Igneous and Metamorphic Rocks of the Øksfjord Area, Vest-Finnmark.

By

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With 1 text-figure and a geologic map.

Abstract. The principal rock of the Øksfjord area is gabbro gneiss, in hand specimen having the appearance of ordinary igneous gabbro but in the field showing conspicuous layering. Thick layers of syenite and thin layers of anorthosite and pyroxenite are interbedded with the gabbro. On the west side of the area garnet-biotite gneiss and siliceous metavolcanic rocks alternate with gabbro layers; on the east side the layers include norite, troctolite and dunite. Small lenses of meta-limestone occur at several places in the gabbro. The uniform layers of diverse compositions suggest but do not prove that the rocks are largely a product of extreme metamorphism of a dominantly volcanic sequence, although some of the layers may be sills of intrusive rock.

Small masses of structureless gabbro, syenite, peridotite, hornblendite and anorthosite show contact relations which suggest that they are intrusive into the layered rocks. Possibly some of these masses represent old volcanic centers from which the original material of the layered series was erupted.

The structure of the layered rocks consists of broad folds roughly outlining a basin open to the north. The basin is cut by several faults with a north to northwest strike.

Introduction.

The Øksfjord area is a peninsula on the northwest coast of Norway about 70 kilometers southwest of Hammerfest (index map, Fig. 1). It is bounded on the west by Øksfjorden, on the north by Stjernsund, on the east by Altafjorden, and on the south by Langfjorden; it is joined to the mainland by a neck of land between Tappeluft and the head of Øksfjorden. The topography is rugged, with a maximum relief of 950 meters. In most places steep slopes rise abruptly from the coast to a dissected undulating plateau at elevations between 600 and 900 meters. The climate is sub-arctic, with snow lingering at higher elevations through most of the brief summer. Settlement is limited to the two villages Tappeluft and Øksfjord and isolated small farms along the coast. A road connects Tappeluft with the head of Øksfjorden, and work has commenced on an extension of the road along the coast to the village of Øksfjord; otherwise there are no routes of communication by land, except local trails between farms on the discontinuous coastal strips.

Geologic work occupied a period of three weeks in the summer of 1953. The work was accomplished by landing from a boat at various places along the coast and making traverses inland. The base map used was the Øksfjord quadrangle (T4), enlarged to a scale of 1:50,000. Reasonably satisfactory air photo coverage was available for about onethird of the area. Shortness of time, difficulties of the terrain, and inadequacies of the base map made it impossible to accomplish more than a reconnaissance survey.

Previous geologic work in the area is limited to reconnaissance along the coast by Kvale and Neumann (unpublished notes and map in the files of the Norges Geologiske Undersøkelse, 1938). Their reconnaissance was used extensively as a guide in the field work, and some of their descriptions are incorporated in this report. Professor T. F. W. Barth suggested the problem and assisted the author in many ways: by his own observations in parts of the area, by his advice based on long experience with similar rocks on adjacent islands, and by facilitating the carrying out of field and office work. Martin Oosterom and Thor Siggerud worked with the author at various times in the field, and their help is gratefully acknowledged. The friendly cooperation of the captain of the boat, Bernhardt Andreassen, and his assistant, Sigmund Pedersen, was of great help in the field work. To the Norges Geologiske Undersøkelse the author is indebted for furnishing the boat and much of the field equipment and for defraying the field expenses. To the Guggenheim Foundation and the U. S. Educational (Fulbright) Foundation the author is grateful for providing him with the opportunity for geologic study in Norway.

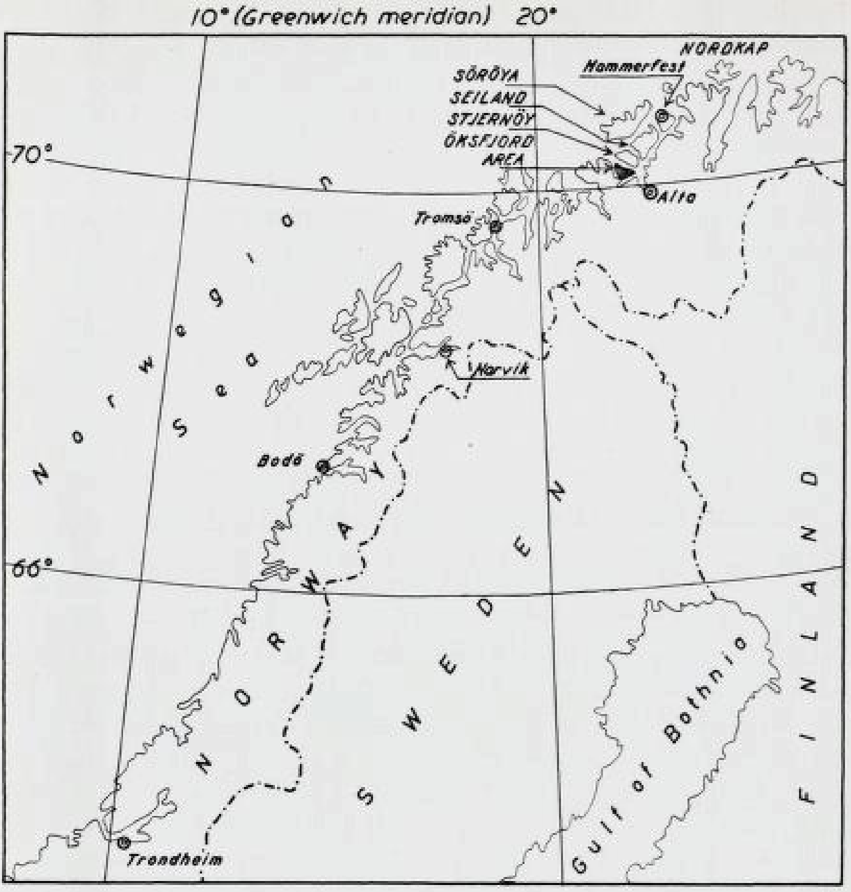

Fig. 1. Index map showing location of the Øksfjord area.

General Geology.

