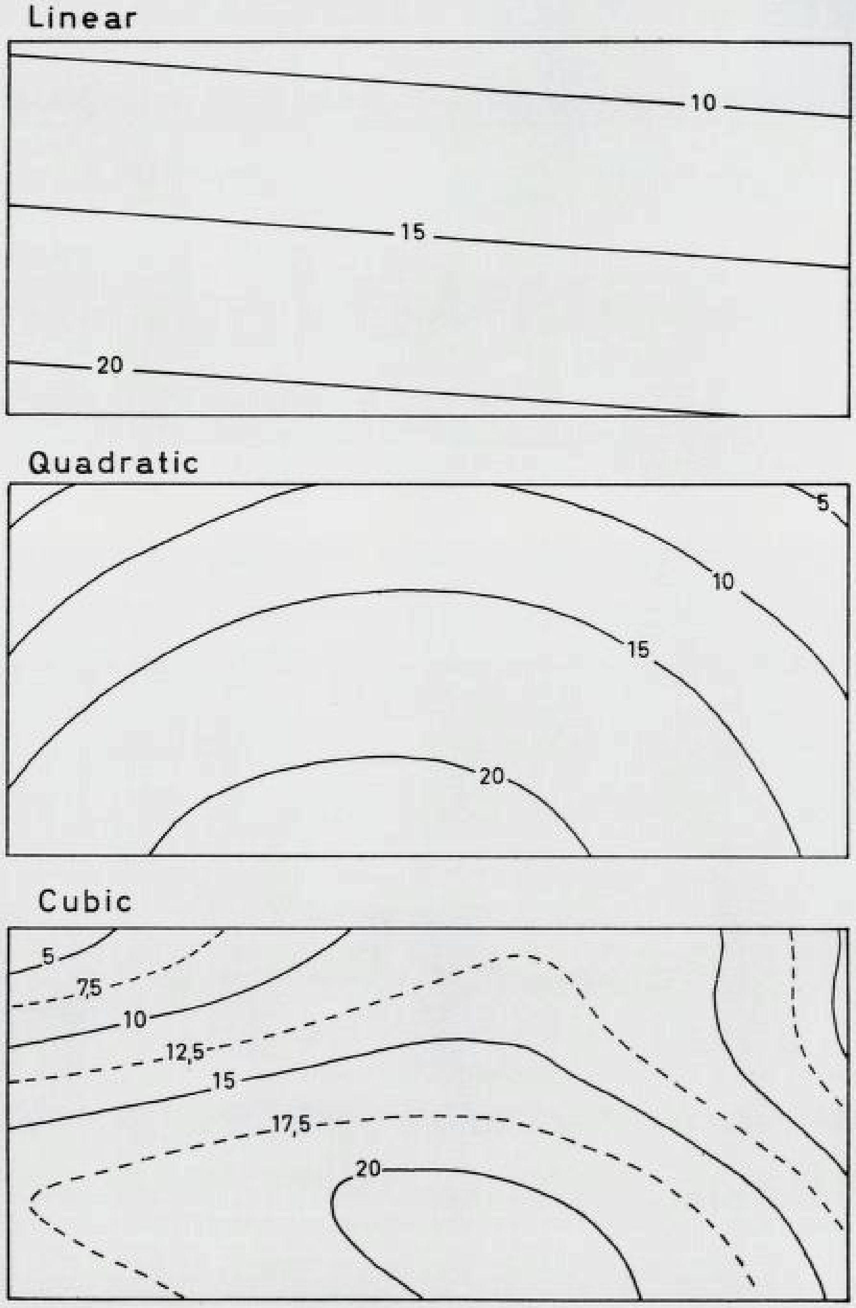
Quadratic



Cubic



Na_2O data. *Deviations*

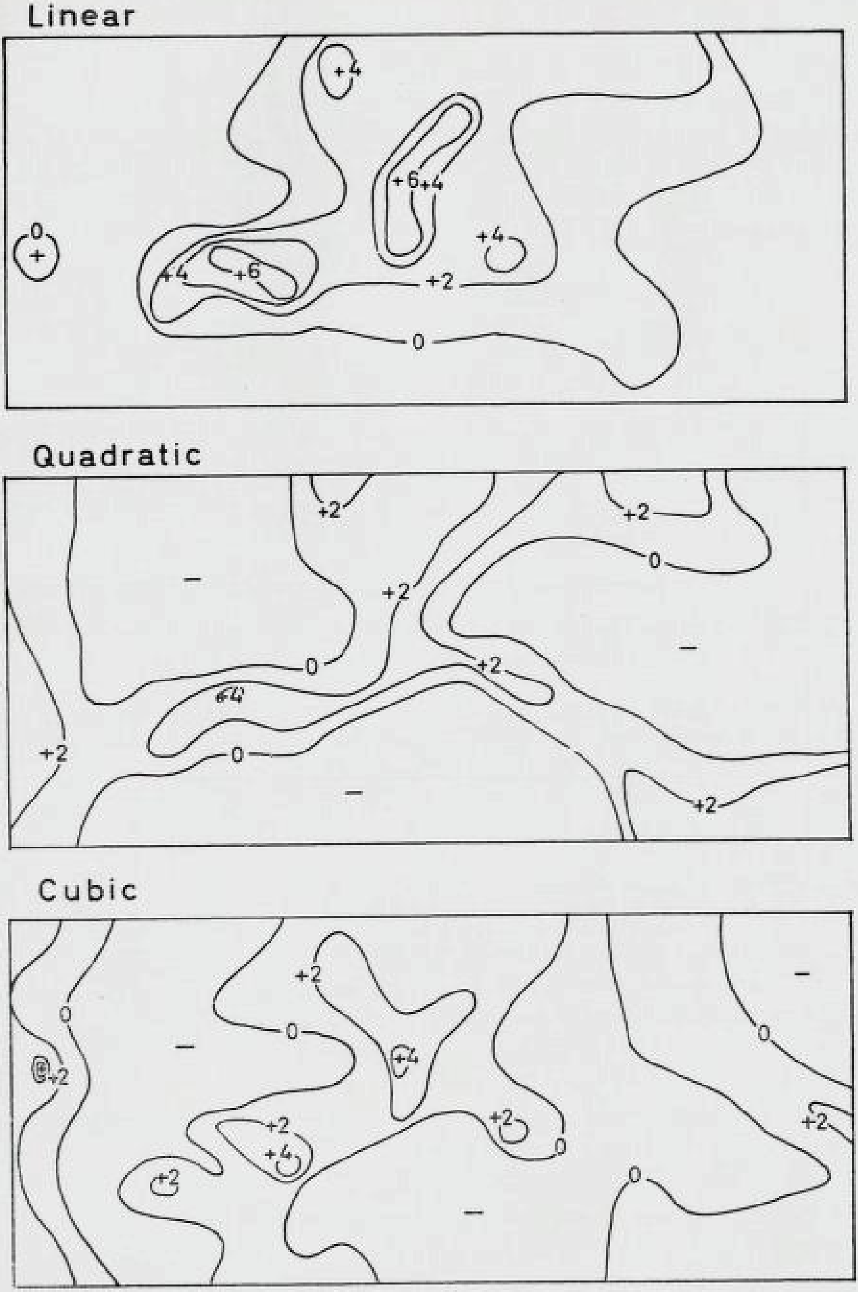


Linear

Quadratic

Cubic

Trends Fig. 36.



Linear

Quadratic

Cubic

Radioactivity-data. *Deviations*

number impure powders from fine-grained rocks were also X-rayed with satisfactory results.

The results show a remarkable lack of variance. Apart from porphyroblast-material from one quartz-dioritic, grey gneiss, which turned out to be albite, and one K-feldspar from a mediumgrained, foliated biotite granite of the gneissgranite group, which gave a $\triangle$-value of 1.07, all investigated specimens gave $\triangle$-values in the range $0.80 < \triangle < 0.95$. The frequency distribution of the 83 K-feldspar obliquities are shown in Fig.

