An Example of Granitization in the Central Zone of the Caledonides of Northern Norway.

By

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With 5 text-figures and 3 plates.

Abstract. A brief outline of the geology of the Holandsfiord area is given and the structural evolution and the granitization processes are discussed. It is concluded that the large masses of granite overlying the paragneisses may be the erosional remnants of a former, extensive sheet of granite corresponding to the sheets of granite in Sweden in the eastern part of the Caledonides. The thrusting cannot be proved in the area in question as folding and granitization have obliterated all traces of cataclastic deformation.

Introduction.

In the summer of 1952 we undertook for the Geological Survey of Norway (N. G. U.) a detailed study at Rendalsviken, Holandsfiord, Nordland, in connection with the graphite there (see fig. 1). Because of the practical purpose of the examination, the fieldwork was confined to a very limited area. However, the results of our study seem to us to be of some importance for the understanding of the structural evolution of the Caledonides of this part of Norway and we hope that the following preliminary note may be of use to other geologists working on similar problems.

The greater part of this paper was written by both of us with the exception of the chapters on the petrography and the granitization which were written solely by Sørensen.

We wish to thank Mr. S. Føyn, director of N. G. U., for the interest he has taken in our work and for his kind permission to have the paper published in the yearbook of N. G. U.

Dr. H. Neumann, who was the leader of the expedition, has offered us much valuable support for which we are most grateful.

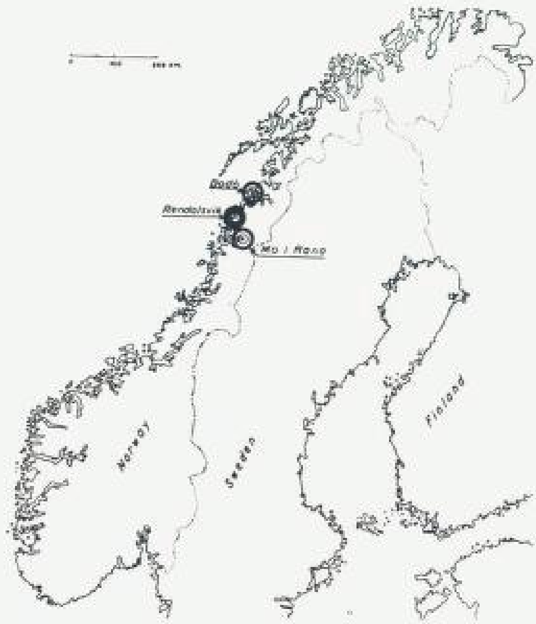

Fig. 1. Key map showing the geographical situation of the Rendalsvik area at Holandsfiord, Northern Norway.

Our best thanks are also due to Mr. R. Kongsgaard who assisted us in the field and surveyed the graphite area.

During our stay at Holandsfiord we received much kind hospitality and invaluable help from the people at Fondal and Rendalsviken, without which it would have been difficult to accomplish the work.

Mr. P. Padget, M. Sc., kindly corrected the English of the manuscript.

A brief Outline of the Geology of the Area.

The Caledonides of the Northern Norway are conventionally divided into a western zone of metamorphosed sediments, a central zone of granitic intrusions, and an eastern zone of metamorphosed sediments. In the latter, the metamorphism decreases towards the east. Holandsfiord is situated in the central zone.

The main strike of the Caledonides is NNE—SSW, but the strikę is locally E—W in the area around Holandsfiord.

The peninsula between Skarsfiord/Holandsfiord and Tjongsfiord is built up of metamorphosed sediments comprising limestones, mica-schists and quartzites. These form an anticlinorium which closes near the western tip of the peninsula. The main strike is E—W and the fold-axes have mostly a gentle western plunge.

Two zones of amphibolite traverse the peninsula in the direction E—W. They have, in places, vertical axes of folding and are associated with bodies of peridotite.

North and South of the peninsula large masses of granite overlie the sediments, apparently occupying the cores of the synclines. A number of smaler granitic masses occur on the peninsula and seem to be connected with the tectonics in a regular way (see p. 178). As the granites mostly form the peaks of the mountains and occupy synclinal structures it seems reasonable to assume that they are remnants of a layer of granite formerly covering the sediments (see p. 178).

Unfortunately, we could only undertake a cursory examination of the western part oft he peninsula. The eastern part, namely the area between the valley Rendalen and the glacier Engenbreen, was examined in a more detailed way.

A simplified representation of the geology of the latter area is given in the map fig. 2. Where the greatest importance is attached to the relation between the granite and the sediments. The granite symbol includes all gneissic rocks of granitic and granodioritic composition as well as the more massive granites. The long arm of the cross in the granite indicates the foliation or lineation of the rocks. We have distinguished three main groups of sediments, namely the mica-schists and quartzite over the graphite horizon (broken lines), the graphite horizon (black) and the lime-rich series under the graphite (unbroken lines).

Fondalen. The steep walls of the valley Fondalen provide two very instructive sections across the strike of the layers (see the map fig. 2 and the profile fig. 3).

Towards the south the large granite mass which underlies the glacier Svartisen (see the map of G. Holmsen, 1932) appears at the foot of the Fondal glacier, and is here developed as a banded granodioritic hornblende-gneiss. The bands consist of more or less granitized amphibolite. Some of the bands which can be followed for long distances show a pronounced boudinage structure (plate 1, figs. 2 and 3). The gneiss is veined, the veins having large crystals of magnetite. Zones of red mylonites and pseudotachylites are common.

The border between the gneiss and the sediments of the "Fondal anticline" to the north is conformable and sharp (see plate 1, figs. 1 and 4). The anticline has, in its southern border, a rusty biotite schist which is graphite-bearing and has as its main components, biotite, plagioclase, quartz, tourmaline and kyanite. It also has layers and "eyes" of granitic material and has thin folded bands of amphibolite a few meters from the border. These beds are underlain by a thick series of lime-silicate gneisses, mica-schists and crystalline limestones. Two layers of limestone can be followed continuously to the northern limb of the anticline.

This series is underlain in its turn by an intensely folded lime-silicate-gneiss which is folded down in a very complicated way, into a layer of amphibolite (see fig. 3). A few faults parallel to the axial plane may have quartz veins (plate 2, fig. 3).

The core of the anticline consists of strongly deformed mica-schists.

Faults parallel to the axial plane repeat the layers in the northern limb of the anticline. The two layers of limestone mentioned above are folded in a peculiar fan-shaped fold in the middle of the northern limb. The layers of the northernmost part of the anticline are horizontal, but display much minor-folding.

The Fondal anticline is inverted, the axial plane dipping steeply southwards. The plunge of the fold axis is 20° W in which direction the anticline dives under the granite (see plate 2, fig. 1).

Towards the north, the amphibolite-banded part of the mica-schist borders on the gneiss. The latter is at first rich in remnants of mica-schist and quartzite and shows faint traces of the complicated folding of these rocks. It has a good deal of "concretion pegmatites" (Ramberg, 1946, p. 64). Towards the north, the gneiss becomes more homogeneous and is gradually transformed into a grey, granodioritic rock having a lineation parallel to the fold axis (which plunges 20° W). The mountains Kløfttind and Middagstind are composed of this rock which, accordingly has a great width of outcrop here, while on the floor of the valley this rock is narrows down to a thin band. Thus, the granite has a phacolithic, or rather a synclinal appearance.

The homogeneous rock is gradually transformed, towards the north, into a gneiss which has remnants of mica-schist (see fig. 3). The gneiss has a thin band of a rusty, quartz-muscovite mica-schist. This band can be followed long distances towards the east and the west (compare fig. 2).

Northwards the gneiss borders on the biotite schist with folded bands of amphibolite. This schist forms the southern limb of a strongly compressed anticlinorium and lies under the granite along both sides of the valley. The fold-axis is still plunging 20° W.

North of this series follows a somewhat granitized quartzite which is most probably folded into a deep syncline with steeply dipping limbs. Then follows in Stortind two quartz-banded zones of amphibolite, the fold axes of which are vertical. (They represent the southernmost of the two amphibolitic zones mentioned on page 156). North of these zones there is another granite in a synclinal structure and then follows the graphite-anticlinorium.

The north-west wall of the valley is composed entirely of granite. The vertical border between this granite and the amphibolite zone of Stortind is comformable and very sharp (see plate 2, fig. 2). The vertical joints in the granite are parallel with the border.

In the eastern wall of the valley the peridotite-peak Rødtind occurs just north of a steep quartzite corresponding to the layer south of Stortind.