The rocks of the Øksfjord peninsula belong to a large area of mafic and ultramafic rocks on Norway's northwest coast, in the deepest part of the Caledonian orogenic zone. Adjacent parts of this province have been described by Barth (1927), Strand (1951), and Pettersen (1874).

Gabbro is by far the most abundant rock of the Øksfjord area. In lesser amounts occur ultramafic rocks, syenite, anorthosite, amphibolite, garnet-biotite gneiss, and meta-limestone. The outstanding peculiarity of the gabbro (and much of the syenite) is its layering. Over large areas outcrops are distinctly banded, the bands being defined by differences in grain size or in ratio of light to dark minerals or both, so that from a distance the gabbro resembles a layered sedimentary series. In hand specimens and thin sections, however, most of the rock is indistinguishable from ordinary intrusive gabbro. The apparent discrepancy between the composition and texture of individual specimens on the one hand, and the field occurrence on the other, is the major problem in the geology of the Øksfjord area. Can the layering be accounted for as an original structure inherited from a sedimentary and volcanic sequence which has been «gabbroized» by extreme metamorphism, or should it be ascribed to such igneous processes as differentiation, crystal settling, and multiple intrusion? The author is inclined to favor the first hypothesis, but the evidence obtained from this reconnaissance is not conclusive.

The approximate distribution of rock types is shown on the map. It should be emphasized that some of the boundaries, notably those between the three varieties of gabbro gneiss, are not as sharp as the map suggests. The mapping of the syenite is unsatisfactory, primarily because of the difficulty of recognizing in the field some of the syenite varieties; additional field work coupled with thin section study should make it possible to separate the principal syenite layers and hence to work out a clearer «stratigraphy» for the banded rocks. The trend lines in the banded rocks are necessarily much smoothed and generalized; the actual data from which the lines are projected are given by the strike-and-dip symbols.

The thickness of the layered series is impossible to determine, since neither its top nor bottom is exposed. The maximum exposed thickness, if it be assumed that there is no duplication of layers between Bjørnskarfjell and Indre Lokkerfjord, is about 10 km. The assumption of no duplication here is unsafe, however, because the fault from the west side of Risefjellet may continue northwestward beyond the point shown on the map. A more conservative estimate of maximum thickness, measured along a north-northeast line through the 508-meter hill east of Riverfjell, is about 8 km.

Rock Descriptions.

Gabbro gneiss I. The commonest rock in the layered series is fine to medium-grained gabbro (conspicuous grains 1—4 mm in diameter) consisting chiefly of labradorite (An_{56-62}) and augite, the plagioclase usually somewhat in excess, with minor amounts of brown hornblende, biotite, apatite, and ilmenite or magnetite. Part of the hornblende occurs as small grains marginal to pyroxene, as if it may be secondary. The pyroxene and feldspar grains are anhedral and often interlocking. Planar foliation due to orientation of mineral grains is clearly visible in most hand specimens, and in thin section is shown by rough alignment either of elongated pyroxene crystals or of pyroxene-hornblende aggregates. Evidence of crushing is completely absent in many sections but in some appears as zones of fine-grained, partly recrystallized feldspar and pyroxene between larger rounded and shattered crystals. The rock is generally quite unaltered, although a little chlorite is visible in some sections.

From one band to another the rock shows great variation in the plagioclase-pyroxene ratio, in grain size, in amount of hornblende and biotite, and in prominence of foliation. Extreme types are represented by amphibolites, fine-grained rocks consisting chiefly of plagioclase and amphibole; pegmatitic gabbro, coarse pyroxene-feldspar or amphibole-feldspar rocks without foliation; anorthosite, generally fine-grained and sugary but locally coarse; and pyroxenite, consisting chiefly of shattered pyroxene grains in a matrix of magnetite and/or ilmenite. Individual bands are most commonly a few centimeters or a few decimeters thick; pegmatitic gabbro layers may be two or three meters, while pyroxenite and anorthosite may occur in streaks less than a centimeter thick. Contacts between bands may be sharp or gradational; the pyroxenite and pegmatitic gabbro mostly show sharp boundaries, while gradations of gabbro into anorthosite are common. Where exposures are good individual thin bands can be followed for many tens of meters along the strike before ultimately lensing out. Regularity in sequence of bands was particularly looked for, but seems completely absent; nor is there any uniformity about the direction in which more mafic rocks grade into less mafic.

Another rock which forms bands locally is syenite, which ranges from a coarse-grained, igneous-appearing rock to fine-grained, well-foliated, pyroxene-rich types. No rocks clearly transitional between syenite and gabbro were observed, either in the field or in thin section, but they may exist nevertheless; the field distinction between fine-grained syenite and anorthosite is a difficult one, and syenite-gabbro transitions may well have been confused with anorthosite-gabbro transitions. Areas where layered syenite is abundant are shown by a special symbol on the map.

The distinctness of the banding varies greatly from place to place. Banding is particularly clear on the south slope of Risefjellet, on the hill east of Riverfjell, on Storvikfjell and Ingafjell, and in the area between Ristefjell and Trollfjell. The gabbro is much less conspicuously banded, but still foliated, on the lower west slope of Risefjellet and on the slopes adjacent to Indre and Ytre Lokkerfjord. Fine-grained types alternating with syenite are especially common northeast of Krekenbukt.

Gabbro gneiss II. The layered rocks in a triangular area between Ytre Kåven, Indre Kåven, and Livllodalsfjell are characterized by an abundance of olivine and orthorhombic pyroxene. The principal rock types include norite, anorthosite-gabbro, olivine gabbro, troctolite and dunite, in addition to normal augite-plagioclase gabbro. Olivine and orthorhombic pyroxene are especially abundant near the anorthosite mass at Ytre Kåven, being replaced by more and more monoclinic pyroxene to the south and west. The contacts mapped for this unit are arbitrary, the southern one simply following a conveniently-located fault and the northern one bounding the last conspicuous light-colored anorthosite-gabbro layer. Actually rocks of this unit appear to grade into ordinary gabbro gneiss both along and across the strike.