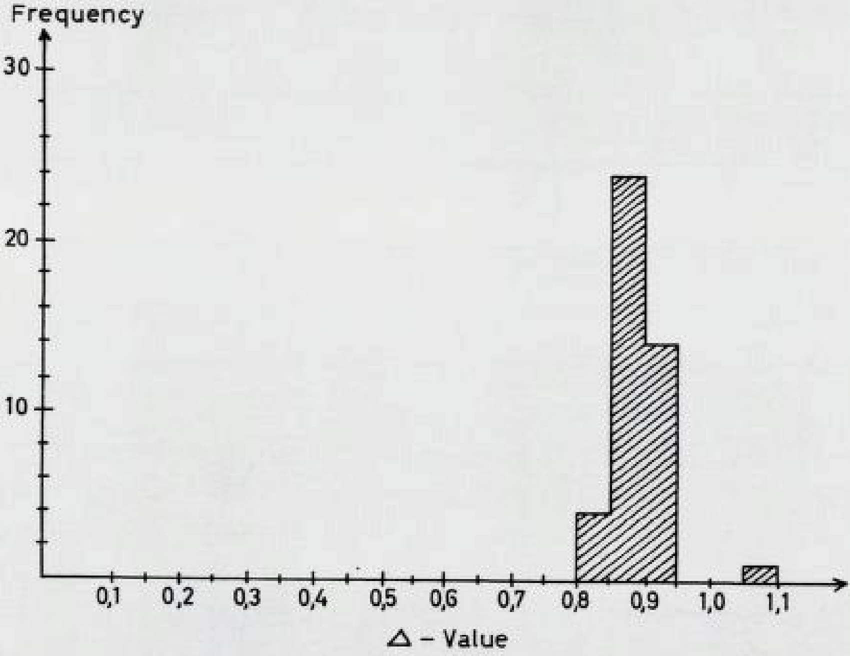


Fig. 37. Frequency distribution of $\triangle$-values for K-feldspars from various granitoid rocks of the mapped area. A total of 83 specimens were investigated.

37. This result is in accordance with the statement already made, that a harmonious relationship prevails among the varius rocks of the investigated area. There is no reason to believe that all K-feldspar orginally crystallized under strictly identical conditions. The result is apparently indicative of the state of the granite complex during the later stages of its development. There must have been uniform conditions, with sufficient temperature, volatiles and shear, over a sufficiently long period, to allow the K-feldspar to obtain equilibrium within the stability field of microcline.

Composition of plagioclase.

The An-content of plagioclase was determined by means of U-stage for several grains within the same thin section. This procedure was applied to thin sections of gneissgranite, granodiorite and quartz monzonite, in a search for mineralogical criteria upon which to differentiate between these important rocks of the granite complex. The results are expressed in Fig. 38.

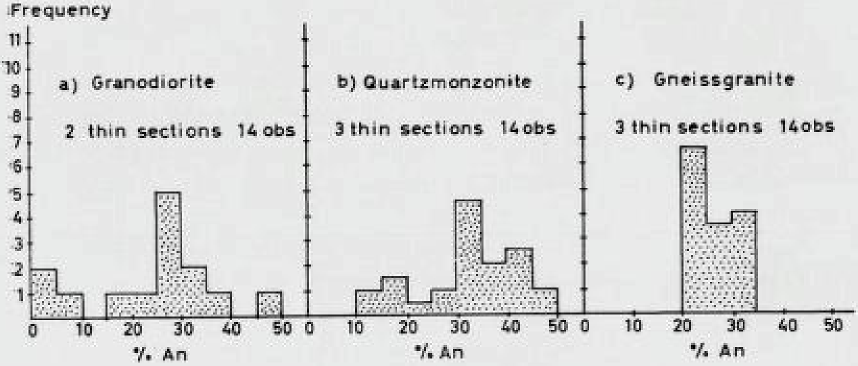


Fig. 38. Frequency distribution histograms expressing the variability of An-content in plagioclase from granodiorite, quartz monzonite and gneissgranite.

In the three investigated thin sections of gneissgranite, the An-content of plagioclase was constant within each single thin section, but a certain variation was found from one specimen to another. All measured plagioclase grains from gneissgranitic specimens have An-contents in the range $20 < \mathrm{An} < 35$.

Two thin sections of granodiorite were investigated in the same way. Here a considerable variation in An-content was found from one grain to another within each thin section. The total scattering for both thin sections is shown in Fig. 38 a.

Three thin sections of quartz monzonite also showed similar internal variation, and the resulting diagram, Fig. 38 b, is rather similar to that for granodiorite.

These diagrams are based on a total of 14 measurements from each rock group. Although this number of measurements is quite insufficient for any conclusions to be drawn, there are indications of a certain systematic difference between the granodiorite and the quartz monzonite as one group, and the gneissgranite group.

In light of the paucity of observations, however, interpretation of this phenomenon should await further accumulation of data.