The peridotite is situated in the eastern continuation of the amphibolite-zones of Stortind and is comformably enclosed in a hornblende-gneiss (in part garnet-bearing amphibolite), which has vertical fold-axes. North of this zone, lime-silicate-gneisses occur. These are represented by a biotite-gneiss towards the north.

Rendalen and Kjølen. In the walls of Rendalen, the valley west of Fondalen, the border between the granite synclinal of Fondalen and the sediments to the north can be studied in detail. The granite, which has a gentle southerly dip, overlies the sediments (plate 2, fig. 4). The border is conformable (but locally "transgressive") and follows the thick layer of quartzite above the graphite horizon. The granitic rock immediately above the quartzite bears traces of mica-schist structures and is garnetiferous. The quartzite shows minor-folding and is in many places granitic in composition close to the granite. In some cases the whole layer has attained granitic composition, the quartzite structure being still preserved (e. g. the border between granite and sediments north of Trolltind).

In the east wall of the valley the graphite-schist is somewhat granitized and contains large masses of pegmatite. The overying granitic rocks are also occasionally rich in pegmatitic material.

Plate 2, fig. 4 shows that the metamorphosed sediments north of Trolltind are almost horizontal. They have intense minor-folding and probably represent a higher level of the structure than that preserved in the east wall of the valley. Plate 2, fig. 4 also shows a granite occupying the core of a small syncline. This is probably the western continuation of the granite between Stortind and the graphite mine.

North of this syncline, the western continuation of the graphite anticlinorium is found. In this locality the core of the anticline is occupied by a granite.

The Graphite Field. The main structure in this area is an anticlinorium with a steep, compressed southern limb and a gently dipping northern limb. The graphite was mined in the southern limb of the structure, the two main shafts (Sørstrossa and Nordstrossa) being driven along two compressed anticlines which are separated from each other by a downfolding of the overlying quartzite. The quartzite is intensely folded. The overlying granite is preserved in a larger syncline in the quartzite. The latter rock may be somewhat granitized and locally the granitization has reached the graphite. Towards the east, the graphite is covered by granite, but its continuation here is proved by borings. The granite continues to the west wall of Fondalen. It is important to note, that the granite here contains, in a restricted area halfway between the eastern part of the graphite and Fondalen, scapolite and diopside indicating that the granite has replaced lime-bearing rocks.

We should at this place mention that the mica-schist south of the graphite mine in the strike direction is gradually transformed into a gneiss which at first bears traces of the plicated structure of the mica-schist. Both rocks are garnetiferous.

The northern limb of the anticline is made up of a series of small folds (see fig. 4). In Midtfeltet, the graphite is exposed in a fairly large area on the slope towards the Holandsfiord. The mica-schist over the graphite is occasionally granitized. The graphite field is bounded by granite towards the east, the gradual transition from sediments to granite may be studied in several localities. It seems as if the entire series of sediments is granitized up to the graphite, a statement which is confirmed in the east wall of the valley Rendalen, where granite is exposed immediately to the north of the graphite mine.

Some of the anticlines of the northern limb are characterized by deep folding and one of these connects the main graphite field with Fondalen (Fondal trial, see page 168). This eastern prolongation of the graphite is caused by a change in the direction of the plunge of the fold-axis.

The larger synclines of the north limb may contain a good deal of granitic rocks, especially in their central parts.

North of the graphite anticlinorium a syncline which has a fairly homogeneous granite in its central parts is present. The somewhat transformed mica-schists of the outer parts may have spots of sillimanite and are often garnetiferous. In the north side of the syncline the graphite appears again and it has been mined here in an open pit near the fiord.

A thin layer of mica-schist beneath the graphite is followed by the biotite gneiss mentioned on page 170 from the north-east wall of Fondalen. The gneiss is rich in plagioclase and has thin bands of more or less transformed limestone. At Rendalsviken bands of amphibolite, in part garnetiferous, are present. Quartz veins in the rock have uralitized diopside. Thus, this rock seems

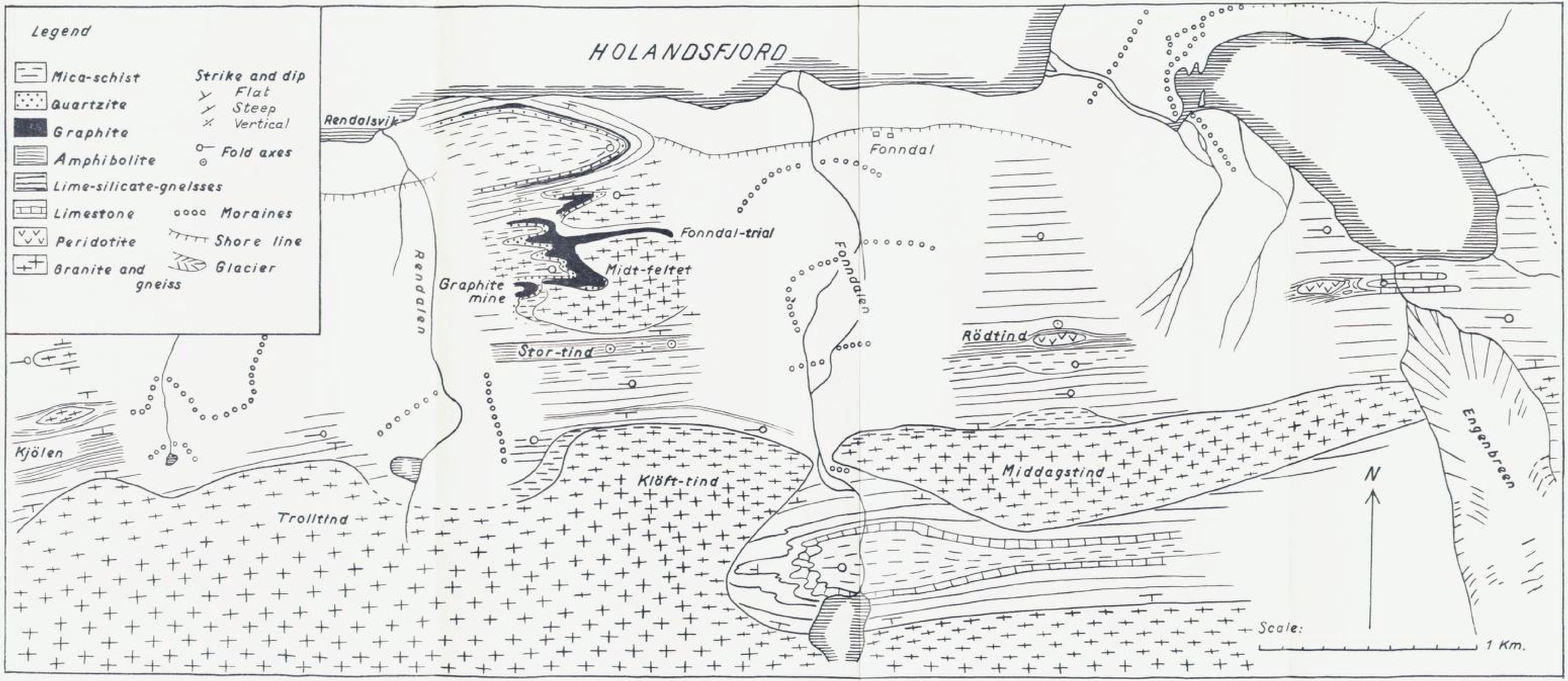

Fig. 2. Simplified geological map of the area between Rendalen and Fonndalen, Holandsfiord.