Light-colored rocks (anorthosite-gabbro) and dark-colored rocks (olivine gabbro and troctolite) of this unit form conspicuous broad bands several meters or tens of meters thick, some of the bands being foliated but otherwise homogeneous and others being subdivided into layers of the usual thickness. Southwest of the summit of Kåvenfjell the norites and troctolites show particularly prominent banding, the layers having thicknesses of a few centimeters and often showing uniform gradations in the amounts of ferromagnesian minerals from one side to the other. Locally the gradations look like the result of a rhythmic process of crystal settling, but this is hardly possible since some layers show the concentration of dark grains increasing in one direction while adjacent layers show an increase in the other direction. These thin bands in general are remarkable for their uniform thickness over long distances, but locally show intricate crinkling and cross-cutting at low angles. Occasional inclusions and schlieren of dark material are found in the light-colored bands, and of light material in the dark bands.

Bands of dunite and olivine-rich troctolite, while not abundant, are conspicuous in the field because of their dark color and red-brown weathered surfaces. Dunite also occurs in lens-shaped bodies a few meters long, with layers in the adjacent rocks partly bending around and partly cut off by the lenses.

Foliated syenite is abundant in the western part of this unit. It is the only syenite in the Øksfjord area in which the presence of olivine was noted.

Gabbro gneiss III. In a strip along the western boundary of the area the gabbro gneiss is interlayered with garnet-biotite gneiss, amphibolite, pyroxene-plagioclase hornfels, metarhyolite and metadacite. These rocks and the adjacent garnet alaskites are the only rocks in which quartz was observed, and even here quartz is far from abundant. The contact of this unit with the main area of gabbro gneiss is probably gradational; on Steigefjell and Trollfjell it is placed along faults, but on Dellafjell and Bjørnskarfjell its position is very uncertain. Small areas of similar rocks crop out on the south coast and at two places on the east coast.

Garnet-bearing rocks range from normal gabbros containing occasional garnet crystals to garnet-biotite-quartz gneisses. (Similar garnet rocks are found at two places in the gabbro gneiss I unit, marked by the letter «G» on the map.) The amphibolites are fine-grained hornblende-plagioclase rocks, generally with some pyroxene; they are not restricted to this unit, but are especially common here. The pyroxene-plagioclase hornfelses are peculiar rocks with compositions not greatly different from gabbros but with conspicuous fine sugary textures. Some of them are practically unfoliated, while others contain enough oriented biotite in thin layers to resemble biotite schists in hand specimen.

Syenite is particularly abundant in this unit, occurring in thick layers of medium-grained rock with distinct but not prominent foliation. Some layers are thickly studded with red garnet crystals up to a centimeter in diameter. In the field much of the syenite is conspicuous because of the reddish color of weathered surfaces, especially near the molybdenum prospect in Fruvikdalen and along the western crest of Danielfjell. Fresh surfaces of the rock often have a dirty green color, apparently due to abundant small grains of pyroxene.

Garnet alaskite and garnet syenite. At two places on the west coast another garnet-bearing unit was distinguished, in which the rocks are coarser-grained, garnet is more abundant and widespread, garnet syenite with apparent intrusive relations is common, and mafic rocks are absent except as inclusions and long ribbons in the garnet syenite. Quartz is present locally, so that syenite grades into alaskite. Planar structures are still evident in some of the garnet syenite and in the numerous inclusions, but are less distinct than in the gabbro gneiss units.

Metalimestone. Several small bodies of metamorphosed limestone were found in the Øksfjord area. Probably there are many more than the number shown on the map, since finding so small a body on a rapid traverse is largely a matter of luck. Most of the bodies are lens shaped, a few meters thick and a few tens of meters long, so that their size must be exaggerated for them to appear on the map. One group of three elongated outcrops north of Kåvenfjell may form parts of a continuous layer. The metalimestone occurs in both the gabbro gneiss I and gabbro gneiss III units, but none was found with the olivine-rich rocks of gabbro gneiss II.

The most common rock types are garnet-diopside-plagioclase skarn (with scapolite and wollastonite locally) and a coarse calcite marble with scattered small (0.5—1 mm) crystals of garnet and pyroxene. The skarn occurs in thin layers which maintain a general parallelism with the surrounding structure but show intricate folds on a small scale. The marble is not layered but has many «inclusions» up to a few decimeters long, the inclusions most commonly being fragments of layered skarn or pyroxenite. Where contacts are exposed the lime-rich rocks grade into gabbro through hornblende-rich varieties within a few centimeters. At three places on or near the west coast — — Øksfjordneset, Finneset, and east of Gamvik — — the metalimestone is intimately mixed with syenite. Not only does the syenite appear to intrude the limestone in small tongues and irregular masses, but it is found as inclusions in the marble and even as isolated crystals of potash feldspar scattered through the marble.

Massive gabbro. At several places gabbro is found without banding and with no consistent direction of foliation. If foliation is present it appears only locally and in random orientations, one direction of foliation often being cut at an angle by another direction. The rock is variable in texture, some of it indistinguishable from the ordinary gabbro gneiss and some much coarser. Gabbro pegmatite with hornblende or pyroxene crystals many centimeters long is common. Locally the rock grades into hornblendite, pyroxenite or peridotite; the two small bodies north of Øksfjord, for example, could almost equally well be mapped as hornblendite. The contacts of the massive gabbro are generally gradational over a short distance. Bodies of this type are recognizable in a rapid traverse only if they are large and contain much coarse material, so it is possible that massive gabbro is considerably more abundant than is indicated by the map.

Hornblendite. Along and near the north coast are several bodies of black, medium to coarse-grained rock consisting chiefly of hornblende. The hornblendite always includes some mafic gabbro and some peridotite. Dikes of coarse hornblende-plagioclase pegmatite are abundant, especially near the margins. Contacts are fairly sharp but are complicated by intrusive breccias and numerous dikes.

