The relation between the basal gneiss and the overlying meta-sediments in the Surnadal district, (Caledonides of Southern Norway).

By

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With 6 text-figures.

Abstract. The boundary between the basal gneiss and the overlying micaschists and micaceous gneisses is marked by a thin zone of "basal quartzite", but the quartzite is generally not at the exact boundary between the two divisions. Geologic and petrographic observations show an even transition between the rock types oligoclase-bearing micaschist, oligoclase gneiss and gneiss more or less rich in microcline, the end member of the series being a light massive gneiss of the basal gneiss type. The basal gneiss can thus not belong to a Pre-Cambrian basement complex, its upper part at least must be of Caledonian origin.

Introduction.

Surnadal is the valley of the river Surna in the district of Nordmøre, in the north-western part of Southern Norway (Fig. 1). In the lower 20 km of its course the valley has been carved out along a synclinal strip of Cambro-Ordovician meta-sediments, a narrow extension from the Trondheim Region, bounded by gneisses at the sides.

The existence of the Surnadal synclinal strip has been known at least as far back as 1870, when it was laid down on the geological map by Th. Kjerulf and K. Hauan accompanying Kjerulf's 1871 paper on the geology of the Trondheim Region.

The western, seaward part of the Surnadal syncline, with which the present paper is concerned, was surveyed in 1875 and 1876 by L. Larsen, cand. real., then a teacher at the Grammar School of Kristiansund, who worked as a field assistant to the Geological Survey under the leadership of Kjerulf. His diaries are to be found in the archives of the Geological Survey.

In Kjerulf's review of the geology of Southern Norway (1879) the Surnadal area was very briefly mentioned (p. 170, p. 182).

The deposits of limestone in the Surnadal area were mentioned by C. Bugge (1906).

In 1909 the seaward part of the Surnadal syncline was surveyed by Olav Melkild, an amateur geologist connected with the Geological Department of Bergens Museum (now the University of Bergen). His diaries and collections are kept at the said institution.

On the map in V. M. Goldschmidt's well known paper (1916) on the Caledonian eruptive rocks of Southern Norway a strip of augen-gneiss has been marked at the northern side of the Surnadal syncline under the heading of "augen-gneisses at the boundary of the Trondheim Region" (translated).

N. H. Kolderup (1932) in a paper on the Caledonian geology of Western Norway devoted a brief section to the Surnadal area. A geological sketch-map in his paper is based upon the work of Melkild.

C. Bugge (1934) discovered green "Trondheim schists" on the islands in the Romsdalsfjord, occurring as a strip in the gneisses and forming an extension to the west—south-west from the Surnadal strip. His paper also deals with the conditions in Surnadal (pp. 167—170) and gives a section from the diaries of L. Larsen mentioned above.

Professor Olaf Holtedahl visited the Surnadal area in 1947, in a paper read at the London Congress in 1948 (Holtedahl 1952, p. 139) he briefly refers to the conditions in that area.

A chief geological problem in the Surnadal area is the relation of the undoubtedly Caledonian meta-sediments to the underlying gneiss or basal gneiss. As generally in this part of the Norwegian Caledonides this gneiss underlies the meta-sediments with a more or less well marked petrographical boundary, but always with a perfect structural conformity. It is thus, at any rate, impossible to regard the basal gneiss as an unchanged Pre-Cambrian basement complex.

The basal gneiss has been dealt with by the writer in an earlier paper, with a review of the chief litterature dealing with the subject (Strand 1949). Three papers recently published by H. Holtedahl (1950) and N.-H. Kolderup (1951, 1952) have a bearing on the problem of the basal gneiss.

The writer made several visits to the Surnadal area during the summers 1947—1951, but has not done any extensive field work, and the general account of the geology here given rests for the greater part upon the work of Larsen and Melkild.[1] Neither do the maps at present available invite any detailed mapping.

Geology.

The geology of the seaward part of the Surnadal district will appear from the map Fig. 1. The boundary between the basal gneiss and the overlying meta-sediments, to be described in more detail in the sequel, is marked by a zone of quartzite generally of 1 to 10 m thickness, referred to as the basal quartzite. The rock above the basal quartzite is either a mica-schist or a gneiss, in the latter case the gneiss in most cases differs from the underlying basal gneiss by a higher content of biotite, which gives the rock a dark colour and a rusty weathered surface, as distinct from the more lightcoloured and massive basal gneiss. But the following descriptions will show that the rocks at the boundary are not of fixed petrographical types.

The mica-rich gneisses of the type referred to above can not be separated from the micaschists of the Surnadal sequence, the two types of rock grade into each other and there are no mapable boundaries between them. At the small lake at (57, 7) it can also be seen that porphyroblasts of potash feldspar develop in the micaschists or mica-gneisses, and that these rocks thus grade into the gneisses rich in potash feldspar, which are the dominating rocks in the area centering about (56.5, 5), in mountains reaching altitudes of more than 900 m a. s. l. The gneisses of this area are not homogeneous, they grade from micaceous gneisses, often augen-gneisses, to very massive gneisses rich in potash feldspar. It may be that this part of the area has an anticlinal structure and that parts of the gneisses here correspond to the basal gneisses surrounding the area. In any case nothing has been found to suggest that the gneisses

[1] The diaries and material of Melkild have been at the writer's disposal, thanks to the courtesy of Professor N.-H. Kolderup.