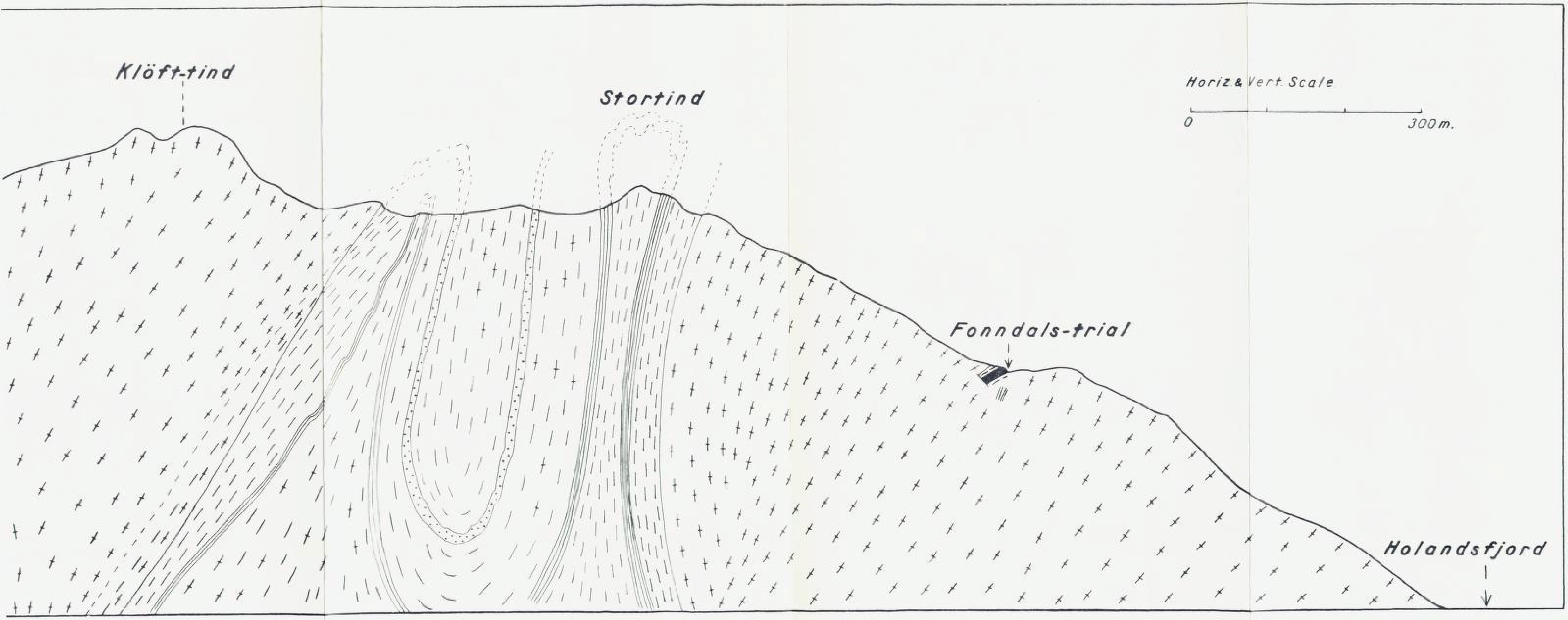

Fig. 3. Section along Fonndalen, showing the main geological structures there. (Explanation see fig. 2.)

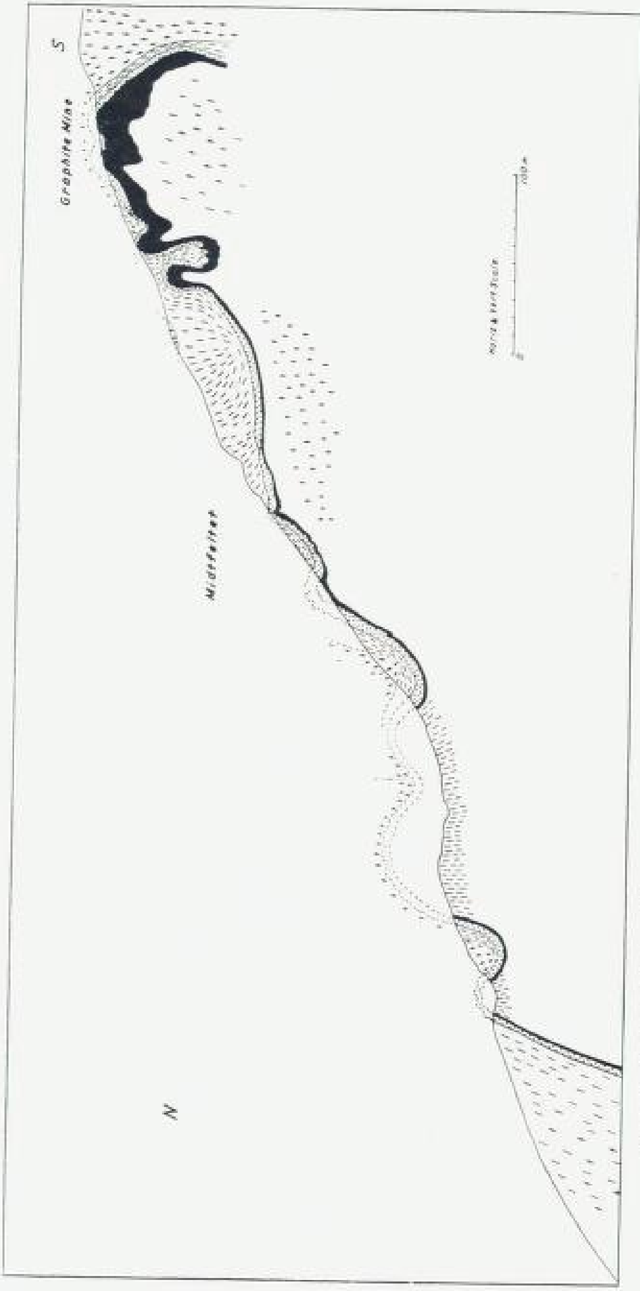

Fig. 4. Geological profile across the Graphite field at Rendalsvik. (Explanation see fig. 2.)

to be a somewhat granitized lime-silicate gneiss. The same rock is found in the eastern closure of the syncline in question where it borders on the granite of the north-west wall of Fondalen.

Engenbreen. The slope between Rødtind and Engenbreen is covered by vegetation for which reason it has been impossible to establish continuous connection between these two areas. But it seems to be beyond doubt that the zone, which contains the amphibolite of Stortind and the peridotite of Rødtind, also contains the peridotite at Engenbreen. The fold-axes are steep around the peridotite. The latter is comformably enclosed by a strongly folded seies of limesilicate gneisses which contain much garnetiferous amphibolite. (See the map and plate 3, fig. 2).

Towards the south this series borders on the syncline to which the granite mountains Kløfttind and Middagstind belong. The border rock is a lime-silicate gneiss with layers of amphibolite, limestone and mica-schist. The syncline is relatively narrow here and is occupied by a biotite-rich gneiss (in part garnetiferous) which has light-coloured patches and veins often with crystals of magnetite. The gneiss has a layer of mica-schist in its northern part; it is more homogeneous in the central part and it has a thin layer of a somewhat granitized quartzite in its southern part.

Towards the south it borders on the Fondal anticline which has lime-silicate rocks against the gneiss and is separated from the latter by a thin layer of a fine-grained rock composed of quartz, feldspar and mica.

Petrography.

The Fondal anticline gives the most complete section through the layers of the area. Of course, it is not advisable to base a stratigraphic division on the metamorphosed rocks of the anticline as mechanical thinning or thickening of the layers and repetition by folding have caused much disturbances. In addition, the granitization has obliterated many primary features. The stratigraphic succession seen in the Fondal anticline seems, however, to be valid for the area studied by us, but it cannot be definitely proved until the neighbouring areas have been studied and comparisons are made with the less transformed rocks further east.

The succession in the Fondal anticline is from bottom to top: Mica-schist, lime-slicate gneiss with amphibolite, banded series of lime-silicate gneisses and mica-schists, limestone, lime-slilicate gneisses with bands of amphibolite, mica-schist with bands of amphibolite, mica-schist, graphite-schist, quartzite and mica-schist.

The rocks have only so far been the subject of a very cursory examination. The following description are very incomplete and are only made to give an impression of the kind of metamorphism by which the sediments have been transformed.

Mica-Schists. The lower series of schists is only exposed in core of the Fondal anticline where it is folded with lime-silicate gneisses and amphibolites. The rocks are: a granitized zig-zag folded muscovite schist, a kyanite-bearing biotite schist and a garnet-bearing biotite schist.

The layers of mica-schist in the lime-silicate series have as their main components: quartz, plagioclase, biotite and muscovite. Graphite, apatite and tourmaline are the most common accessories. The rocks should be termed lime-mica-schists. Most rock have large grains of sillimanite and/or garnet. These minerals are clearly formed in an early stage of the deformation as they are of a "rolled" appearance. Thus, the large grains of sillimanite are built up of numerous, small bent fibres arranged in a "spiral-nebula' fashion. The occurrence of garnet and sillimanite seems to be determined by a deficiency in potassium as indicated by the sporadic occurrence of microcline in these rocks.

The upper series of mica-schist includes the horizon of graphite. The main rock is a zig-zag folded muscovite-quartz schist in which the rectangular flakes of muscovite are not bent. Most horizons are graphite-bearing, the graphite being mined in a layer containing up to 10 per cent of graphite.