Peridotite. Rocks ranging in composition from pyroxenite to dunite form several masses around the periphery of the area, as well as dikes and small irregular intrusives elsewhere. The grain size is medium to coarse, with finer material as dikes. Except for the dikes the peridotite bodies appear to be completely structureless. Contacts are commonly sharp. Small peridotite bodies of lens-like or completely irregular form may be found anywhere in the gabbro gneiss I and II units; they are particularly abundant near the anorthosite on Kåvenfjell and in the large valley which drains into the east end of Kåvvann. Thick uniform layers of ultramafic rocks like those described by Barth on Seiland are rare in this area, being noted only on Kåvenfjell and on the north side of Småholmfjellene.

Anorthosite. A roughly circular area of anorthosite about two km. in diameter forms spectacular light gray cliffs above Ytre Kåven. The rock is coarse-grained, some of it nearly pure plagioclase (An_{67}) and some containing several per cent of pyroxene (chiefly hypersthene). Symplektitic intergrowths of pyroxene and green spinel are common. A few apparently primary grains of calcite appear in thin section. Vague planar structures in random directions are visible locally, but much of the rock appears completely structureless. Contacts with the surrounding layered rocks are sharp.

Syenite. In addition to the syenite interlayered with gabbro gneiss, there are several areas of massive, coarse-grained syenite with little apparent relation to surrounding structures. The larger of these bodies are easy to recognize, but small ones may escape notice. Also, the problem of separating "layered" syenite from "massive" syenite is made difficult by the fact that a syenite poor in mafic minerals shows directional structures only faintly. It is quite possible that the map should include serveral more massive syenite bodies, particularly near the west coast.

In thin section the rock is 90 % or more perthite, with minor amonts of plagioclase, potash feldspar without perthite lamellae, pyroxene, apatite, and ilmenite or magnetite.

Dikes. Fine-grained mafic dikes, for the most part only a few centimeters thick, are found in all parts of the area and are especially numerous near the ultramafic bodies. Some are peridotite, some are finegrained gabbro, and some have the euhedral crystals of mafic minerals characteristic of lamprophyres.

More spectacular are the pegmatites, which include at least four varieties. (1) Gabbro pegmatites are abundant in and near the ultramafic bodies and the massive gabbros, and are occasionally found elsewhere in the banded gabbro series. Commonly they have crystals of plagioclase and either hornblende or pyroxene 1—3 cm long, together with considerable magnetite and/or ilmenite. Some of the hornblende pegmatites have spectacular crystals of hornblende more than 30 cm long. A special variety of these pegmatites containing olivine and pyroxene is found on Kåvenfjell; olivine crystals were observed up to 5 cm long and pyroxene crystals up to 15 cm long. These dikes generally have irregular shapes rather than straight, parallel walls. (2) Pegmatites containing chiefly alkali feldspar and nepheline occur in the northeast corner of the area. These are similar to the nepheline-feldspar dikes of Stjernøy and Seiland described by Barth, but fairly small; the maximum observed thickness was about two meters. In the same area is an unusual pegmatite at least 3 km long containing bright blue scapolite in addition to two feldspars and pyroxene. (3) Pegmatites consisting chiefly of alkali feldspar, with minor pyroxene and ilmenite and/or magnetite, are especially common near Krekenbukt and on the west slope of Langfjordfjell. A peculiar dike of this kind, with apatite and molybdenite in addition, crops out on the south face of Danielfjell. (4) Dikes consisting chiefly of alkali feldspar but containing a little quartz appear near the west edge of the area, notably at the south end of Gresdalsfjell, on Danielfjell and on Dellafjell. It is worthy of note that dikes containing quartz are restricted to the part of the area where quartz is present in some of the surrounding rocks.

Anorthosite forms small dikes of irregular shape, generally not more than 20 cm thick, in the olivine and hypersthene rocks of Kåvenfjell.

Structure.

General. Most of the rocks of the Øksfjord area are foliated, in the sense that some of their mineral constituents show preferred orientation. Pyroxene crystals, slightly elongated and often eye-shaped, most commonly define the foliation. In some rocks hornblende or biotite gives the orientation, and in others aggregates of two or more mafic minerals may be aligned. More rarely the foliation is defined by feldspar augen separated by fine-grained recrystallized material. The structure is almost entirely planar, the elongated crystals or aggregates having random orientations in the foliation planes; well developed linear structures were seen in only a few places.

Most of the foliated rocks are distinctly layered, the layers being distinguished by differences in composition or grain size or both. Individual layers range from a fraction of a centimeter to several meters in thickness, but most commonly have a thickness in the range 5 to 50 cm. Contacts between layers are in part gradational, in part fairly sharp. The layering is always strictly parallel to the planar foliation, at least over distances of a few hundred meters, and the structure symbols on the map refer to both. In most places the layers maintain a uniform thickness for distances of at least several tens of meters, but occasionally they can be seen to thin and wedge out in the space of a few meters. Locally the layers show intricate folding, and one set of layers may be sharply cut off by another set. Layering and foliation may conceivably have developed simultaneously, but the sharp contrasts between adjacent layers and the lack of any uniform sequence in the layering makes it more probable that the foliation is a secondary structure following original S-planes defined by the layers.

A major difficulty in working out a structural pattern is the absence of good "marker beds" or "marker horizons" in the layered rocks. One possible horizon for structural purposes is the contact of gabbro gneiss I and the garnet biotite rocks of gabbro gneiss III, a contact which appears near the west coast, on the south coast west of Riverbukt, and at two places on the east coast between Indre and Ytre Kåven. On Kvale and Neumann's map a similar contact, trending roughly northwest, is shown about two kilometers west of Tappeluft. If this contact is assumed to mark everywhere the same stratigraphic position, the general structure appears to be a broad basin opening northward, with beds on the west margin overturned. This hypothesis is supported by an observation of Hans Ramberg (personal communication) that garnet rocks on Stjernøy, the island immediately north of Stjernsund, form an outcrop pattern in the shape of a U opening southward — which could be the northern half of the basin structure suggested by the Øksfjord area. The basin, of course, is complex in detail, the complexities indicated by the vertical foliation in the northeast corner of this area being particularly troublesome.

Folds and faults. Folds are limited to broad, open synclines roughly outlining the basin structure and to intense but small-scale contortions near faults and intrusive contacts.