Interpretation of textural features.

In the course of the microscopic examination of thin sections from the different rock types of the mapped area, several interesting textural features have been encountered. The writer is convinced that many of these features, provided the conditions for their development may once be unambigously formulated, represent important sources of information about the rock-forming processes. However, before observations of textural features can form a basis for conclusions regarding petrogenesis, more research is demanded concerning the physico-chemical principles at base of texture development. No attempt is made to take up these questions in the present work.

Adhering to the discussion and tentative conclusion of Smithson (1963, p. 124), the widespread occurrence of flame perthite and relics of plagioclase in microcline grains of all the major rock types of the granite complex are interpreted as a growth of the microcline through replacement of older plagioclase grains. Potassium metasomatism or at least local redistribution of potassium has to be assumed as a consequence of this interpretation.

CONCLUDING REMARKS

Geology.

The purpose of the present work has been two-fold. In the first place, the work has aimed at being a modest contribution to the geology of this remote part of Norway. Secondly, it was the intention of the writer, by performing this study to become familiar with the present research achievements in the field of granite petrology — a field which, as it appears to the writer, is intimately connected to the essential problems of metamorphic petrology in general.

When the writer here leaves the problems of the Neiden granite complex, it is not with the feeling that his task as an investigator is accomplished, and because this is so, he is not really in the position to draw final conclusions. There are, however, some statements for which the writer claims a certain truth value.

In the terminology of Raguin (1965), the Neiden granite complex belongs to the group of Anatectic Granites with Suites of Migmatites. The essential characteristics of the granite complex have been developed under ultrametamorphic conditions. Through diverse processes of transformation, the major rocks were formed from older rock material of the Bjørnevatn series and its underlying granitic gneiss. The development of the granite complex took place probably during the culminating and subsequent stages of the «Bjørnevatn orogeny». Field relations are in evidence of a largely in situ — position of most of the rock types.

Concerning the nature of the processes of transformation responsible for the development of the sundry granitoid rocks, some tentative statements are offered, which in light of the present state of knowledge seem plausible.

Genetically, a sharp distinction should be made between the gneiss-granite group on one side and granodiorite and quartz monzonite on the other. The granodiorite and the quartz monzonite are both best explained as being formed through the process of partial anatexis. The quartz monzonite might have had the character of a palingenic, granitic melt, which became more or less completely separated from its residual paleosome and managed to ascend as a magma to form minor intrusions at a somewhat higher level.

In the case of the granodiorite, no considerable separation of melt and residuum has taken place, but through complicated flowing movements, the crystal mash must have experienced a thorough homogenization, whereby also material from the underlying granitic gneiss was incorporated into the quartz-dioritic and amphibolitic material of the Bjørnevatn series to form a massive, homogeneous granodiorite. The flow-fold structures of the migmatitic gneiss forming the border zones of the granodiorite, are expressions of sweeping tectonical movements which the presently homogeneous granodiorite probably also experienced, and which here is emphasized as the major homogenizing factor. The relict zone of iron formation discovered in the Munkefjord-Sandnes granodiorite is of great importance in showing that gneissmaterial was incorporated in the granodiorite, and that the granodiorite has not moved essentially relative to its site of formation. The broad and vague outline of the iron-high anomaly, Fig. 29, is attributed to the mentioned process of homogenization within the granodiorite, whereby the iron, most likely in the form of solid grains of magnetite and/or hematite, was disseminated in the moving crystal mash.

All preceding statements being accepted, there still remains the question of how the rocks of the gneissgranite group were formed. In the vague and unsatisfactory notion of «classic» geology, it is safe to state that the rocks of the gneissgranite group exhibit all signs of having been formed by granitization. This does not, however, solve the genetic problem, since there is no way of accounting for the vast amounts of potassium apparently required to form these rocks. Some mechanism unknown is suspected, whereby ultrametamorphism may take the form, not of partial anatexis, but of a giantic «steaming off» of mobile, potassium-rich emanations capable of migrating through overlying, solid rocks and provoking «granitization» in them. Finally, it should be pointed out that the geological relations established in the course of this study are not at all particular for the present area. Sudovikov (1964, p. 400) suggests the following succession in the progress of ultrametamorphism:

Regional metamorphism — — → granitization and feldspar porphyroblastesis — — → selective melting — — → rheomorphism — — → intrusion — — → cooling and crystallization.