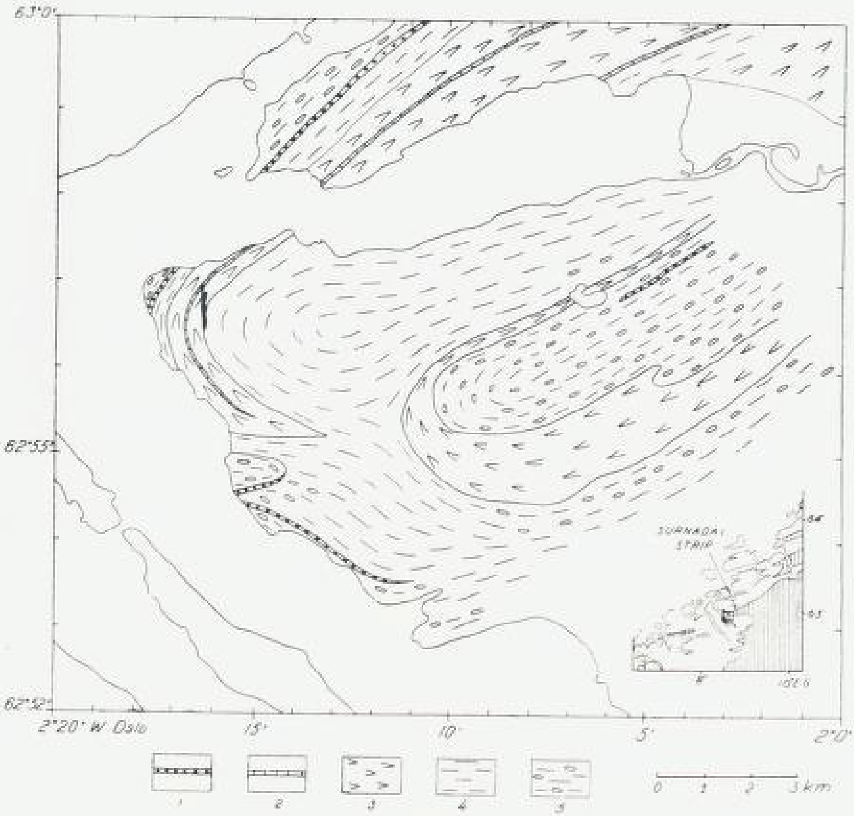

Fig. 1. Geological sketch-map of the Stangvik peninsula.
1. Quartzite. 2. Limestone. 3. Greenstones (fine-grained amphibolites of volcanic origin). 4. Oligoclase-bearing micaschists and oligoclase gneisses. 5. Gneisses more or less rich in potash feldspar.

in question should represent a sheet of rock overthrust above the meta-sediments, as was suggested by N.-H. Kolderup (1932, p. 37).

Apart from the micaschists and the gneisses derived from them the Surnadal sequence contains bands of volcanic greenstones of the type characteristic of the Trondheim Region. A north-western band can be followed from east of Stangvik (about 55, 12), where it seems to pinch out to the east, in a curve to the north and north-east across the Surnadal Fjord.

Intercalated in the greenstone is a band of limestone, which is being worked at the north side of the Surnadal Fjord.

A south-eastern band consists of rather fine-grained amphibolites, which may be in general more massive and dark-coloured than the rocks in the north-western band. But the rocks can be followed across sections of great thickness without being coarse-grained or assuming massive structures, this should indicate a supracrustal origin. In the top of the mountain Vindnebba (56, 3) porphyritic structures were observed in these rocks, at the same locality there were intrusions of massive saussurite gabbro. As shown by the map Fig. 1 this band of greenstones occurs on both sides of the area of gneisses mentioned above, but it is unknown whether the band is really continuous at the corner about (55.6, 9).

Concerning the stratigraphy and tectonics of the Surnadal sediments little or nothing can be said until the area has been mapped in detail.

Intrusive gabbroid rocks are common in the Surnadal sequence. In a wholly recrystallized state they occur as concordant bands of amphibolite, less common as larger bodies with more ar less well preserved original structure.

Ultrabasic intrusives occur as small lense-shaped bodies. One such body is exposed at the road-side just east of Skei, 1 km east of the eastern boundary of the map Fig. 1, other bodies are found at Vasseng (58, 3,5) and above Røen seter (about (54.5, 10)), where soapstone has been quarried for local use, according to Melkild.

Mining claims on sulphide ores are found within the area of the map Fig. 1 at Vasseng and at Søyset. As far as can be seen, the deposits are very small.

The micaschists and the dark micaceous gneisses contain bands, mostly of about decimetre thickness, of light rocks of a trondhjemitic composition (quartz, oligoclase and a little biotite). Characteristic of these rocks is a rather coarse-grained gneissic structure with diffuse boundaries to the side rocks, thus they may degenerate into scattered porphyroblasts of oligoclase, as beads on a chain. At the north side of the Surnadal Fjord, at

Glærum (about 59.5, 4.5) the same sort of rocks occur with very irregular cross-cutting boundaries to the side rocks.

The lack of sharp boundaries and of fine-grained congealing structures makes it difficult to consider the rocks in question as intruded igneous rocks. They are certainly homologous to the light bands, often of quartz-dioritic composition, found in many banded gneisses.

In the following a number of sections displaying the boundary between the basal gneiss and basal quartzite and the overlying rocks are to be described in some detail.

We are to begin with the section at the road Øye—Bæverfjord at the north-west side of the Surnadal syncline, situated at 63° 1′.5 N, 2° 4′ W Oslo, north of the area of the map Fig. 1. (Fig. 2.)

The basal gneiss is here a reddish rather homogeneous rock, rich in potash feldspar. The basal quartzite appears as two or three bands of quartzite or quartzitic light gneiss separated by dark micaceous gneiss with bands of amphibolite. To the south-east follows dark fine-grained gneiss with large, scattered augen of potash feldspar and further micaschists with porphyroblasts of oligoclase, which may gather to form veins.

The basal gneiss comes to light in the promontory at (57, 18). According to Melkild (diary August 5. to 7., 1909) the gneiss is overlain by a quartzitic rock of some metres thickness. Above the quartzite he records the sequence: micaschist, augen-gneiss, amphibolite, micaschist. He declares to be quite at a loss to decide if this sequence belongs with the overlying sediments or with the underlying "Archaean" basal gneiss.

