SUPRACRUSTAL AND INFRACRUSTAL ROCKS IN THE GNEISS REGION OF THE CALEDONIDES WEST OF BREIMSVATN[1]

By

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Contents.

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Abstract.

Two rock complexes can be distinguished in the Gneiss region west of Breimsvatn in Sogn & Fjordane, West Norway.

The upper complex is composed essentially of original supracrustal rocks: calcareous, psammitic and pelitic schists and biotite-plagioclase gneiss with significant intercalations of gneiss, meta-anorthosite, amphibolite and ultrabasite. An «eclogite-like rock» is also recorded. The lower complex is largely composed of migmatite, two-feldspar gneiss and gneiss-granite which has been mechanically transformed into augen gneiss. It is regarded as part of the infracrustal, Precambrian core of the Caledonides in West Norway. The rocks of the upper complex can be arranged in a succession of mappable units, but possible sliding tectonics and recumbent folding make stratigraphical relations still uncertain. The age of the supracrustal rocks is not clear, although it is assumed to be Eocambrian or older corresponding to Precambrian units of the central nappe region.

The contact between the supracrustal rocks and their basement is concordant, but strong differential movements shared by both complexes have taken place. Both have experienced two phases of east-west folding, the latest of which is responsible for the pattern of lithological distribution in the investigated area.

Introduction.

The Basal Gneiss problem.

The contact zone between schists on the coast and the gneisses further inland has presented intriguing problems since the early days of geological studies in West Norway (Fig. 1). Early geologists (Irgens & Hiortdahl 1864, Kjerulf 1879, Reusch 1881 and C. F. Kolderup 1923) regarded the gneiss in the east as the Archaen basement for the schists. The choice of rock types to be incorporated among the «schists» am, however, equivocal. N.-H. Kolderup (1928) reduced the area previously mapped as «schists» considerably by relating the anorthosites and their associated quartzites and mica-schists of Nordfjord and Sunnfjord to the Precambrian or possibly Eocambrian. He draw attention to the lack of evident break between the metamorphic sedimentary rocks and the gneisses: the contact was concordant and gradational like in the Oppdal—Sunndal area.