The different rocks of the Neiden area fit well into this scheme, which might mean that they represent various stages in a continuous and harmonious metamorphic evolution. In terms of the rocks of the Neiden area, this metamorphic evolution is expressed in the following way:

Regional gneiss group — — — gneissgranite group — — — migmatite of the transition zones — — — — granodiorite — — — — quartz monzonite — — — — various late stage phenomena.

Methodology.

More space will not be devoted to discussing more or less probable explanations of the geological situation in the Neiden area. There are numerous excellent works published on areas similar to the present one, where the relevant questions are thoroughly debated. Furthermore, in several articles and textbooks, the different aspects of the granite problem have been treated by scientists far more proficient than the present writer. A conclusion reached by this writer after having studied the granite area here described and fragments of the voluminous literature, is that the basic problems of granite formation have as yet not been solved. Rather than favouring one particular out of a set of equally defective theories, the theme worthy of discussion appears to be along which lines to conduct the future investigations, in order that real progress is experienced in the field of granite research.

The present writer is not in the position to give the final answer to this question. It appears to him as if the possibilities of the conventional ways in granite investigations, like qualitatively describing the variety of observed phenomena, mapping without defining the criteria for classification and drawing conclusions about chemical changes in rock masses from analyses of a few «representative» specimens, are by now fully exhausted. Truly, this approach has led to remarkable achievements. but the stage seems now to have been reached, at which further contributions along the same lines will bring nothing new, apart from adding to the body of regional geological knowledge.

With regard to granite petrology, there are three fields of research which stand forth as particularely promising. The first and most advanced of these is the field of experimental investigations into chemical systems similar to those in the earths crust. In this field there is at present much activity and continuous progress. Another expanding field of investigation is that of spatial variability of quantitative geological variables. This kind of systematic observation, paired with various statistical techniques aquires increasing importance as the methods of modern analytical chemistry and the facilities of fast electronic computers confront the geologists with enormous amounts of quantitative data and efficient means of handling them This approach is still in its initial stage.

The third and, the writer thinks, the perhaps most promising approach to the problems of granite genesis as well as to metamorphic petrology in general, is the study of what may be called texture forming processes. Much more information is required concerning the physico-chemical principles involved in solid state reactions in rock systems under metamorphism and the mechanism of reaction, transport and growth of crystals, as well as the kinetics of such processes. These problems may be attacked both through study of textural features of natural rocks and through laboratory experiments. Although a few important contributions have been made, this field is largely neglected.

Final conclusion.

The fundamental principles of granite genesis are as yet not understood. Complicated and elaborate theories are advanced in order to explain the particular geological situation of one area, these same theories failing when applied to another area where a different, and equally intricate theory is demanded. It is tempting to draw a parallel between the present situation of the geology of granite and the state of Newtonian physics at the end of last century, and to quote P.W. Bridgeman:

> «Before Einstein, an ever increasing number of experimental facts concerning bodies in rapid motion required increasingly complicated modifications in our naive notions in order to preserve self-consistency, until Einstein showed that everything could be restored again to a wonderful simplicity by a slight change in some of our fundamental concepts.»
>
> Bridgeman (1961).

SAMMENDRAG

Ved feltundersøkelser sommeren 1963 og en kortvarig prøvetaking i en del av feltet høsten 1964, er et 400 km^2 stort område sørøst for Neiden i Øst-Finnmark kartlagt og gjort til gjenstand for videre undersøkelser, med sikte på å klargjøre bergartenes dannelseshistorie. Området omfatter et kompleks av granitiske bergarter og tildels omgivende regional-metamorfe gneiser og amfibolitter som utvilsomt tilhører Bjørnevatn-serien.

Innen selve granitkomplekset er det utskilt tre hoved-grupper av bergarter: *Gneisgranit-gruppen*, *Granodiorit* og *Kvarts-monzonit*. Flere generasjoner av pegmatitter, aplitter og granitiske ganger har tilknytning til granitkomplekset, og det antas at en ultrabasisk gang som opptrer i granitkompleksets sentral-parti, muligens også er genetisk knyttet til dette. Foruten de nevnte bergarter opptrer tallrike diabaser og liknende gabbroide ganger. Disse har stor utbredelse også utenfor granitkompleksets grenser, og det er ingenting som tyder på at de står i genetisk forbindelse med granitkomplekset.