Biotite, in part growing at the expense of muscovite, is common in many localities. Its formation is clearly connected with the granitization and it grows along the secondary cleavages, (see p. 168). Sillimanite, garnet or both are occasionally present, in all examples examined so far, in rocks poor in microcline. Thus the potassium enters the biotite easier than microcline.

Kyanite and tourmaline are present in the mica-schist in the south limb of the Fondal anticline.

The Quartzites. We may distinguish between two types of quartzite in the present area, namely the muscovite-graphite-bearing rock overlying the graphite horizon and rusty graphite-pyrrhotite bearing layers in the lime-silicate series.

Lime-Silicate Gneisses. The main constituents are: quartz, plagioclase, microcline, biotite, diopside and hornblende. Scapolite and garnet are occasionally present, the latter often in large diablastic grains with a "rolled appearance. Sphene, apatite and ore are constant accessories, graphite is present in some rocks. Calcite occurs in varying amounts, most often in very irregular grains. The diopside is always more or less uralitized.

The lime-silicate gneisses are clearly formed at the expense of impure limestones, possibly quartz-limestones.

The Limestones. Calcite is the predominant mineral occurring in twinned grains varying in shape from polygonal to most irregular. The twin lamellae may be bent. No search for dolomite has been made so far. The limestones have scattered grains of quartz, plagioclase, diopside, hornblende and phlogopite, often arranged in (folded) layers. Sphene, apatite, graphite and ore are common accessories.

Some of the layers of limestone, especially at Engenbreen, are separated from the surrounding slilcate rocks by zones of skarn with diopside as the predominant mineral (compare plate 3, fig. 5).

The Amphibolites. This rock type may be divided into the following groups:

1) bands of amphibolite in limestone. They are composed of hornblende (often with cores of diopside) plagioclase, quartz, calcite, sphene, apatite and pyrrhotite. They may be separated from the adjoining limestones by zones with hornblende prismae perpendicular to the border or by scapolite or epidote,

2) layer of amphibolite in the lime-silicate gneiss in the Fondal anticline. This layer consists in part of skarn-amphibolites, clearly formed at the expense of the diopside-bearing lime-silicate gneiss, in part of garnet amphibolite. There seems to be a gradual transition from the skarn rock to the latter,

3) bands of amphibolite in mica-schist, for instance in the Fondal anticline. They are fine-grained with hornblende as the

main component. Quartz and plagioclase constitute the groundmass. Garnet, sphene, apatite and ore are present in small grains,

4) the amphibolite of Stortind is quartz-banded and has vertical elongation. Most of the prismae of hornblende are arranged parallel with the fold axis (*i.e.* vertical), but a considerable number of prismae are perpendicular to the fold axis and lie in the plane of deformation. Small grains of garnet are present, often enclosed in the hornblende, but also forming thin, monomineralic layers. Biotite occurs in small, irregular flakes which may be enclosed in the hornblende in such a way that the hornblende seems to be the last formed mineral. The remaining minerals are: quartz, plagioclase, sphene, apatite and ore. The rock resembles the amphibolite of group 3),

5) the amphibolite of the boundins in the banded gneiss south of the Fondal anticline is somewhat granitized with biotite, plagioclase and quartz replacing the hornblende,

6) the garnet-bearing amphibolite around the peridotites of Rødtind and at Engenbreen. The garnet is in some types present in large, diablastic grains which may be of a somewhat "outrolled" appearance. Other types have monomineralic layers of garnet attaining a thickness of three centimeters or more. The layers of garnet consist of a multitude of tiny garnet grains.

Garnetiferous amphibolites are enclosed in the peridotites, and have peculiar border zones rich in diopside and clino-zoizite against the latter.

The Metamorphic Facies. The parageneses listed above indicate that the sediments were metamorphosed under P, T-conditions corresponding to amphibolite facies.

Diopside is obviously a metastable phase as it is always more or less transformed into hornblende. The fairly well-preserved grains of diopside shows that the period of transformation under high grade metamorphism was of a comparatively short duration (see H. Sørensen, 1953, p. 49).

Most rocks bear traces of retrograde metamorphism, thus, the plagioclase is altered in many rocks and the biotite is often chloritized.

On the Origin of the Amphibolites. The amphibolites of groups 1) and 2) (listed above) are clearly formed at the expense of diopside-bearing lime-silicate gneisses. While the transformation of the metastable phase diopside to the stable phase hornblende in general is incomplete in this area, it is almost complete in the two above mentioned rock-types which are situated in zones of strong deformation (see plate 1, fig. 5 and plate 3, fig. 3). Thus, the rate of transformation is accelerated by deformation in "zones of strong penetrative movement".

The amphilobites of groups 3), 4) and 5) are much alike and they may have been formed through related processes, for instance by metamorphism of original basic layers (e. g. tuff) or by metamorphic differentiation. The amphibolite of Stortind is most probably formed in the last-named way.

The amphibolite of group 6) is clearly formed in a zone of strong deformation judging from the behaviour of its garnet.

The Peridotites. These rocks are composed of olivine, bronzite and chromite. They have often large prismae of bronzite and actinolite and a good deal of serpentine in their marginal parts and have talc along traversing fractures. A description of the peridotites is being prepared at the moment.

The Granites and the Gneisses. Most of these rocks have a granodioritic composition with the main constituents quartz, microcline, plagioclase and biotite. Muscovite is found close to the mica-schists and corroded grains of hornblende are present in the banded gneiss south of the Fondal anticline. The most common accessories are zircon, apatite, sphene and allanite. Scapolite and diopside are observed in a restricted area (see page 160).

The Pegmatites. They are composed of quartz, microcline, plagioclase, biotite and occasionally muscovite. Tourmaline is frequently present. The pegmatites in the graphite have flakes of graphite.

4. The Granitization.

The granites of the central zone of the Caledonides of Northern Norway are generally described as laccolithic or phacolithic intrusions (J. Rekstad, 1912 and G. Holmsen, 1932), as these granites overlie the metamorphosed sediments. The eastern-most "bottomless" granites have been regarded as representing parts of the Pre-Cambrian basement (J. Oxaal, 1919).

Nobody has doubted the magmatic origin of the granites, in spite of the fact, that the descriptions accompanying the old, geological maps of the area contain the information that the schists are transformed into gneisses and granites in their strike direction and that inclusions of schist and limestone in the granite have the same orientation as the surrounding sedimentary gneisses.

We have observed similar feaures in the Holandsfiord area and cannot accept the mechanic intrusions of the granites for the reason that the injection would destroy the structure of the sediments and, in addition, would produce an insuperable space-problem.

We have during the fieldwork, never observed structures which could be connected with intrusions, nor have we seen any traces of the granitic- and trondhjemitic sills described by the earlier writers. On the other hand, thin, often fine-grained layers of granite were often observed in the central parts of the larger syncline, but they were evidently formed in situ. Only the pegmatites are of a cross-cutting nature but they must have been formed by replacement proceses since they have undisturbed inclusions of the adjacent rocks and do not show dilation (see plate 3, fig. 6). A few quartz-rich veins occur in the displacement-zones (plate 2, fig. 3).

The descriptions in chapter 2 contain much evidence for a metasomatic origin of the granite. A few additional examples will now be discussed.

The amphibolite in the banded gneiss at the foot of the Fondal glacier is clearly being replaced by the gneiss. The first stage in the transformation is the appearance of "amoeba-like" pegmatitic patches in the amphibolite. The patches have often large crystals of magnetite. In later stages, the patches are transformed into light-coloured veins with large grains of magnetite. There is a continuous transition from the dark rock with the light-coloured veins to the banded gneiss which also has, as mentioned on page 157, magnetite-bearing veins. The gneiss is hornblende-bearing.

In the southern border of the deep anticline which connects the main graphite area with the Fondal trial, the granitization has reached the graphite. The graphite- and muscovite-bearing quartzite immediately above the graphite has small grains of plagioclase which have small inclusions of microcline. About half a meter from the graphite, the muscovite quartzite contains a good deal of microcline and small grains of plagioclase in a subordinate amount. The plagioclase seems to be younger than the microcline. This rock also a concentration of pyrrhotite. One meter further in the direction of the granite, the microcline has disappeared and larger grains of plagioclase occur. The rock is rich in sphene, a mineral which is otherwise rare in this transition zone, and the mica is pale brown in colour. Half a meter from this rock microcline reappears in larger grains in a rock which has traces of zig-zag folded layers of mica, mainly consisting of muscovite but also having biotite of a slightly darker colour than in the previous rock. Towards the granite the amount of microcline increases at the expense oft he quartz. Plagioclase is present in comparatively small grains often with myrmekitic structure. Biotite increases in amount becoming darker as the granite is approached. The zone between the graphite and the granite is approximately five meters wide.