The promontory at Toreslott (54, 15.5) is formed by basal gneiss overlain by quartzite of a thickness up to 15 metres while no rocks above the quartzite are exposed (Fig. 2). The lower part of the basal gneiss is very massive and homogeneous, its upper part below the quartzite consists of dark micaceous gneisses, partly devoid of potash feldspar, and of augen-gneisses. Of special interest is the find of a band of oligoclase micaschist in the basal gneiss at this locality. This rock has a striking resemblance to the oligoclase-bearing micaschists of

Surnadal both in hand specimen and under the microscope, it also contains a few small grains of staurolite, commonly found in the Surnadal micaschists.

At Kråkhaug west of Kvanne (53.5, 12) a massive basal gneiss is overlain by a quartzite of a few metres thickness, above this basal quartzite follow grey gneisses, partly very schistose and rich in biotite, partly more massive. The boundary is here well marked and appears distinctly in the landscape.

East of the area of the map Fig. 1 there is a good section at the south side of the Surnadal valley and syncline, at the tarn above Honstad (63° 59′ N, 1° 53′ W Oslo) (Fig. 2).

In the valley near the road at Honstad a micaschist with porphyroblasts of oligoclase is exposed, further up the valley slope dark rather massive finegrained rocks are met with, the same oligoclase gneisses as are found farther west. At the tarn the rock is a massive reddish gneiss rich in potash feldspar. The gneiss is not homogeneous, as it contains bansd of augengneiss (augen of walnut size), schlieren very rich in biotite, and bands of finegrained schistose rocks, and also a band of amphilobite. South of this gneiss a quartzitic rock is exposed, parts of it show distinctly a banding indicative of a sedimentary quartzite. Further south at the foot of the mountain Honstadknyken is a light gneiss rich in quartz, which may be perhaps of a quartzitic derviation. Thus the basal quartzite at this locality seems to grade into the basal gneiss without any marked boundary.

Petrology.

Micaschists and plagioclase gneisses.

The micaschists are darkish brown and rather coarsegrained. They grade from normally fissile schists to more tough and massive rocks, similar to gneiss and shown by the microscope to be especially rich in oligoclase.

The following minerals are found in these rocks:

Quartz.

The plagioclase is oligoclase of a composition varying from An 15 to An 25—30, but more commonly on the calcic side of

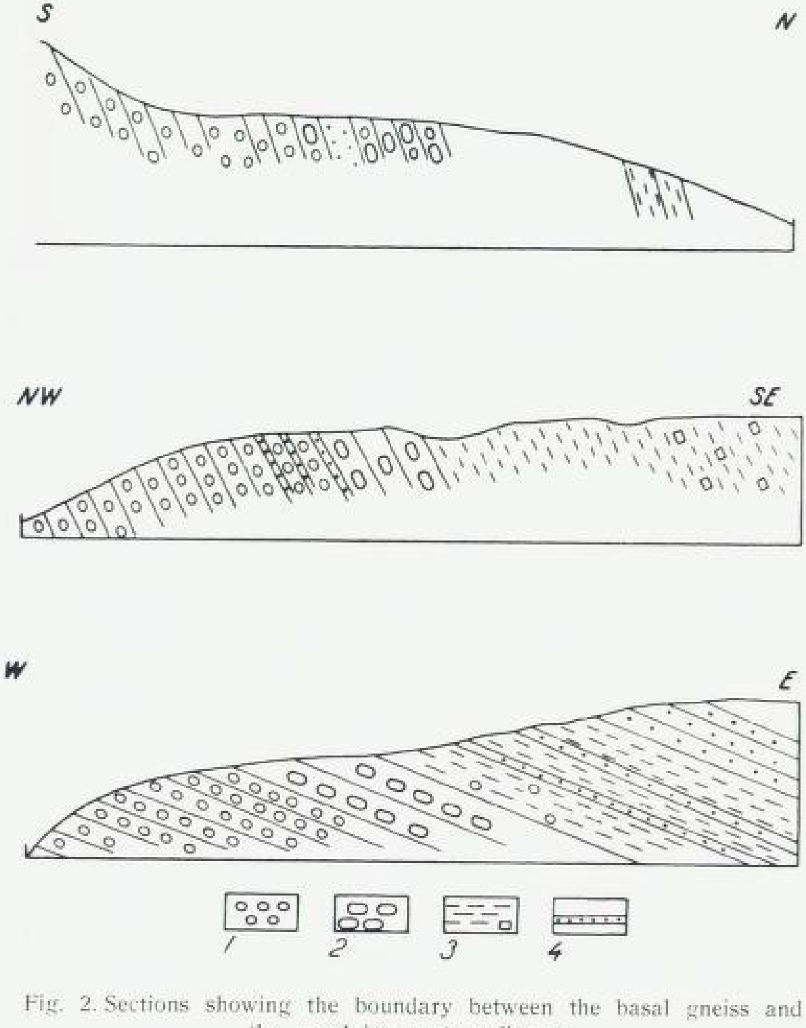

Fig. 2. Sections showing the boundary between the basal gneiss and the overlying meta-sediments.

Upper section: at the tarn above Honstad, middle section: at the road Øye—Bæverfjord, lower section: at Toreslott. See the text p. 105.
1. Gneisses more or less rich in microcline. 2. Augen-gneisses (with large porphyroblasts of microcline). 3. Oligoclase-bearing micaschists and oligoclase gneises (partly with large porphyroblasts of oligoclase). 4. Quartzite.

the oligoclase interval. The variation in composition is shown by the occurence of zoned grains, partly of the inverse type.

Zoisite and clinozoisite.

The biotite has a light yellowish brown colour, and can be easily distinguished from the biotite of the gneisses to be described later. The index of refraction on cleavage flakes is near to 1.625, according to measurements of the biotite in four of the rocks.

Chlorite, faintly greenish and optically positive is certainly an alteration product of the biotite.

Muscovite.

Garnet.

Staurolite is found in some of the rocks, occurring as a single or a few grains in some of the slides, less than a millimeter in size.