De kjemiske og mineralogiske forskjeller mellom de ulike granitoide bergartstyper er små og ikke egnet som grunnlag for en tilfredsstillende klassifikasjon av bergartene, dersom det legges vekt på å få et geologisk kart som er meningsfylt med hensyn til bergartenes dannelse og utvikling. Det foreliggende kart bygger i stor utstrekning på bergartenes struktur i mesoskopisk og makroskopisk skala, men klassifikasjonen er også influert av et subjektivt helhetsinntrykk av områdets geologi.

Gneisgranitgruppen er meget heterogen. Felles for bergartene i denne gruppen er at de later til å være dannet ved metasomatiske prosesser, der utgangsmaterialet har vært på forhånd tilstedeværende gneiser og amfibolitter av Bjørnevatn-serien, samt dennes granitiske gneis-underlag.

Granodiorit opptrer som større og mindre legemer av massiv, grå middelkornig bergart uten noen form for retnings-struktur. Mellom granodiorit og regionalt opptredende gneis, forekommer alltid en migmatitisk overgangssone med agmatit og gneis med flytestrukturer. Ved overgang til massiv granodiorit blir alle flytestrukturer og øvrige inhomogeniteter gradvis utvisket. Det antas at granodioriten er dannet ved partiell oppsmelting av tidligere tilstedeværende gneis. Granodioriten har øyensynlig tatt opp i seg store mengder av Bjørnevatn-seriens bergartsmateriale, og det later til at granodiorit-legemene ikke er nevneverdig forflyttet i forhold til åstedet for deres dannelse.

Kvarts-monzonit opptrer som mindre intrusiv-legemer i gneisgranit og i migmatitisk gneis. Det antas at denne bergart, i likhet med granodioriten, er dannet ved en partiell oppsmelting av gneismateriale. Mens granodioriten stort sett forble in situ, representerer kvarts-monzoniten sannsynligvis bergarts-smelte som er blitt atskilt fra sitt uoppsmeltede residuum, og som har steget til høyere nivå der den er størknet i form av mindre intrusiv-legemer med avkjølingskontakt mot sidebergarten. En overveiende del av plagioklas-kornene i kvarts-monzoniten har sannsynligvis vært tilblandet smelten som faste krystaller.

Kvartsbåndet jernmalm, identisk med den velkjente malm fra gruvedriften ved Bjørnevatn, opptrer som smale, mer eller mindre sammenhengende soner i gneisene omkring granitkomplekset. Denne karakteristiske jern-bergarten representerer høyst sannsynlig primære lag i den sedimentær/vulkanske Bjørnevatn-serien, og de utgjør en viktig kartleggbar formasjon innen gneis-området.

Jernmalmsoner av samme type opptrer også i granit-kompleksets grenseområder, og ved en systematisk prøvetaking og jern-analyse av bergarter i et område mellom Munkefjord og Sandnes, er det fremkommet sterke indikasjoner på en relikt kontinuasjon av en slik jernmalm-sone gjennom homogen granodiorit.

Selv om det har vært mulig å oppstille noenlunde tilfredsstillende forklaringer på isolerte fenomener i forbindelse med granit-kompleksets dannelse, forblir de grunnleggende spørsmål vedrørende granit-dannelsen uløste. Forfatteren hevder at en fortsatt akkumulasjon av kvalitative beskrivelser om områder med granitiske bergarter, i likhet med foreliggende beskrivelse, neppe vil kunne bidra nevneverdig til løsningen av disse grunnleggende spørsmål. De betydningsfulle bidrag til løsningen av granit-problemene ventes i fremtiden å komme fra eksperimentelle undersøkelser som dem utført av Tuttle og Bowen, Orville og Winkler et al., samt som resultat av studium av geografisk arealmessig variasjon av ulike geologiske variable, undersøkelser av den type Whitten har gjort seg til talsmann for. Forfatteren har forøvrig tro på at en øket innsats i utforskningen av bergartsteksturer og de fysikalsk-kjemiske prosesser som kommer til uttrykk gjennom dem, vil kunne føre til en langt dypere forståelse av bergartsmetamorfosen generelt og derved også til en løsning av granit-problemene.

REFERENCES

Barth, T. F. W., 1959. Principles of classification and norm calculations of metamorphic rocks. Jour. Geol., Vol. 67, pp. 135—152.