Perhaps the most beautiful example of granitization in the present area may be studied immediately to the south of the Fondal trial (see fig. 5). The muscovite schist, which overlies the graphite of the Fondal trial, plunges into the underlying granite in the direction of the fold axis, in such a way that the zig-zag structure of the mica schist continues a few centimeters into the granite.

The mica schist is folded in a zig-zag fashion and consist of muscovite and quartz. The flakes of muscovite are rectangular and show no trace of bending. About 20 centimeters from the border with the granite, microcline appears in larger grains; the rock has a very subordinate amount of plagioclase and biotite. About ten centimeters from the border, biotite and plagioclase occur in slightly larger amounts. There are accasionally small fibres (probably of sillimanite) between the muscovite and the microcline.

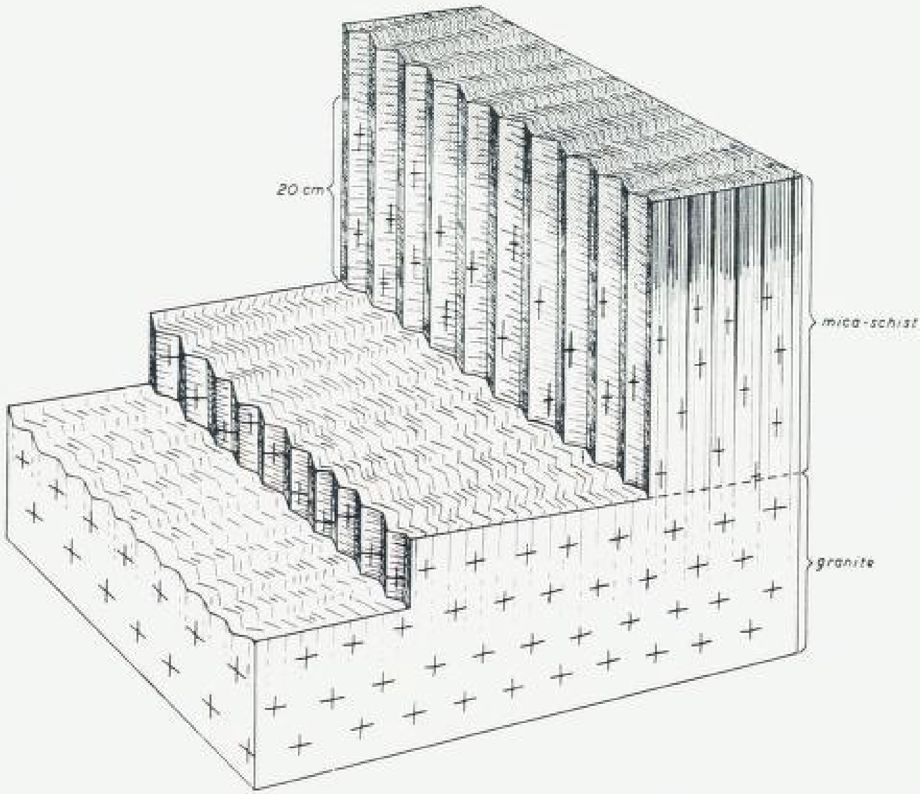

Fig. 5. Block-diagram, showing schematically the granite—micaschist contact just south of the Fonndal trial.

The mica schist in the border has the same composition as the rock (described above) 20 centimeters from the border. The flakes of muscovite may be bent here and are clearly being replaced by microcline.

Microcline is the predominant mineral just inside the border of the granite. The rock has subordinate amounts of quartz and plagioclase, the latter mineral often having myrmekitic structure. Biotite is present in larger amount than the muscovite. The granite, one meter from the border, contains large, highly altered grains of plagioclase. Quartz and microcline also occur in large grains and biotite is present in irregular flakes. The muscovite is reduced to a few, heavily corroded grains. Ore, zircon and allanite are accessories.

It is worth noting that the muscovite schist, about two meters from the border against the granite, has a concentration of garnet in a zone which cuts the schistosity of the rock.

A short distance to the north of this locality, namely in the steep wall under the Fondal trial, a muscovite schist underlies the graphite and overlies the granite conformably. The lower part of the schist is very granitized and is crumpled. It is overlain by a mica schist rich in large porphyroblasts of garnet. The schist has small aggregates of bent fibres of sillimanite which are enclosed by all the minerals of the rock, namely, muscovite, garnet, quartz and plagioclase. The garnet encloses all these minerals. Biotite and microcline are absent.

The granitization of the lime-bearing rocks follows a somewhat different trend than that described above, but it has not been examined in detail so far. It should be mentioned that there seems to be a gradual transition from impure limestones through diopside-bearing lime-silicate gneisses to the biotite gneiss mentioned on page 160 from the shore of Holandsfiord. This transition can be particularly well studied on the glacier eroded surface immediately west of Engenbreen.

As regards the tectonics of the granite, we may state that it always has cross joints vertical to the fold axes. Horizontal joints have caused a secondary bedding in many of the granite mountains. Fans of longitudinal joints may be studied locally, for instance, in the west wall of Fondalen in the continuation of the most northerly of the graphite anticlines.

It appears from the descriptions in chapter 2, that *there is an upwardly directed granitization in many of the anticlines, while the granitization is directed downwards in most of the synclines.* Locally, all traces of sedimentary rocks have disappeared between these two fronts of granitization as can be seen in the north-west wall of Fondalen.

The peculiar mode of occurrence of the (upper) granite, namely in the cores of the synclines which indicates a former extensive sheet of granite covering the whole area, may be explained in at least the following two ways.

1) *The layer of granite was formed by selective granitization of a thick layer of mica schist (over the graphite) which*

were more susceptible to granitization than the limestone series. This was our working hypothesis in the field.

2) *There was formerly a layer of allochtonous granite from which the granitization started.*

The first hypothesis is in close agreement with the explanation which P. Misch (1949, p. 687) has given of similar phenomenae in Central Washington.

The hypothesis has however its limitations. What forces could move the granitizing medium for long distances in one and the same layer following all its bends and only occasionally transgressing its borders? How could the downwardly directed granitization be explained and why has this large scale granitization in general been unable to granitize the lime-rich rocks, when the latter are totally transformed in some of the anticlines?

Although this explantion cannot be entirely dismissed the second hypothesis seems to be much more promising and will now be discussed at some length.

The idea, that there was originally an extensive sheet of granite over the paragneisses is supported by the observations of G. Kautsky (1946) in the Swedish part of the Caledonides. He describes (op. cit. p. 597) how an incipient folding of the thrust sheets of granite can be seen when approaching the Norwegian border. This folding is intensified towards the west. The thrust planes are cut by pegmatites and the mylonites are obliterated by granitization. He states that the granites of the central zone of the Caledonides are folded and mobilized "nappes" of granite (compare the profile op. cit. p. 109).

We shall not discuss Kautsky's interpretation of the central zone of the Caledonides as it is based on the geology of the Tysfiord area which we have had no opportunity of studying.

As a matter of conveniance, a few general remarks on granitization will now be advanced.

The style of folding of the Holandsfiord area and the parageneses corresponding to the amphibolite-facies indicate that the metamorphism has taken place under comparatively high temperature and pressure. As a matter of experience, granitic- and granodioritic rocks have the most stable parageneses in this level of the crust, the so-called granite-shell. Ramberg's examination of the Pre-Cambrian gneisses in West Greenland is most instrucive in this connection (Ramberg, 1952). The observations of P. Misch in Nanga Parbat are also of the greatest value for the understanding of the problems involved in the granitization. He states that "in all areas of synorogenic migmatites known to me, metamorphism has achieved a mesozonal mineral facies before granitization has set in" (1949, p. 244), and further "in the Nanga Parbat area, regional metamorphism without granitization did not go beyond the phyllitic (and perhaps upper mesozonal) stage" (op. cit. p. 242).

The writer cannot agree with Misch when he interprets the phenomenae as follows: "if the analysis given above is correct, high-grade regional metamorphism is not only necessarily linked with synkinematic granitization, but depends on it for a supply of additional heat, with the exception of the great depths of the crust" (op. cit. p. 242).