Amphibole is found only in a few of the slides and is of no importance quantitatively.

Calcite.

Apatite, iron ore and tourmaline are accessories, the latter very rare.

A composite sample of two specimens of micaschist from Stangvik in the Melkild collection of the Geological Institute of Bergen (labelled M28 and M32 by the writer) was analysed (No. 1), while an analysis of a micaschist from a road-side quary near the Glærum farm (E26v 176) is found under No. 2. The calculated modes show these rocks to be more rich in plagioclase than would be judged from the sections studied, it must, however, be emphasized that the mode calculations are in general uncertain, as the accurate composition of the minerals are unknown.

An analysis of a composite sample of micaschists especially rich in oligoclase is found under No. 3, the following rock specimens were used for the preparation of this sample: E26v 103, Grønnes (53.8, 12.8), E26v 110, Vasseng (58, 0.5), E26v 135 Toreslott (band in gneiss, see p. 105) (54.2, 14.5), E26ø 121, at the road west of the Skei road-junction (58.3, 59.8), E25v 104, at the road to Bæverfjord (1, 4) and two specimens from Stangvik in the Melkild collection, labelled M30 and M33 by the writer.

Analysis No. 4 is of a composite sample of two specimens from a road-side quarry just east of Surnadalsøra (E26v 162—63) (58.4, 2.7). The rocks are schistose and of a dark colour like that of the micaschists, but are more tough; the microscopic examination shows plagioclase to be an important constituent of the rock occurring as lense-shaped porphyroblasts 0.5 to 2 mm in size and surrounded by the other minerals of the rock. The biotite is of the yellowish brown type characteristic of the micaschists.

The epidote mineral mainly found in the oligoclase gneiss is clinozoisite which grades into epidote poor in iron; zoisite is found in one of the rocks.

The four analysed samples represent sediments of an original pelitic composition, changed during metamorphism in the direction of decreasing excess of alumina by means of an increase in the contents of calcium and sodium (low k-values). The silicate lime of the rocks may partly or wholly have its origin from the reaction between carbonates and silicates, while the increase in the sodium contents must be due to metasomatic processes during metamorphism. This question has been discussed by the writer in a recent paper (Strand 1951, p. 92 f).

The mineral facies of the rocks is determined by the occurrence of oligoclase (An 20—30) together with zoisite or clinozoisite-epidote, the metamorphism may be classed as being in the middle part of epidote amphibolite facies (saussurite facies or low gneiss facies of Rosenqvist (1952)). The varying composition of the plagioclase indicates a variation of temperature during the metamorphism.

The five main components Al, Mg—Fe, Ca, Na, K are represented by the five minerals plagioclase, clino-zoisite (zoisite), muscovite, biotite and garnet. The amphibole and staurolite, in some of the rocks appear to be extra minerals, indicating that the rocks did not reach any perfect equilibrium at a fixed point or in a very small interval in the P. T. space.

Lime silicate gneisses and limestones.

The material used for the analysis No. 5 of lime silicate gneiss is composed of the samples E26v 116, 157 and 159, collected at the road-junction at Grimsmo (58.2, 0.2). The rocks are heterogeneous with alternating bands of biotite-rich schist and of coarse-grained, greenish rock with the appearance of a gneiss.

The minerals are:

Quartz.

The plagioclase is oligoclase with small extinction angles in sections (100). Some of the grains are zoned.

Potash feldspar, occurring as irregular inclusions in the plagioclase.

Zoisite and clinozoisite, the latter in subordinate amounts. Both the α and β varieties of zoisite occur, sometimes in the same grain, while other grains show heterogeneity in the variation in birefringence and axial angle.

The biotite is of the faintly coloured yellowish brown type also occurring in the micaschists, refractive index on cleavage flakes 1.620.

An amphibole with faint greenish colours and a large negative axial angle is found. $\gamma \sim 1.660$ (159) $\gamma \sim 1.665$, $\alpha \sim 1.635$ (157), indicating mg about 0.60 on the assumption that the mineral belongs to the tremolite-actinolite series.

Pyroxene has been observed in sample 116, it is a colourless clinopyroxene.

Accessories are calcite, sphene and pyrite.

The schistose bands of the rock rich in biotite, have an average grain size of about 0.5 mm and are composed of all the usual minerals except pyroxene. There are also coarse-grained bands free of biotite, with quartz, zoisite (in porphyroblasts up to 5 mm), amphibole and occasionally pyroxene. The pyroxene hast hus not been found in immediate association with the biotite.

Microscopic observations show that similar lime silicate gneisses are rather common among the rocks exposed along the road-side both east and west of the locality of the analysed sample.

M34 is impure crystalline limestone from near Stangvik (55.15) (coll. Melkild, Geol. Inst. Bergen). Grain size of the calcite 1—3 mm, silicate minerals are scattered through the rock and separated by the calcite grains.

The silicate minerals are:

Quartz.

The plagioclase is of varying composition often with an inverse zoning, in sections $\perp$ [100] the kernels have negative extinctions angles, $\alpha \wedge$ (010) up to 9°, the rims have small positive extinction angles, $\alpha \sim 1.540$ or lower, maximum contents of anorthite thus about 25.

The potash feldspar is untwinned, it can be easily recognized by the low refraction. Most of it occurs as antiperthitic intergrowths in the plagioclase.

The zoisite is β-zoisite with the axial plane normal to the good cleavage, $+\ 2V \sim 30°$.

Biotite, yellowish brown, a few tiny flakes, in wholly subordinate amounts.

Muscovite, $-\ 2V \sim 30$—$40°$, many of the grains with ragged and sutured outlines, indicating a partial resorption of the mineral.

M35 is impure crystalline limestone from near Stangvik (55,15), (coll. Melkild, Geol. Inst. Bergen).

The silicate minerals are:

Quartz.

The plagioclase of a varying composition.