Faults are a more important element of structure, at least five being recognizable by sharp discordances in the foliation and by brecciation and distortion of foliation near the fault plane. (1) A fault clearly separates gabbro gneiss I from gabbro gneiss III on the narrow saddle between Vasdalsfjell and Gresdalsfjell in the northwest corner of the area, as is shown by discordance in the planar structures and by irregular orientations near the contact. It seems reasonable to extend the fault along the contact northward, even though the discordance in attitude disappears; southward the fault cannot be traced beyond the adjacent valley. (2) A fault probably follows the contact between the same two units on the east side of Trollfjell. Here the evidence is less convincing, depending on a 30-degree discrepancy in strike east of Danielfjell and on some minor contortions of beds on the steep cliff face south of Vasdalsvann. (3) A fault probably separates the flat and gently dipping layers on the top of Feistfjellet from the vertical layers on the west side. Additional evidence is furnished by a large area of mylonite on the extension of the fault to the sea at the east side of Indre Lokkerfjord. (4) Faulting is necessary to account for the marked discordance in strike and dip between the top and the lower west side of Risefjellet. Evidence for a southward continuation of the fault is furnished by erratic attitudes on the east slope of Riverfjell. (5) A fault clearly separates gabbro gneiss II from gabbro gneiss I on the south slope of Livllodalsfjell, dragging the gabbro layers through a 90-degree angle in the space of half a kilometer. Similar bending of gabbro layers on the shore south of Indre Kåven suggests a southeastward extension of the fault.

All of these faults are at least partly healed by later flow of plastic material. They have no topographic expression, and the fault planes are not visible. Mylonite is associated with only one out of five. No estimate is possible of the direction or amount of displacement.

The possibility of more recent faulting related to the present topography is suggested by the apparent offsets of the contact between gabbro gneiss I and gabbro gneiss III on the west side. The offset at Vasdalsvann could be explained by a roughly east-west fault through the lake, over Vasdalsfjell and into Ytre Lokkerfjord, and the offset at Fruvikdalen suggests another fault up this valley and into Ytre Lokkerfjord. The only other reasonable explanation for these offsets would be a rapid change of facies, layers of garnet-biotite gneiss changing to gabbro gneiss toward the south. Another possible east-west fault may follow the lowland from the head of Øksfjorden through Kåvvann to Indre Kåven; this would make the curve in fault (4) less extreme and would help to account for anomalous dips and strikes near the oulet of Kåvvann. Since independent evidence for these three later faults is lacking, they are not shown on the map.

Zones of mylonite also suggest additional faults, but except for the one at Indre Lokkerfjord are not associated with visible displacements of layers. Small faults of relatively recent origin, with displacements ranging from a few centimeters to a few meters, are commonly observed wherever the banded gabbro is well exposed.

Intrusives. Structural relations suggest that the peridotites, the anorthosite and the massive syenites were emplaced as intrusives. The evidence is of the classical sort given by field relations: tongues and stringers of the intrusive penetrating its surroundings; fragments of the surrounding rocks caught up in the intrusive; layers of the intruded rock partly cut off, partly pushed aside by the intrusive. For the hornblendite the field relations are less convincing, but at least suggest that this rock is also intrusive. The massive gabbro likewise is probably intrusive, but the similarity of the rock to its surroundings makes this difficult to establish.

Discussion.

Origin of the layered gabbro. The chief peculiarities of the layered gabbro which a theory of origin must explain may be summarized: (1) uniform, continuous, parallel layers differing in grain size and in proportions of the constituent minerals, (2) lack of regularity in the sequence of layers and in the direction of gradations within layers, (3) prominent foliation defined by planar orientation of elongated mafic minerals and aggregates of mafic minerals, (4) foliated syenite interlayered with the gabbro, and (5) the presence within the gabbro series of metalimestone and garnet-biotite rocks, which are almost certainly metamorphic derivatives of original sedimentary material. Evidently a hypothesis to account for these peculiarities can be based on one of two fundamental assumptions: either the rock was originally in large part intrusive, and the separation into layers is due to processes operating in a molten magma; or the layering is primarily an inherited structure, and the igneous appearance of the rock is due to extreme metamorphism. The hypothesis of intrusive origin would be greatly strengthened if the contact of the gabbro with original wall rock could be found, and the hypothesis of metamorphic origin would be equally supported by a gradation along the strike of gabbro into less metamorphosed material. But neither intrusive contacts nor significant differences in metamorphic grade were noted, so that a decision between rival hypotheses must be based solely on the characteristics of the rock itself.

Let us examine first the possibilities of deriving a layered rock by intrusive processes. Perhaps the simplest suggestion would be crystal settling in a large body of quiescent magma: the difference in density between crystals of pyroxene and plagioclase would cause a difference in rate of settling, hence a partial separation as the crystals settle into a layer at the bottom of the magma chamber; movements in the magma due to convection or orogenic pressure might change the conditions of crystallization slightly and stir the remaining liquid, so that the process of settling and accumulation could be repeated time after time with slight variations. On this hypothesis the observed orientation of mineral grains could be explained as a result of flow, and the metalimestone bodies would be inclusions or roof pendants not completely digested by the invading magma. Such a process is so far from the realm of laboratory experiment that it is difficult to match predictions with observations, but one might reasonably expect some sort of regular pattern in the formation of the layers — — a general, over-all progression from mafic to less mafic material in one direction, and at least locally a rhythm in the succession of individual layers. Regularities of this sort are almost completely lacking, which is probably the most damaging evidence against a process of crystal settling. The foliation is another difficulty: flow should produce a linear orientation of elongated crystals, rather than random orientations in the foliation planes. Still another problem is presented by the syenite layers, for crystal settling in a gabbroic magma can hardly produce large quantities of nearly pure alkali feldspar rock. Furthermore, to explain the numerous metalimestone bodies as inclusions and roof pendants is not satisfactory, since it seems strangely fortuitous that all should be conformable with the surrounding structures.