— 1962, Theoretical petrology. 2nd. Ed., Wiley, N. Y.

Bergstrøm, L., 1963. Petrology of the Tjørn area in western Sweden. S. G. U. Ser. C, No. 593, Årsbok 57, No. 4.

Berthelsen, A., 1961. Structural classification of gneisses — as used in team work in SW Greenland. In Sørensen, H., Editor. Symposium on migmatite nomenclature.

Boldizar, T., 1964. Referred to in Winkler (1965).

Bridgeman, P. W., 1961. The logic of modern physics. Macmillan N. Y.

Bugge, J. A. W., 1950. Sedimentære jernmalmer og deres deformasjon. Tidsskr. Kjemi, Bergv., Met., 6, p. 227.

— 1960. Precambrian of eastern Finnmark. In Holtedahl, O. Editor. Geology of Norway. N. G. U. 208, pp. 78—92.

— 1965. Grunnfjellsgeologi i Øst-Finnmark. Summary. N. G. T., 45, p. 137.

Carstens, H., 1955. On clouding of plagioclase in coronited meta-dolerites. N. G. T. 35, pp. 129—134.

Chayes, F. 1956. Petrographic modal analysis. Wiley, N. Y.

— and *Suzuki, Y.*, 1963. Geological contours and trend surfaces. Journ. of Petr., Vol. 4, pp. 307—312.

Emmons, R. C., 1964. Granites by recrystallization. Amer. Jour. Sci., Vol. 262, No 5, pp. 561—591.

Eskola, P., 1950. The nature of metasomatism in the process of granitization. Int. Geol. Congr., XVIII Session, Great Britain 1948, Part III.

Frasl, G., 1963. Die mikroskopische Untersuchung der akzessorischen Zircone als eine Routinearbeit des Kristallingeologen. Jb. Geol. B. A., Wien, Bd. 106, pp. 405—428.

Føyn, S., 1945. Spalteganger i Sør-Varanger. N. G. T. 25, pp. 127—146.

Gejer, P., 1912. Contributions to the geology of the Sydvaranger iron ore deposits. G. F. F. 33, p. 312.

Hausen, H., 1926. Über die Präquartäre Geologie des Petsamo-Gebietes. Bull. Comm. Geol. Finl. 76, p. 1.

Holtedahl, O., 1918. Bidrag til Finnmarkens geologi. N. G. U. 84.

Hoppe, G., 1963. Die Verwendbarkeit morphologischer Erscheinungen an akzessorischen Zirkonen für petrogenetische Auswertungen. Abh. Akad. Wiss., Berlin, Klasse f. Bergbau . . ., No. 1.

Krumbein, W. C., 1959. Trend surface analysis of contour-type maps with irregular control-point spacing. Jour. Geophys. Res., Vol. 64, No 7, p. 823.

— and *Graybill, F. A.*, 1965. An introduction to statistical models in geology. Internat. Ser. Earth Sci. McGraw-Hill.

Link, R. F., and *Koch, G. S.*, Jr., 1962. Quantitative areal modal analysis of granite complexes. Discussion. Geol. Soc. Am. Bull. 73, pp. 411—414.

Marmo, V., 1962. On granites. Bull. Comm. Geol. Finl., No. 201.

Orville, P. M., 1962. Alkali metasomatism and feldspars. N. G. T. 42, Feldspar volume.

Poldervaart, A., 1950. Statistical studies of zircon as a criterion in granitization. Nature 165.

— and *Eckelmann, F. D.*, 1954. Growth phenomena in zircon of autochtonous granites. Geol. Soc. Amer. Bull., 66.

— and *Gilkey, A. K.*, 1954. On clouded plagioclase. Amer. Min. 39, pp. 75—91.

Polkanov, A. A., 1939. Pre-Quarternary geology of the Kola peninsula and Karelia, or of the easternmost part of the Fennoscandian crystalline shield. Int. Geol. Congr. XVII. Session, U. S. S. R. 1937, Vol. 2, pp. 25—56.

Raguin, E., 1965. Geology of granite. Interscience Publ., Wiley, N. Y.

Read, H. H., 1948. Granites and granites. In Gilluly, J., Editor. Origin of granite. Geol, Soc. Amer. Mem. 28, pp. 1—19.