Potash feldspar occurs very sparingly as a few small grains.

Zoisite.

Biotite is light yellowish brown. $\gamma \sim 1.615$.

Amphibole has faint greenish absorption colours, $\gamma \sim 1.650$. In an immersion liquid with index 1.620 three grains were found with α greater and one with α smaller than the liquid. This indicates mg ~ 0.75 on the assumption that the mineral belongs to the tremolite—actinolite series, if it is an alumineous amphibole the mg-value will be still higher.

There is an obvious association between the amphibole and biotite, some inclusions of biotite in the amphibole are apparently remnants of almost wholly resorbed grains.

E26v 174, is from the road section near Glærum (59.5, 6) it is a fine-grained impure crystalline limestone.

The silicate minerals are:

Quartz.

Plagioclase, $\alpha \sim 1.540$, about An 20.

Clinozoisite with a varying birefringence, showing interference colours up to red of the first order, parts of it thus to be classed as epidote.

Muscovite, small flakes of a colourless mica occur sparingly in one band in the rock.

Biotite, reddish brown, $\gamma \sim 1.620$.

Amphibole with normally strong absorption colours, γ blueish green, β yellowish green, α colourless, $\gamma \sim 1.655$, $2V \sim 80—85°$. Probably it is an aluminous amphibole of the type characteristic of the present facies, in that case it will have mg ~ 0.75 (Foslie 1945). A member of the tremolite—actinolite series with the same indices of refraction will have mg ~ 0.60.

Accessories are iron ore, pyrite (or pyrrhotite) and a few grains of tourmaline.

In this rock also the amphibole is associated with the biotite.

A lime silicate rock of a very extreme composition occurs as a lense in the dark micaceous gneiss at the road-side 2 km east of Skei (E26ø 105, 58.5, 57.5).

It consists of quartz, zoisite and clino-zoisite, clinopyroxene and calcite, with iron ore and sphene as accessories.

The clinopyroxene has $+ 2V$ about 60°, $c \wedge \gamma$ 40°, $\alpha \sim 1.690$, $\gamma \sim 1.720$, this indicates mg to be about 0.65. A powder preparation of this rock was examined in an immersion liquid with index 1.660, but no carbonate other than calcite could be detected.

There can be no doubt that the lime silicate rocks and impure limestones described in the preceding contain lime silicates formed by the reaction with carbonates. In the impure limestone M34 the reaction muscovite, calcite → zoisite, potash feldspar has certainly taken place. Ramberg (1944, pp. 58, 82) has earlier shown that this reaction sets in at a stage in the epidote amphibolite facies where the anorthite contents of the plagioclase amounts to 15—20. This has been confirmed by the rock here described.

Even if amphibole occurs in two of the impure limestones here described, there is no equally convincing evidence of a reaction between biotite and calcite resulting in the formation of amphibole. The fact that biotite commonly occurs together with calcite seems to indicate that this reaction must have been a slow one.

There is a possibility that the formation of the amphibole may have been at the expense of dolomite. No dolomite has been found in any of the rocks by tests on the index of refraction, but the mineral may have been present originally and exhausted by reaction with the silicates. This assumption would explain the high contents of magnesia relative to iron, as shown by the analysis of the lime silicate gneiss and also by the refractive indices of the amphiboles and pyroxenes in the other rocks here described.

When a potash-bearing mineral (mica) reacts with a carbonate to form a lime silicate, a simultaneous formation of potash feldspar is to be expected. But in most of the rocks here described the potash feldspar is absent or present in very subordinate amounts only. This seems to indicate that metasomatic processes have been involved in the formation of the lime silicate rocks, at least so far as removal of potash from the rock is concerned. This must certainly be true in the case of the quartz—zoisite—pyroxene rock described above. It is very doubtful if pyroxene can form at the expense of carbonate at the facies stage of the present rocks.

Lime silicate rocks of a similar extreme composition have been described and discussed by the writer in an earlier paper (Strand 1951, p. 80 f.).

The gneisses.

The rocks to be treated under this heading are immediately connected with the basal gneiss, and the material is from the localities described in the foregoing, the greater part of it is from the sections in Fig. 2. The following minerals have been found in the gneisses.

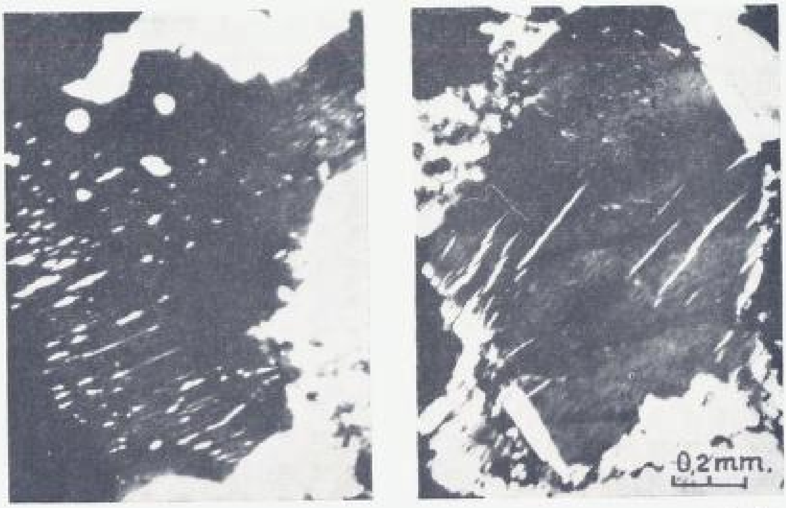

Fig. 3. Microcline perthites from the gneisses of the Surnadal district. Left: patch and film perthite, E26v 128. Right: vein perthite, E26v 143. Nic. +

Quartz.

The plagioclase is an oligoclase. Part of the plagioclase is myrmekite.

Epidote, mostly rich in iron, is present, but clinozoisite or zoisite have not been found.