Another intrusive process which might be active in producing layered gabbro, either by itself or in conjunction with crystal settling, is multiple injection of sills. This is clearly a more satisfactory hypothesis, because is offers at once a possible explanation for the randomness in the alternation of mafic and less mafic layers and provides also a convenient explanation for the syenite layers. On the other hand, the foliation remains a puzzle and the metalimestone bodies are not satisfactorily accounted for. Furthermore, the hypothesis must be strained to give an explanation for thin, uniform, continuous layers which show no cross-cutting. Pyroxene-magnetite bands and sheets of pure anorthosite only a centimeter or two thick are particularly difficult to understand as separate intrusives.

As a third possible intrusive process one can imagine the rock as homogeneous gabbro initially but subjected to shearing and metamorphic differentiation during a period of orogeny. But certainly no process of metamorphic differentiation is known capable of forming layered rocks on so large a scale; and if such a process be assumed the problem is removed from the area of profitable discussion, since obviously the unknown process could operate as well on supracrustal rocks as on intrusive gabbro.

If we turn now to the possibility of deriving the layered gneiss by metamorphism of supracrustal rocks, the difficulties are somewhat lessened but by no means completely removed. This hypothesis adds a convenient new variable, in that one can postulate (within limits) an original series of lavas, tuffs and sediments of precisely the right composition to account for the observed variations from layer to layer. Large-scale "gabbroization" of basaltic tuffs and lavas is not a widely recognized geologic process, although Barth (personal communication) has suggested such a possibility for the banded gabbros on Seiland. In an area cited by Barth at Skreifjord on the north coast of Seiland various stages in the last part of the process can be observed, for here the recent retreat of a glacier has left beautiful exposures of an amphibolite-gabbro contact along which the amphibolite seems to show progressive alteration to an igneous-appearing rock. Near the contact metacrysts of feldspar and pyroxene appear in the amphibolite, the rock becomes filled with stringers and isolated patches of gabbro, and spectacular intrusive breccias are found with fragments of amphibolite in various stages of fragmentation and incorporation into the "igneous" matrix. The phenomena are precisely analogous to those often cited as evidence for granitization.

Some of the difficulties encountered by the "intrusive" hypotheses are much less formidable on the assumption of metamorphism of originally layered rocks. The striking parallelism, uniformity, and rarity of cross-cutting shown by the layers are all readily understandable. The foliation would be expected as a result of recrystallization guided by original bedding planes. The metalimestone and garnet rocks find a ready explanation as original sedimentary beds interlayered with a predominantly volcanic sequence. The syenite layers may be regarded as products of contemporaneous "syenitization" of original trachytes and trachyte tuffs. Some of the coarser, structureless syenite layers, as well as some of the coarser gabbro, may of course represent sills injected during the metamorphism. Quartz-rich rocks on Danielfjell, containing large crystals of quartz and feldspar in a recrystallized matrix, are readily interpreted as original rhyolitic and dacitic members of the volcanic sequence.

The outstanding difficulty with the hypothesis of metamorphic origin is the extreme compositions of some of the layers. Tuffs, lavas or sediments with the composition of anorthosite or pyroxene-magnetite rock are non-existent or extremely rare. The difficulty is compounded if the olivine rocks of Kåvenfjell are also considered to be metamorphosed volcanic layers, for volcanic rocks with the composition of troctolite or dunite are unknown. Some additional process for the separation of these layers must be invoked, presumably a process of metamorphic differentiation. Here at least metamorphic differentiation is a more reasonable assumption than it would be for a large mass of intrusive gabbro, for it need act only on a small scale on isolated individual layers.

To summarize, the hypothesis of metamorphism of a volcanic-sedimentary sequence seems the most attractive explanation for the layered gabbro gneiss, but in its simple form leaves unaccounted for some of the layers with extreme compositions.

Comparison with other areas. Banded gabbros resembling in some respects the rocks of the Øksfjord area have been described from many parts of the world. The Western Isles of Scotland, the Bushveld complex of South Africa, the Stillwater complex of Montana, the Duluth lopolith of Minnesota, the Skaergaard intrusive of east Greenland are famous examples. Literature describing these banded rocks and discussing hypotheses of origin has been summarized by Coats (1936), Hess (1938), and Wager and Deer

(1939). The hypotheses proposed have been based almost exclusively on some sort of magmatic differentiation; a possible sedimentary derivation of part of the Bushveld complex, however, has recently been suggested by Van Biljon (1949).

The Øksfjord rocks are similar to other described layered gabbros in (1) range of thickness of the bands, (2) types of contact between bands, (3) range of mineral composition of bands, (4) orientation of mineral grains to give planar structures but not linear structures. Major differences are (1) greater continuity of individual bands, (2) no splitting of bands into two or more bands, (3) no predominance of density stratification in one direction, (4) rhythmic alternation of bands conspicuous only very locally, (5) lack of any floor, wall or roof, (6) presence of interlayered metalimestone, garnet rocks and syenite. The differences seem sufficient to warrant a conclusion that the Øksfjord rocks are unrelated to previously described layered gabbros and probably have a different origin.

Relations of the massive rocks. If the banded gabbros are assumed to be original tuffs and lavas, the areas of unlayered gabbro fit into the hypothesis most reasonably as remnants of the old volcanic centers from which the lavas and pyroclastics were erupted. The general similarity of the rocks in these areas to the surrounding material, the heterogeneous assemblage of fine-grained and coarse-grained varieties, and the local and randomly oriented foliation are all to be expected in the rocks of a volcanic neck. Some of the layers in the banded gneiss may represent sills from these old centers.

The massive syenite bodies may be regarded similarly as centers of trachytic volcanoes, the probable sources of the material in syenitic layers in the banded gneiss. The finer-grained and more foliated of these layers perhaps represent original trachyte tuffs, while the coarser, structureless layers are more probably sills. Since the syenite plugs appear to be completely structureless, the evidence for their origin as pre-metamorphic volcanic necks is less convincing than for the gabbros; they could equally well be considered as later intrusives, except for their association with foliated syenitic layers.