The writer would explain the phenomenae in a somewhat different way, namely by saying that *the granitization processes first obtain a sufficient rate of reaction when the P, T-conditions attain values corresponding to the middle mesozone (epidote-amphibolite-facies)*. The sedimentary rocks are also unstable in lower metamorphic facies, but the P, T-conditions prevailing there are of such a low order that the reacting materials are not able "to jump over the energy barrier". [The static granitization described by Misch from the Sheku area (op. cit. p. 372) is illustrative. The more or less untransformed red beds there which enclose irregular masses of porphyritic granite had originally an approximate granitic composition. The granitization has, in the writer's opinion a close similarity to the devitrification of glassy rocks (the components of the rock are rearranged under the formation of the most stable minerals under the given P, T) and may have been brought about if the temperature for some reason was raised sufficiently, for instance when the sediments were buried by later effusives (compare Misch, op. cit. p. 377).]

The fact that the granitization is of importance only in high-grade metamorphism is, in the writer's opinion, in support of the idea that granites are formed through reactions in the solid state and not as a result of rising hot solutions as suggested by Misch and others. First of all there are, as stated by several writers, no fractures through which the solutions can migrate in the regions of high grade metamorphism (and plastic deformation) where granitization takes place. Secondly the diffusion is facilitated by the prevailing strain and by impurities in the minerals because of incompleted metamorphic reactions. Thirdly it is stated by Misch and others that phyllitic rocks and rocks of lower metamorphic grade are not granitized. These rocks have been transformed at such a high level of the crust that circulating hot solutions have been effective. It is a matter of common experience that these solutions only result in the formation of quartz- and calcite-veins, in chloritization, albitization etc., but not in granitization.

With reference to the statement (Misch, op. cit. p. 241) that the rise of temperature during metamorphism and granitization is unrelated to geological depth, the writer would like to call attention to the rôle of the mechanically and chemically generated heat.

When discussing steep metamorphic isograds (see for instance Misch, op. cit. p. 217), we should remember that the central and most transformed parts of the orogenic zones (*i. e.* the deepest parts) are elevated most by the readjustment processes following the orogenesis. The originally flatlying "isograds" might be steepened in this way and this may be the explanation of the gradual increase in metamorphism from the east towards the west in the Caledonides of Scandinavia.

We may now resume the discussion of the granites of the area around Holandsfiord.

If a series of sediments with layers of granite is folded down into a level of the crust where the rate of reaction of the gratization processes is considerable, the elements of the granite have lower chemical activities in the granite than in the sediments as the granite is the most stable rock in this level of the crust. Because of this difference in activity, an activity gradient will be established between the granite and the sediments and the elements will migrate from places of high activity to places of low, *i. e.* from the sediments towards the granite. The elements which do not enter the minerals of the granite will have higher activity there than in the surounding rocks and will be removed by diffusion (difusion a double sens according to Perrin and Roubault). Thus, *the granites grow at the expense of the sediments,* and the downwardly directed granitization is easily explained.

The assumption of an original layer of granite gives, in the writers opinion, a much better explanation of the kind of granitization (upwards and downwards, along and across the strike of the layers) observed at Holandsfiord, than the selective granitization of a layer of mica-schist. In the latter case, the granitizing materials have either had to migrate long distances in one and the same layer or haveh ad to migrate through the underlying layers, having in many cases left no traces of granitization in the latter.

The preliminary examination of the rock does not permit a discussion of the details in the chemical changes accompanying the granitization. The example mentioned on page 168 shows that the quartzite was desilicated (feldspathized). The front of the granitization is characterized by plagioclase and, in a thin zone, by sphene (indicating geochemical culminations of Na and Ti). This is in accordance with the observations of D. L. Reynolds (1946, p. 413) who points out that the transformed psammitic rock often has more Na than K when the original rock and the granite contain more K than Na. The oposite is true if the original rock has more Na than K.

The granitization at Fondal trial demonstrates a thin basic front 10 centimeters from the border.

Regarding the occurrence of a zone enriched in garnet and/or silliminate in the mica-schist a couple of meters from the border against the granite, the examples studied so far indicate that this is due to a deficiency in potassium (the rocks are free from or are poor in microcline). If potassium had been available biotite would have been formed. Thus the two minerals in question may be regarded as metastable phases. The garnet zone probably represents a geochemical culmination of Fe and Mn.

The mode of occurrence of sillimanite mentioned on page 170 from the transition zone north of the Fondal trial, where small fibres of it occur between the muscovite and the microcline, indicates that the sillimanite there is a released mineral.

It is extremely difficult to say what happened to the material removed during the granitization. A part of it may have migrated to deeper levels of the crust where more basic rocks are stable (see Ramberg, 1952), a part of it may have migrated to higher levels giving rise to mineralization (the only "hydrothermal" ore found in the area examined by us is molybdenite).

As to the source of the granitizing material there are no reason for believing, as P. Misch did (1949, p. 703), that it originated from beneath the granite-, or sial-zone. It is admitted that the geochemical differentiation of the earth's crust (compare Rankama, 1946) may be responsible for a supply of material, but material driven out of the down-folded sediments and degranitization in lower levels of the crust (see Ramberg, 1952) seem to be of much greater importance.

The lineation and foliation of the granite indicate that the greatest part of the granitization was synkinematic. The granitization continued probably in the tension phase subsequent to the deformation (compare the boundins of amphibolite in the granite). The most beautiful examples of static granitization are, however, the fracture-controlled replacement pegmatites.

It sems to be a general rule that the graphite-bearing layers of the mica-schist are more resistant to the granitization than the graphite-free layers. This is very apparent in the graphite-field. One of us (S. Skjeseth) visited several occurrences of graphite in Northern Norway last summer (for instance Langøya and Morfiord in Vesteraalen) and found that the graphite-bearing layers often are preserved in mases of granite, where the remaining part of the sediments has been totally granitized. This may be of importance for the further study of that area as the graphite may be used as a guide horizon.

We shall not discuss here whether this resitance to the granitization is caused by the high electrical conductivity, by the insulating properties, or by still other qualities of the graphite.[1]

5. Tectonics.

The main strike of he Caledonides of Nordland is NNE—SSW. This direction appears clearly on the old geological maps (e. g. J. Rekstad, 1929 and G. Holmsen, 1932), where the layers of limestone are especially instructive.

The strike on the peninsula between Skarsfiord/Holandsfiord and Tjongsfiord is, as mentioned in chapter 2, E—W. The limestone layers of the peninsula are continuous with the limestones to the north and the south as indicated on Holmsen's map. Therefore it is natural to explain the anticlinorium of the peninsula as a result of an axial culmination in the main structure (cfr. C. Bugge, 1951).

K. Landmark (1951) has discussed the cross-folding in the Caledonides of Norway and advanced four possible explanations of its formation. It seems to us that the structural influence exerted by the basement is the probable explanation of the E—W strike at Holandsfiord.

The Deformation of the Sediments. The paragneisses have, in place developed a very intricate type of folding which is caused by the varying competencies of the constituent layers. Because of this, folds of several orders are formed.

The *mica-schists* are characterized by an intense zig-zag folding and have usually developed a more or less pronounced false cleavage which may be transformed into true schistosity. The zig-zag folding is of the same type as in the slates in the less metamorphosed parts of the Caledonides and, as the flakes of muscovite in general show no traces of bending and are arranged parallel with the limbs of the small folds, the zig-zag folds mey be remnants of the original style of folding of the unmetamorphosed pelitic sediments.

The *graphite* schist has been transformed in a somewhat different way because of the gliding properties of the graphite. For the reason the graphite is squeezed out along the limbs of the folds and is thickened in the anticlinal crests as shown in fig. 4.

The *quartzites* are in general folded in a multitude of minor folds which have great similarity to the type of folding of the quartzites, for instance, at Mjøsa in southern Norway. The down-foldings of the quartzite, such as the one between Sør- and Nordstrossa (see fig. 4) have, on the contrary, a well-developed schistosity. Thus, the quartzites may show folds of two generations.

We have observed no traces of the primary folding of the *limestones* and of the *lime-silicate rocks*. They have most probably behaved as competent layers during the first stages of folding. The style of folding of the Fondal anticline may be taken as evidence of this (see plate 2, fig. 1). In the later stages of deformation the limestones have been deformed plastically, because of the mobilization of the calcite, while the mica-schists have been the most competent layers. Therefore, the limestones, showing typical flow folds are accumulated at the crests of the anticlines.