Microcline is of the type with a hazy twinning pattern. It has perthitic inclusions of three diferent kinds. The first type is a vein perthite in which a clear albite form faintly undulating veins with acutely tapering ends (Fig. 3, right). There is another type of vein perthite with the form of the inclusions irregularly lense-shaped or of a quite irregular form, approaching that of patch perthite. The boundary to the microcline is not very sharp and the albite material is often turbid due to small dark-looking inclusions. The third type is film perthite with the albite in very thin sheets. The film perthite is associated with the perthite of the second type and the thin films are often seen to be in connection with lense-shaped veins. (Fig. 3, left.) Fig. 4 shows the position of the perthite inclusions.

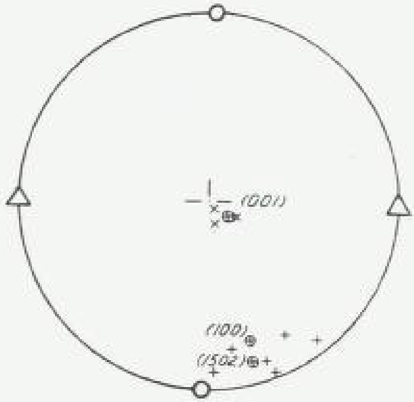

Fig. 4. Diagram (stereographic projection) showing the position of 6 poles of perthite lamellae in gneisses from the Surnadal district, also with 3 measurements of (001) cleavage cracks. Poles of faces of microcline according to Nikitin (1936, pl. 6).

The biotite of the gneisses can be distinguished from the biotites of the micaschists and associated rocks by their much stronger absorption colours, often of dirtyish green shades.

At Toreslott, as mentioned on p. 105, a band of micaschist rich in oligoclase was found in the gneisses, this micaschist is a remnant of the material which by further transformation gave rise to the gneisses. The biotite in this micaschist is of a faint yellowish brown colour, the refractive index on cleavage flakes is about 1.625, a usual value for the biotites of the micaschists. The biotite in the gneiss E26v 133 from the same locality (1 in the diagram Fig. 6) is of a dark brownish colour, with n on cleavage flakes about 1.640. A light granitic gneiss, occurring as a band in more dark gneisses (E26v 135, 7 in the diagram Fig. 6) has a dark almost opaque-looking biotite with n on cleavage flakes about 1.650.

Muscovite is found in some of the gneisses as rather large, scattered porphyroblasts, which may appear to have penetrating relations to the other minerals of the rock.

Garnet and amphibole may be found in some of the gneisses.

Iron ore and sphene are found as accessories.

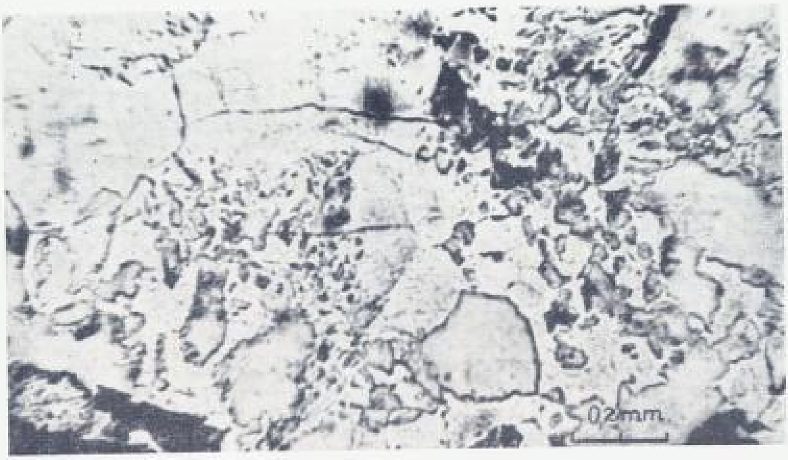

Fig. 5. "Amoeboid" structure of microcline in gneiss, E26v 104. Focus a little below the plane of the section, the microcline appears light by the Becke line effect.

All the microcline-bearing gneisses show very characteristic structures in the boundary relations of the microcline to plagioclase and other minerals. The microcline seems to penetrate in among the other constituents of the rock, one might be tempted to say in an "amoeboid" manner (Fig. 5). The plagioclase often occurs as inclusions in the microcline, often the inclusions have a very irregular outline and several neighbouring inclusions may be in the same optical orientation, indicating that they are remnants of one larger grain. Part of the plagioclase occurring under these conditions is myrmekite, and antiperthitic plagioclase seems also to be characteristic.

The structures of this kind must be taken to indicate that the microcline was deposited in the rock by a simultaneous corrosion and replacement of the plagioclase. During this process the amounts of the biotite decrease, the decrease being accompanied by a rise in the strength of the absorption colours and refraction of the mineral.

These trends in the history of the rocks is illustrated by the diagram Fig. 6.

In the monograph of Drescher-Kaden (1948) on the "Feldspat—Quarz—Reaktionsgefüge" of the granites and gneisses a

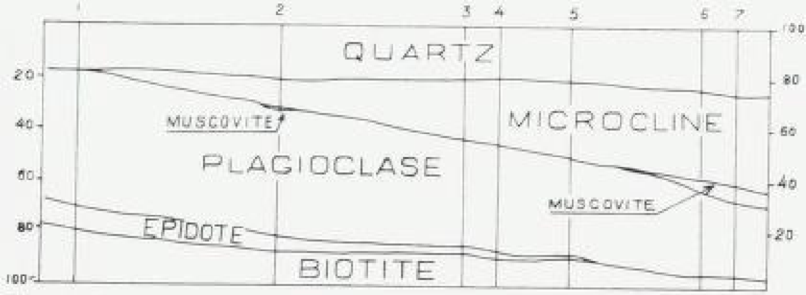

Fig. 6. Diagram showing the mineral composition of microcline-bearing gneisses from the Surnadal area. 1. E26v 130, north-west of Toreslott, 2. E26ø 110, Honstadtjernet, 3. E25v, road Øye—Bæverfjord, 4. E26v 104, Kråkhaug west of Kvanne, 5. E26v 133, same loc. as 1, 6. E26v 128, promontory at the Church og Stangvik, 7. E26v 136, Toreslott.

chapter is devoted to the description of myrmekite of the pre-microcline type formed during the corrosion of plagioclase and the simultaneous growth of potash feldspar. Here a series of descriptions and very good illustrations are given of the penetrative and corrosive structure of the potash feldspar referred to above. The monograph of Drescher-Kaden shows these structures to be of a very common occurence in gneisses and granites. Structures of this kind in Norwegian gneisses have been described by the present writer in an earlier paper (Strand 1949, pp. 21—26).