The peridotite and hornblendite bodies are not clearly related to any of the banded rocks. Despite the theoretical difficulty of postulating a peridotite or hornblendite magma, the field relations of these rocks satisfy the usual criteria for intrusives. Intrusive contacts are particularly well shown by some of the peridotites: apophyses and dikes cutting the wall rocks, inclusions of country rock within the peridotite, and the cutting off and bending aside of layering in the country rock at the peridotite contact. No special study of the ultramafic rocks was made, and conclusions about their origin are unsafe; but superficially at least they behave like intrusive bodies later than the main period of metamorphism.

The relations of the anorthosite to its surroundings are especially puzzling. On the southern side of the mass, where exposures are excellent, it seems clearly intrusive into the adjacent banded rocks. The banded rocks here are largely norite and anorthosite-gabbro, not very different in composition from the anorthosite itself. These field relations suggest, by analogy with the massive syenite and gabbro bodies, that the anorthosite could be the remnant of another volcanic center from which came the effusive equivalents of the adjacent hypersthene and olivine-bearing rocks. This requires, of course, the dubious assumption of an anorthosite magma, which is just as objectionable theoretically as peridotite magma, and the further assumption of tuffs or flows with the compositions of norite, anorthosite-gabbro, troctolite, and perhaps even dunite.

Summary.

The outstanding geologic problems in the bedrock geology of the Øksfjord area are the origin of the layered rocks and the relation to them of the small bodies of massive rock. Data accumulated in this reconnaissance are obviously inadequate for a complete solution of these problems. The situation is especially confusing because the hypotheses which seem to fit the field observations most satisfactorily are at variance with accepted ideas about the behavior of mafic and ultramafic rocks. The banded gabbro, which in composition and texture resembles rocks generally thought to be intrusive, shows fairly convincing evidence of metamorphic origin; on the other hand peridotite and anorthosite, for which an origin as intrusive magma is commonly considered unlikely, give clear evidence of intrusive relationships.

Economic Geology.

The frequent occurrence of ore deposits with ultramafic rocks and banded gabbros elsewhere in the world suggested the possibility of finding similar deposits in the Øksfjord area. Despite a careful search, however, no indication was found of the presence of ore minerals in economically significant amounts. In addition to geologic observations magnetometer readings were made at several points near the coast, but no important anomalies were discovered.

The pyroxene-magnetite bands in the layered gabbro may contain 30—40 per cent magnetite, but the bands are nowhere abundant and most are less than 4 cm thick. The anorthosite contains a little ilmenite, but no specimen examined had more than 1 per cent. Megascopically visible pyrite, pyrrhotite and chalcopyrite are found locally in both peridotite and banded gabbro, but nowhere make up more than a per cent or two of the rock. Molybdenite occurs at the small prospect in Fruvikdalen, but in insignificant amounts.

The feldspar-nepheline pegmatites in the northeast corner of the area would conceivably furnish material for ceramic manufacture, but similar rocks are found in larger quantity and in more accessible locations on the adjacent islands Stjernøy and Seiland.

No chemical tests for small amounts of rare metals were made, either of the rocks or the surficial material or the drainage water, nor were heavy constituents separated from stream sands. It is possible, of course, that such tests would lead to the discovery of ore deposits. It is possible also that careful prospecting with ordinary geologic techniques would uncover more than was found in this reconnaissance. But the present study was sufficiently detailed to warrant the conclusion that the area is a most unpromising one and that the discovery of important ore deposits is at least unlikely.

Sammendrag.

Eruptive og metamorfe bergarter i Øksfjordområdet, Vest-Finnmark.

Et stort område i Vest-Finnmark (Seiland, Stjernøy, en del av Sørøy og halvøya i på nordøstsiden av Kvænangen) består av gabbroide og ultrabasiske eruptivbergarter. Øksfjordområdet (halvøya mellom Øksfjorden og Langfjorden) er en del av dette større område.

Hovedbergarten i Øksfjordområdet er gabbrogneis. I håndstykke ser denne ut som alminnelig gabbro, men ved undersøkelse i marken viser den seg å ha utpreget lagdeling eller båndstruktur. I veksel med gabbroen finnes det tykke lag av syenitt og tynne lag av anorthositt og pyroksenitt. I den vestre delen av området finnes granat-biotitt-gneis og omdannete kiselsyrerike vulkanske bergarter i veksel med gabbroen, i den østre delen lag av noritt, troctolitt og dunitt (olivinstein). Flere steder finnes det små linser av omdannet kalkstein i gabbroen.

Områdets oppbygging av ensartede lag tyder på at det opprinnelig har vært en serie av vulkanske bergarter (lavaer og tuffer) av forskjellig beskaffenhet, som senere er blitt utsatt for en vidtgående omdannelse med omkrystallisasjon. Noen av lagene kan også være inntrengte lagerganger. Å skaffe sikre beviser for denne oppfatning er imidlertid ikke mulig.

Gabbro, syenitt, peridotitt, hornblenditt og anorthositt finnes også som mindre masser uten båndstruktur. Disse kan oppfattes som eruptivbergarter som er trengt inn i de båndete masser. Muligens kan noen av dem representere vulkanske sentrer som har gitt opphav til materialet i de båndete masser.

Områdets bergarter er lagt i brede folder og danner stort sett et bekken som er åpent mot nord. Det finnes atskillige forkastninger med retning mellom nord og nordvest.

Mange steder i verden finnes det malmforekomster i lignende bergarter som vi har i Øksfjordområdet. Men til tross for omhyggelig leting er det ikke funnet malmforekomster av økonomisk verdi i området. Heller ikke er det funnet betydelige magnetiske anomalier som kunne tyde på forekomst av magnetisk malm.

I den båndete gabbro er det pyroksen-magnetittbånd som kan inneholde 30—40 % magnetitt (magnetjernstein), men disse bånd er få og tynne (de fleste mindre enn 4 cm tykke). Ilmenitt (titanjernstein) kan finnes lokalt i anorthositt, svovelkis, magnetkis og kopperkis i peridotitt og båndet gabbro, men bare i små mengder (1 til 2 % av bergarten). Fruvikdalen skjerp fører molybdenglans, men mengden er ubetydelig.

I det nordøstre hjørne av området finnes det feltspat-nefelinpegmatitter, som muligens kunne utnyttes til keramisk råstoff, men slike pegmatitter finnes i større mengde og lettere tilgjengelig på Seiland og Stjernøy.