The quartz-bearing limestones were also deformed by flow. The calcite, which was not used in the reaction between the quartz and the carbonate minerals, may in some cases be squeezed out of the resulting lime-silicate gneiss. Plate 3, fig. 4 shows an example of this.

The folded *amphibolite* of plate 1, fig. 5 is in-folded with lime-silicate gneiss. The folding of the more rigid amphibolite may have taken place by shearing, or it may have been formed in a similar way to the folds of the lime-silicate gneiss, if the amphibolite was formed at the expense of the lime-silicategneiss, in zones of strong "penetrative movement" (compare page 166).

Where thin bands of amphibolite occur in the limestones they are occasionally boudined (along diagonal shear surfaces) when the limestone is mobilized (see plate 3, fig. 3).

It is extremely difficult to distinguish drag folds in this area, but they are probably of secondary importance as the movement took place in and not between the layers.

A kind of gleitbretter fold-structure is developed in the amphibolite-banded mica-schist at the top of the Fondal anticline.

Finally, the *boudinage structure* of the amphibolite south of the Fondal anticline should be mentioned. The bands of amphibolite behaved as rigid layers while the granite was more plastic, and probably was deformed by creep. When the cohesional strength of the amphibolite was exceeded, the resultant fractures were invaded by disperse material from the granite which attacked and granitized the amphibolite along the fractures. Plate 1, figs. 2 & 3 show, however, that measurable movement occurred as the banding of the gneiss closes around the boudins and fragments of the amphibolite, broken loos from one end of the boudins, slipped along the latter to a new position. The planar banding of the gneiss shows, that it has not attained the mobility of the limestone (compare plate 1, fig. 2 and plate 3, fig. 3) to anything like the same degree.

The Relationship Between the Tectonics and the Granite. The mode of occurrence of the granite has been described and discussed in chapters 2 and 4.

The presence of large masses of granite north and south of the anticlinorium on the peninsula in question, and the fact, that granitic rocks most often occur as "core-fillings" in synclines in the anticlinorium, renders it probable, that the granite in the synclines represent remnants of a former extensive layer of granite overlying the metamorphosed sediments.

This expression is strengthened when the geological maps of the Salta (J. Rekstad, 1929) and Rana (G. Holmsen, 1932) quadrangles are studied. It is apparent that the Holandsfiord area is situated in a synclinorium which has its northernmost closure at Sagfiord. The fold axis of the synclinorium is parallel with the main strike of the Caledonides, *i. e.* NNE—SSW. Granitic rocks are predominant in the central part of this synclinorium and seem to overlie the metamorphosed sediments.

The origin of the granites was discussed in the preceding chapter. Two possible explanations of their mode of formation wee advanced. Neither of them can be proved or disproved at the moment.

A few objections to the first possibility (selective granitization of a thick layer of mica-schist) were mentioned in the preceding chapter. We would also point out that it is strange that this thick layer of schists is not preserved in the deeper synclines.

The second possibility (the overthrust theory) was discussed from a petrological point of view in the preceding chapter. A few additional point in favour of this idea will now be given.

1. Kautsky (1946) has demonstrated a gentle folding of the thrust-planes of the sheets of granite in the eastern part of the Caledonides. This folding is accompanied by an incipient granitization (formation of "Augengneisses").

2. O. Holtedahl and J. Dons (1953) have in their new geological map of Norway distinguished between the eastern masses of granite belonging to the basement and the intrusives of the central zone. These two main zones of granites are sepa-

rated by the eastern zone of schists which contain thin, conformable layers of granite.

3. Sections across thee astern zone of schists (Oxaal, 1919 and Rekstad, 1924) show alternating layes (or sheets) of sediments and granites, mainly dipping towards the west.

4. Folding of thrust surfaces is well known in many orogenic zones, for instance the Appalachians, the Rocky Mountains and the Alps.

5. Finally is the movement of plutonic masses for very long distances, more or less horizontally, as emphasized by Holtedahl (1944, p. 15), a main characteristic feature of the Caledonides of Norway.

The objection that no traces of thrust planes are seen in the area examined by us can easily be accounted for since the mylonite zones are the first to be attacked by the granitization. The original disconformities were obliterated by the folding and the granitization. There are of course no reasons for believing that we should find in this area, which was metamorphosed under P, T-conditions corresponding to amphibolite-facies, traces of cataclastic deformation so characteristic of areas where the sediments have hardly been metamorphosed.

We are well aware that it is extremely dangerous to draw far-reahing conclusions from the study of such a small area as the peninsula south of Holandsfiord, especially when the rocks there have been exposed to high grade metamorphism, but we find that Kautsky's observations in the eastern part of the Caledonides justify the above discussion of the allochtonous granites.

The presence of allochtonous granites in the central zone of the Caledonides may be proved or disproved.

1) by a careful study of the Caledonian zone from the eastern border towards the west,

2) by a search for sediments overlying the granites of the central zone,

3) by a study of the central parts of the great masses of granite.

In a recent paper, Eskola (1949) has discussed the possible occurrence of granite domes in the central zone of the Caledonides. Our examination shows that these granites could be better described as basins.

Faults. Faults are extremely rare in this area where the deformation has been highly plastic. A few, parallel with the axial plane of the Fondal anticline are seen, especially in the layers of amphibolite and mica-schist.

In a late stage of the deformation crush-zones were formed, the most prominent example of this may be seen in the west wall of Fondalen.

The Structural Evolution of the Area. 1) Period of thrusting resulting in the eastward movement of the sheets of granite and the "Amphibolite-sheet" (Amphibolitt-dekke see Kautsky, op. cit.). In this period the sediments were folded (primary folding of the sediments).

2) Downfolding of the central zone of the Caledonides. (The area studied by us gives no information as to why the deeper sheets have been prevented from eastward movement and instead have been deformed by compressional deep-folding). The downfolded rocks were the subject of high-grade metamorphism and a plastic style of folding was superimposed on the primary folds. The granitization commenced when the downfolded rocks reached a level where the rate of reaction of the granitizing processes was sufficiently high.

3) Postkinematic granitization in a transition stage where the rocks were in a state of tension (strain) and the temperature was high. The stage grades into

4) the pegmatitic stage. Replacement pegmatites were formed along fractures, often perpendicular to the fold axes. The pegmatites are most numerous in the amphibolites and in the lime-silicate gneisses.

5) The tension was not released with the formation of the pegmatites. This may be seen at Engenbreen where a pegmatite cutting a layer of marble is displaced along the latter (plate 3, fig. 5).

6) In the latest stages of deformation, displacement and crushing took place along zones of discontinuity. Quartz- and calcite-filled fractures were formed.

PLANSJER

PLATE 1.

Fig. 1. The east wall of the upper part of Fondalen. Banded gneiss with boudins of amphibolite to the right. The border between the gneiss and he sediments of the Fondal anticline rises from the lake. Towards the top left granite overlying the anticline. (Sørensen phot.).

Fig. 2. Close up of the amphibolite boudins from plate 1, fig. 1. (Skjeseth phot.).

Fig. 3. Detail of amphibolite boudin (see text page177). (Skjeseth phot.).

Fig. 4. The southern border of the Fondal anticline (compare plate 1, fig. 1). Note the banded appearance of the mica-schist to the left. (Sørensen phot.).

Fig. 5. Folds in the lime-silicate gneiss and amphibolite in the Fondal anticline (text page 177). (Skjeseth phot.).

PLANSJE 1.

Fig. 1. Østveggen av Fonndaien (foran breen). Grensen mellom gneis (syd) og sedimenter (nord) omtrent fra midten av vannet. Øverst til venstre gneis over sedimenter.

Fig. 2 og 3. Detaljer fra gneisen, syd på fig. 1. Amfibolitten (mork) er brutt opp under plastiske bevegelser i gneisen.

Fig. 4. Samme grense som vist på fig. 1.

Fig. 5. Småfolder i sedimentserien (Fonndalen).

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PLATE 2.

Fig. 1. The Fondal anticline seen from the east. The overlying granite in Kløfttind in the background. (Sørensen phot.).

Fig. 2. Stortind seen from Rødtind. In the foreground peridotite, in the background, the border between amphibolite/mica-schist and granite. The Fondalsskjerp to the right (compare fig. 3). (Sørensen phot.).

Fig. 3. Quartz vein in displacement zone in amphibolite. The Fondal anticline. (Skjeseth phot.).

Fig. 4. The west wall of Rendalen seen from the graphite mine. The granit of Trolltind (to the left) overlying anticline of sediments (center). To the right granite in a smaller syncline. (Sørensen phot.).