The rocks described in the preceding chapter show a progressive change from micaschists to plagioclase gneisses by the growth of plagioclase with a decrease in the surplus of alumina in the rock. An end member of this transformation series may be a gneiss as exemplified by No. 1 in the diagram Fig. 6. A second phase in the transformation process is the progressive replacement of a great part of the plagioclase by microcline, described in the present chapter. The two phases may overlap to some extent, as is shown by some augen-gneisses with large porphyroblasts of microcline in a matrix corresponding to a micaschist rich in oligoclase and epidote. Field geology and descriptive petrography can thus give the proof of rock metamorphism taking place with a regional, large scale exchange of material in the earth's crust, but it is quite another matter to be able to understand the processes at work. In the present case we know from the determination of the mineral facies of the rocks that the temperature was too low to allow the rock complexes involved to be in a magmatic state. Neither is there any trace of intrusion of magmas, which could justify our looking upon the process as an injection in a more verbal sense. We are thus forced to believe in the transport of material in a highly dispersed state.

Summary and conclusions.

The Surnadal Region displays a continuous series of rocks ranging from micaschists rich in oligoclase to gneisses of a granitic composition. There are two phases in the metasomatic changes undergone by the rocks. In the first phase addition of sodium and lime takes place and the original pelitic material is finally changed into a gneiss consisting of about one fifth of quartz, about three fifths of plagioclase (eventually with zoisite—epidote minerals) and about one fifth of biotite. In the second phase part of the plagioclase is being replaced by microcline and the amounts of biotite decrease, so that some of the rocks may reach a typical granitic composition.

There is a more or less marked boundary between a microcline-bearing basal gneiss and the overlying plagioclase-bearing gneisses and micaschists more rich in biotite. A horizon with quartzite, the "basal quartzite", is found near or at the abovementioned boundary. If this boundary separates an Archæan basement from overlying Caledonian rocks, the division must be drawn below the "basal quartzite' as was suggested by the writer in an earlier paper (Strand 1949, p. 8). The sections here described and pictured in Fig. 2 show that the boundary between the more massive gneiss of the basal gneiss type and the overlying more biotite-rich rocks may be found below as well above the "basal quartzite".

No definable boundary can thus be recognized between the basal gneiss and the overlying rocks of an undoubted Caledonian age. We must conclude that he upper part at least of the basal gneiss in this region is a Caledonian rock, formed from Caledonian material by metasomatic processes.

Conditions corresponding to those in the Surnadal area will certainly be found in many other regions in the north-western gneiss area of Southern Norway (Ramberg 1944, p. 140 f, Strand 1949, p. 13 f.). It is, however, very probable that gneisses of an Archæan derivation are present in parts of this large area. In those regions where the Caledonian migmatisation has transformed the lower part of the Caledonian sediments, it will certainly be very difficult, perhaps at present impossible, to distinguish between the Caledonian and the underlying Archæan gneisses.

One observation should be made here: in their present state the rocks show little or no sign of tectonical movements localized on distinct planes, as might have been expected, e. g., between the "basal quartzite" and the adjacent rocks. Thus the tectonical *mise-en-place* of the rocks must be older than the metamorphism and metasomatism, by which the present sets of minerals were formed. On the other hand there is much to indicate a younger age of the large scale folding which gave rise to the Surnadal synclinorium.

Sammendrag.

Forholdet mellom basalgneisen og de overliggende omvandlete sedimenter i Surnadalsområdet.

Surnas dal følger en synklinal av glimmerskifrer og grønstener, som på siden er omgitt av underliggende gneis, Surnadalsfliken, en utløper mot WSW fra Trondheimsfeltet. L. Larsen og Olav Melkild har gjort geologiske undersøkelser i Surnadal henholdsvis i 1875—76 og 1909. I den geologiske litteratur er området blitt behandlet av Th. Kjerulf 1879, N.-H. Kolderup 1932, C. Bugge 1934 og O. Holtedahl 1952.

Basalgneisen i Surnadal overleires av glimmerskifrer eller mørke glimmerrike gneiser, som utvilsomt geologisk hører sammen med glimmerskifrene. Som ellers i det nord-vestlige gneisområde er grensen mellom de to avdelinger fullstendig konkordant. Et kvartsittlag på noen meters tykkelse, »basalkvartsitten«, finnes mange steder ved grensen mellom basalgneisen og de overliggende sedimentbergarter. Et nøyere studium av »basalkvartsitten« viser at den ikke alltid ligger nøyaktig på grensen, den kan ligge både et stykke over basalgneisen og et stykke nede i den (profilene fig. 2).