Det utførte arbeid har vært tilstrekkelig detaljert til at man kan si at området er lite lovende med hensyn til malm- og mineralforekomster, selv om det ikke helt kan utelukkes at det kunne finnes slike ved ennå mer inngående undersøkelser.

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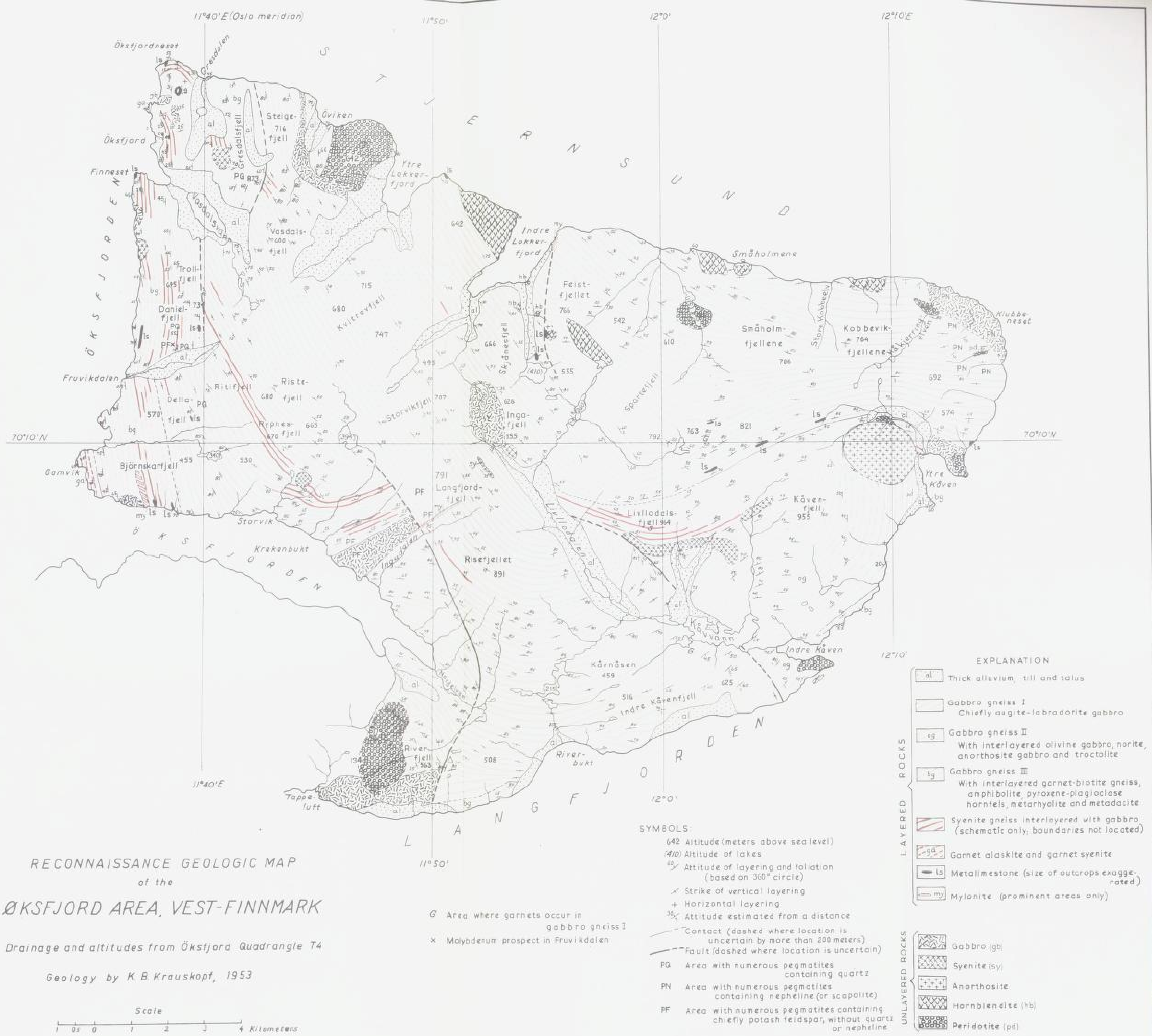
RECONNAISSANCE GEOLOGIC MAP
of the
ØKSFJORD AREA, VEST-FINNMARK
Drainage and altitudes from Öksfjord Quadrangle T4
Geology by K. B. Krauskopf, 1953
Scale
1 0.5 0 1 2 3 4 Kilometers
11°40'E (Oslo meridian)
11°50'
12°0'
12°10'E
70°10'N
STJERNSUND
ÖKSFJORDEN
LANGFJORDEN
EXPLANATION
LAYERED ROCKS
al Thick alluvium, till and talus
Gabbro gneiss I
Chiefly augite-labradorite gabbro
og Gabbro gneiss II
With interlayered olivine gabbro, norite, anorthosite gabbro and troctolite
bg Gabbro gneiss III
With interlayered garnet-biotite gneiss, amphibolite, pyroxene-plagioclase hornfels, metarhyolite and metadacite
Syenite gneiss interlayered with gabbro (schematic only; boundaries not located)
ga Garnet alaskite and garnet syenite
ls Metalimestone (size of outcrops exaggerated)
my Mylonite (prominent areas only)
UNLAYERED ROCKS
Gabbro (gb)
Syenite (sy)
Anorthosite
Hornblendite (hb)
Peridotite (pd)
SYMBOLS
642 Altitude (meters above sea level)
(410) Altitude of lakes
Attitude of layering and foliation (based on 360° circle)
Strike of vertical layering
Horizontal layering
Attitude estimated from a distance
Contact (dashed where location is uncertain by more than 200 meters)
Fault (dashed where location is uncertain)
PG Area with numerous pegmatites containing quartz
PN Area with numerous pegmatites containing nepheline (or scapolite)
PF Area with numerous pegmatites containing chiefly potash feldspar, without quartz or nepheline
G Area where garnets occur in gabbro gneiss I
× Molybdenum prospect in Fruvikdalen