PLANSJE 2.

Fig. 1. Sadel (antiklinal) i sedimentserien innerst i Fonndalen, sett fra øst. Overliggende granitt i Kløfttind i bakgrunnen.

Fig. 2. Stortind sett fra Rødtind. Grense (buet) mellom granitt og sedimenter.

Fig. 3. »Kvarts-åre« i amfibolitt (dannet i sleppe). Fonndalen.

Fig. 4. Vestsiden av Rendalen sett fra grafittgruva. Granitt i Trolltind (til venstre) ligger over sedimenter (midten av bildet). I bakgrunnen Kjølen.


1


2

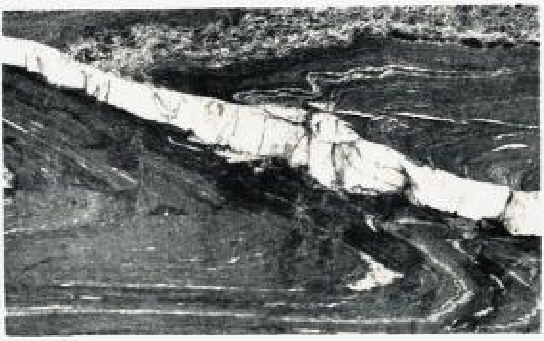
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PLATE 3.

(Photographs from Engenbreen).

Fig. 1. The glacier-eroded surface in front of Engenbreen seen from the west. Peridotite in the foreground, in center and towards the top right two closures of white marble in synclines with steep axes of folding (compare the map fig. 2). (Sørensen phot.).

Fig. 2. Close up to show steep axes of folding in the top right closure of plate 3, fig. 1. (Sørensen phot.).

Fig. 3. Plastic flow in limestone (light-coloured) with folded and broken bands of amphibolite; boudinage structure developed towards the top left. (Sørensen phot.).

Fig. 4. Plastic flow of limestone (to the left) around lime-silicate rock (to the right) tending towards development of boudinage structure. (Sørensen phot.).

Fig. 5. Alternating layers of limestone and skarn cut by pegmatite. The pegmatite has been displaced by secondary flow of the marble to the right. Note the detached fragments of pegmatite in the marble. Darker lines in the marble are also displaced. (Sørensen phot.).

Fig. 6. Banded lime-silicate gneiss with replacement pegmatite. Note the constant alignment of the bands in- and outside the pegmatite. A few dark bands can be followed into the pegmatite (see below the center of the photograph). (Sørensen phot.).

PLANSJE 3.

(Fotografier fra Engenbreen.)

Fig. 1. Den is-skurte fjell-flata foran Engenbreen. De lyse stripene er kalk-marmor-lag.

Fig. 2. Småfoldet kalk-marmor-lag.

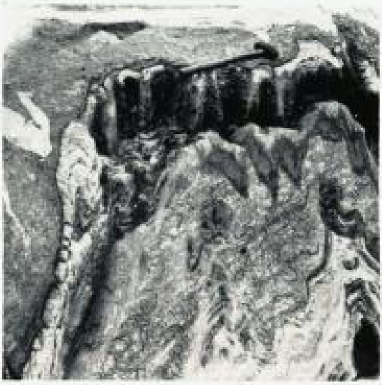
Fig. 3 og 4. Amfibolitt (mørk) brutt opp ved plastiske bevegelser i kalkstein (lys).

Fig. 5. Kalkrike sedimenter (stripet) som skjæres over av pegmatittgang. Pegmatitten er »forkastet« og brutt ved bevegelsen langs marmorsonen (lys). Den fortsetter på høyre side av marmorsonen, bakerst på fotografiet.

Fig. 6. Båndet kalksiliatgneis med pegmatitt.

Pl. III

1



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The Zones of Amphibolite. These zones are, as mentioned on page 156, characterized by vertical axes of folding and have lenticles of peridotite. We have had no opportunity of studying the behaviour of these zones in the western closure of the anticlinorium of the peninsula, but we are, for the time being, strongly inclined to relate their formation to the first phases of the downfolding, when they may have functioned as shear zones. If this is correct, then the peridotites were formed in the first tension stages of deformation (compare H. H. Hess, 1948 and H. Sørensen, 1953). The two perioditic masses are, in accordance with this view, highly deformed.

The bands of amphibolite in the gneiss south of the Fondal anticline may be a remnant of another amphibolite zone.

Sammendrag.

Et eksempel på granittisering i den sentrale sonen av kaledonidene i Nord-Norge.

Innledning.

Sommeren 1952 ble det foretatt en detaljert undersøkelse av Rendalsvik grafittfelt, Holandsfjord, Nordland (beliggenhet se oversiktskart fig. 1) for Norges Geologiske Undersøkelse. På grunn av undersøkelsens praktiske formål ble feltarbeidet begrenset til et lite område. Da resultatene av de geologiske undersøkelsene synes å ha betydning for forståelse av kaledonidene (fjellkjeden) i denne delen av Norge, har vi gitt denne foreløpige oversikten. Ved siden av den geologiske kartlegginga tok stiger R. Kongsgård ved Norges Geologiske Undersøkelse opp et detaljert topografisk kart (1 : 1000) over grafittfeltet.

Vi ble møtt med usedvanlig stor vennlighet og hjelpsomhet av befolkningen omkring Holandsfjord. Dette lettet arbeidet for oss betraktelig og vi vil benytte anledningen til å takke for all hjelp.

En oversikt over geologien i området. Kaledonidene i Nord-Norge blir vanlig delt i en vestlig sone (langs kysten) med metamorfe (omdannete) sedimenter, en sentral sone med granittintrusjoner og en østre sone med metamorfe sedimenter. Holandsfjord ligger i den sentrale sonen. Mens strøkretningen (retningen av lagene i fjellet) hovedsakelig er NNØ—SSW ellers i kaledonidene, stryker lagene øst—vest i området omkring Holandsfjord. Halvøya mellom Skarsfjord—Holandsfjord og Tjongsfjord er bygget opp av metamorfe sedimenter — opprinnelig kalksteiner, glimmerskifer og kvartsitter. Disse bergartene ligger nå stort sett som en sadel (antiklinal) på halvøya. Toppen av sadelen går omtrent langs midten av halvøya, mens de bratte skråningene mot Holandsfjord og Tjongsfjord er henholdsvis nord- og sydsidene (-benene) av sadelen. På disse stedene ligger store granittmasser over sedimentene. En rekke mindre granittpartier opptrer på halvøya.

Området mellom Rendalen og Engenbreen var gjenstand for detaljerte geologiske undersøkelser. Et forenklet kart over geologien der er gitt i fig. 2. Vi har skilt ut tre hovedgrupper av sedimenter på kartet, kvartsitt og glimmerskifer (prikker og brutte linjer), grafittlaget (svart) og en kalkrik serie (sammenhengende linjer). Granitt og gneis er avmerket med kryss.

De dype snittene (på tvers av strøkretningen) langs Fonndalen og de blankskurte fjellflatene foran Engenbreen og breen innerst i Fonndalen ga gode opplysninger om geologien i området. Profil (fig. 3) viser et geologisk profil langs Fonndalens vestside. Hovedtrekkene av geologien i grafittfeltet går fram av profil (snitt) (fig. 4) som er lagt nord-syd over Hovedgruva og Midtfeltet. Granittene og de granittiske bergartene er gjenstand for en nærmere beskrivelse og diskusjon.

Granittene i den sentrale sonen av kaledonidene i Nord-Norge er alminnelig beskrevet som intrusiver (lokolitter og fakolitter) (magmatisk opprinnelse). Vi kan ikke akseptere en mekanisk intrusjon(»framtrengning«) av granittene ved Holandsfjord. Det er en gradvis overgang fra sedimenter til granitt. Strukturene i sedimentene er ofte bevart i gneiss og granitt — uten tegn på oppbrytning ved grensen. Overgangen fra glimmerskifer til granitt like syd for Fonndalsskjerpet er vist skjematisk på fig. 5. Det er tydelig at granitt og gneis flere steder er dannet på bekostning av sedimentene (omdannete sedimenter). I Nord-Sverige finner de flere steder at granitt, under fjellkjedebevegelsene, er skjøvet fra vest over og opp på sedimentserien. Det er mulig at også granittens opptreden omkring Holandsfjord delvis kan forklares ved at den er skjøvet inn over sedimentene på samme måten. Vi fant imidlertid ikke noe tegn på overskyvning i det området vi undersøkte.

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