Glimmerskifrene inneholder ganske store mengder av plagioklas (kalk-natronfeltspat), og de går uten tydelig grense over i ganske massive mørke glimmerrike bergarter, som kan betegnes som oligoklasgneiser (analyser 1—4). Det finnes også mange steder bergarter som etter mineralinnhold og geologisk opptreden hører sammen med glimmerskifrene, men som inneholder innsprengninger (øyne) av mikroklin (kalifeltspat). Mikroklinen må ha vokset fram i bergarten under omvandlingen. Disse bergarter kan videre med jevn overgang følges over i massive gneiser med rikelig innhold av mikroklin, helt av samme type som basalgneisen. Geologiske iakttagelser i marken viser således at disse gneiser kan oppstå av glimmerskifrer ved omvandling ledsaget av stofftilførsel og stoffomsetning (metasomatose). Det nærmere petrografiske studium tyder på at stoffomsetningsprosessene kan deles i to faser. I en første fase opptar glimmerskifrene natrium og kalsium og går over til plagioklasgneiser, i en følgende fase tilføres det kalium og kalifeltspat vokser fram i bergarten, til dels på bekostning av biotitt, men for en stor del på bekostning av plagioklasen. Mikroskopiske strukturer tyder på at plagioklasen blir korrodert samtidig som mikroklinen vokser, sistnevnte mineral brer seg i bergarten med meget uregelmessig »amøboid« struktur (fig. 5). Gangen i denne fase av stoffomsetningsprosessen illustreres av diagrammet fig. 6.

Hvis basalgneisen skulle være av prekambrisk alder, som det tidligere har vært alminnelig antatt, måtte »basalkvartsitten« markere grensen til de overliggende sedimenter av sikker kambro-ordovicisk (kaledonisk) alder. Men de ovenfor omtalte forhold viser at »basalkvartsitten« ikke ligger nøyaktig ved grensen. Når dette sees i sammenheng med den påviste omvandling av glimmerskifer til gneis, må konklusjonen bli at i all fall den øvre del av basalgneisen er en kaledonisk bergart, oppstått av kaledoniske sedimenter ved omvandlingen under fjellkjededannelsen. Basalgneisens ganske skarpt markerte øvre grense blir å betrakte som en grense for gneisomvandlingen ved kalitilførsel og dannelse av kalifeltspat i bergartene.

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Analyses, norms and modes.

1. Micaschist, composite of two specimens from Stangvik (p. 108).
2. Micaschist, Glærum (p. 108).
3. Micaschist rich in oligoclase, composite sample of seven specimens from the Surnadal area (p. 108).
4. Oligoclase gneiss, composite of two specimens from Surnadalsøra (p. 109).
5. Lime silicate gneiss, composite of three samples, Grimsmo (p. 110).

Analyses.

Analyst: Brynjolf Bruun.

	1.		2.		3.		4.		5.	
SiO_2 ...	71.03	11823	56.54	9414	62 62	10426	59.24	9863	57.59	9589
TiO_2 ...	0.85	106	0.95	118	1.07	134	0 86	108	0.86	108
Al_2O_3 ..	12.87	1263	18.80	1845	15.00	1472	14.61	1433	14.93	1465
Fe_2O_3 ..	0.71	45	0.82	51	0.72	45	0 72	45	1.40	88
FeO ...	4.78	665	7.76	1079	5.63	784	5.59	779	4.60	640
MnO ..	0.09	13	0.14	20	0.07	10	0.12	17	0.17	24
MgO ...	2.57	637	4.61	1143	3.96	982	3 69	915	4 96	1230
CaO ...	1.84	328	2.14	382	3.55	633	6.94	1238	9.54	1701
Na_2O ..	1.75	282	1.96	316	2.08	336	1.96	316	1.66	268
K_2O ...	2.57	273	2.75	291	2.40	255	2.28	241	2.00	212
P_2O_5 ...	0.22	16	0.15	11	0.28	20	0.07	5	0.18	13
CO_2 ...	nil		0.31	70	0.67	152	2 90	660	0.95	216
H_2O+..	0.01		0,12		0.09		0.09		0.02	
H_2O+..	1.00		2.79		1.56		1.26		0.98	
	100.29		99t84		99.70		100.33		99.84	

Niggli parameters.

	si	al	fm	c[1]	alk	mg	k	$\frac{c+alk}{al}$
1.	330	35.7	39.6	9.2	15.5	.45	.49	.54
2.	184	36.2	45.8	6.1	11.9	.49	.48	.49
3.	235	33.3	42.4	10.9	13.4	.52	.43	.73
4.	225	32.6	41.1	13.4	12,9	.51	.43	.79
5.	175	26.6	37.6	27.0	8.8	.59	.43	1.32

[1] The c values do not include carbonatic lime.

Mol — norms.

	1.	2.	3.	4.	5.
Q	39.4	18.0	26.0	23.4	15.2
Or	15.8	17.0	14.9	14.8	12.4
Ab	16.3	18.6	19.6	19.4	15.6
An	7.9	8.1	12.2	17.2	28.6
C	5.0	11.4	5.5	3.9	-
Σ sal	84.4	73.1	78.2	78.7	71.8
Wo	-	-	-	-	5.4
En	7.3	13.4	11.6	11.2	14.4
Fs	5,8	11.5	7.2	8.4	5.3
Mt	0.8	0.9	0.8	0.8	1.5
Il	1.2	0.8	1.6	0.7	1.2
Ap	0.5	0.3	0.6	0.2	0.4
Σ fem	15.6	26.9	21.8	21.3	28.2
	100.0	100.0	100.0	100.0	100.0
Cc	-	0.8	1.8	8.1	2.6

Modes.

	1.	2.	3.	4.	5.
Quartz	45	22	31	28	20
Oligoclase	18	25	25	25	20
Zoisite, clinozoisite—epidote	2.5	-	3	6	24
Potash feldspar	-	-	-	-	0.x
Biotite	15	18	18	19	21
Chlorite	2	15	6	-	-
Muscovite	10	13	9	7	-
Garnet	6	5	5	5	-
Staurolite	0.ox	-	0.ox	-	-
Amphibole	-	-	0.ox	2	9
Pyroxene	-	-	-	-	0.5
Iron ore	1	1	1	1	0.5
Sphene	-	-	-	-	2
Apatite	0.5	0.3	0.5	0.2	0.5
Calcite	-	0,8	1.5	7	2.5
	100.0	100.1	100.0	110.2	100.0