— 1957. The granite controversy. Interscience Publ., Wiley, N. Y.

Reford, M. S. and *Summer, J.*, 1964. Aeromagnetics. Review Article. Geophysics., Vol. XXIX, No. 4, pp. 482—516.

Rittmann, A., 1929. Die Zonenmethode. Schweiz. Min. Petr. Mitt. 9, pp. 1—46.

Rosenqvist, I. Th., 1951. Investigations in the crystal chemistry of silicates. III. The relation hematite — microcline. N. G. T. 29, pp. 65—76.

Sarantschina, G. M., 1963. Die Fedorow-Methode. VEB Deutscher Verlag der Wissenschaften, Berlin.

Schiedlowski, M. O. G., 1963. Studies of zircons from quartzite-xenoliths in the southern Bushveld norite and their significance for some aspects of the Bushveld petrogenesis. N. Jb. Min. Abh., 100, h. 2. pp. 145—163.

Sederholm, J. J., 1907. Om granit och gneis. Deres uppkomst, uppträdande och utbredning inom urberget i Fennoskandia. Bull. Comm. Geol. Finl., No. 23.

— 1930. Några ord om berggrunden i Sydvaranger och närliggande deler av Finland. G.F.F., 52, p. 435.

Smithson, S. B., 1963. Granite studies: II. The Precambrian Flå granite, a geological and geophysical investigation. N. G. U. 219.

Sudovikov, N. G., 1964. Regional metamorphism and some problems of petrology. (In Russian), Leningrad University Press.

Sylvester, A. G., 1964. The Precambrian rocks of the Telemark area in south central Norway. III. Geology of the Vrådal granite. N. G. T. 44, h. 4, pp. 445—482.

Sørensen, H., Editor 1961. Symposium on migmatite nomenclature. Int. Geol. Congr., XXI. Session, Norden, 1960. Part XXVI.

Trøger, W. E., 1959. Optische Bestimmung der gesteinbildenden Minerale. Teil 1. Schweizerbart'sche Verlagsbuchh., Stuttgart.

Turner, F. J. and *Verhoogen J.*, 1960. Igneous and metamorphic petrology. 2nd. ed., Internat. Ser. Earth Sci. McGraw-Hill, N. Y.

— and *Weiss, L. E.*, 1963. Structural analysis of metamorphic tectonites. Internat. Ser. Earth Sci. McGraw-Hill, N. Y.

Tuttle, O. F. and *Bowen, N.*, 1958. Origin of granite in light of experimental studies in the system $NaAlSi_3O_8$ — $KAlSi_3O_8$ — SiO_2 — H_2O. Geol. Soc. Amer. Mem. 74, 152 p.

Vogt, J. H. L., 1910. Norges jernmalmforekomster, N. G. U. 51, p. 38.

Wegmann, C. E., 1929. Zur Kenntnis der tektonischen Beziehungen metallogenetischer Provinzen in der nördlichsten Fennoskandia. Zeitschr. f. prakt. Geologie, 37, p. 193.

Whitten, E. H. Timothy, 1959. Composition trends in a granite, modal variation and ghost stratigraphy of the Donegal granite, Eire. Jour. Geophys. Res., Vol. 64, pp. 835—848.

— 1960. Quantitative evidence of palimpsestic ghost-stratigraphy from modal analysis of a granite complex. Int. Geol. Congr., XXI. Session, Norden, 1960, Part 14, pp. 182—193.

Whitten, E. H. Timothy, 1961. Quantitative areal modal analyses of granite complexes. Geol. Soc. Amer. Bull., Vol. 72, No 9, pp. 1331—1360.

— 1962. Sampling and trend surface analyses of granites: A reply. Geol. Soc. Amer. Bull., Vol. 73, pp. 415—418.

— 1963. Application of quantitative methods in the geochemical study of granite massifs. Studies in Analytical Geochemistry. The Royal Society of Canada. Spec. publ., No. 6, Univ. Tonronto Press.

Winkler, H. G. F., 1961. Genesen von Graniten und Migmatiten auf Grund neuer Experimente. Geol. Rundsch., Bd. 51, H. 2.

— 1965. Die Genese der metamorphen Gesteine. Springer Verlag, Berlin.

NEIDEN GRANITE COMPLEX

GEOLOGICAL MAP

COMPILED BY [illegible]