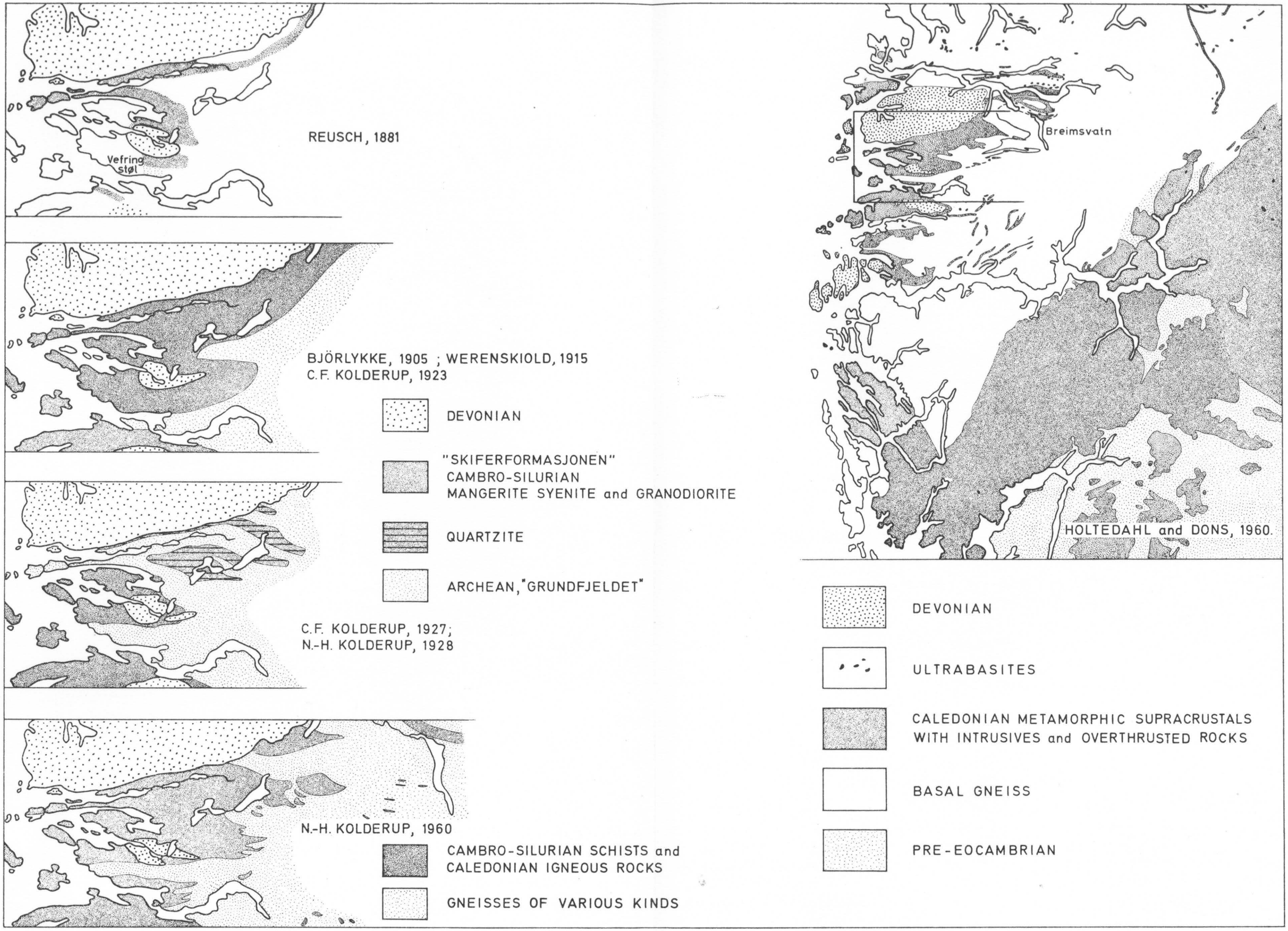

Fig. 1. Various interpretations of the contact between «schists» and the gneisses further inland in parts of West Norway. One of the localities where Reusch (1881 p. 145, 168) first described the contact between the «schists» and their Precambrian basement is indicated in the upper left insert (Vefring støl).

Results of the present mapping of the contact between infracrustals and supracrustals is shown by full and dashed line on map to the right.

The vast Gneiss region of the Norwegian Caledonides was later reinterpreted (O. Holtedahl 1936 p. 136, 1938 p. 52, 1944 map, Kolderup & Kolderup 1940 p. 129, N.-H. Kolderup 1952b p. 238): the rocks in the central zone of the orogen were «believed to have been mainly formed by high-grade metamorphism, migmatization, and granitization of preexisting rocks (Archean, Eo-Cambrian, Cambro-Silurian)» The quote was made from the legend to the map accompanying O. Holtedahls paper from 1944. It could not be doubted that Precambrian (Archean) rocks formed part of the Gneiss region (Rosenqvist 1941 p. 25, Strand 1960 p. 232), but where and in what state?

Gjelsvik (1951 p. 36, 44) suggested that the gneisses of Sunnmøre were essentially transformed Eocambrian and Cambrian metasediments with mobilized and completely transformed Precambrian basal layers possibly uncovered in some anticlines. He inferred later (1953 p. 86, 93 and Fig. 4) that less altered Precambrian rocks might be present in the anticlines between Nordfjord and Sogn. N.-H. Kolderup (1960 p. 15) explained the gneisses of Nordfjord and Sunnfjord as products of granitization of Cambro-Silurian and Eocambrian rocks, but said that it could not be denied that also Precambrian elements might form parts of the area. A Late Precambrian eugeosynclinal stratigraphic sequence was postulated by Hernes (1965, 1967) for this and adjoining parts of the Gneiss region. Skjerlie and Kildal (personal information 1965) who have undertaken detailed geological mapping in Sunnfjord and Sogn have strongly advocated that a distinction between Caledonian supracrustals and their original Precambrian basement *could* be defined in the field, – in fact, the distinction originally made in Irgens & Hiortdahl (1864) and Reusch (1881) was valid in principle.

The structural relations of the Gneiss region were depicted by O. Holtedahl (1936, 1938, 1944 and 1952) as a system of recumbent folds. Field evidence from the Oppdal area indicated that rocks in this central part of the Caledonides had obtained a state of plasticity which made basement as well as cover deform by recumbent folding. The mobilized basement could be expected to form extended zones congruently incorporated within the supracrustals. A structure of this sort was illustrated by Muret (1960) in a significant contribution which showed piling-up of Pennine-type nappes composed essentially of Precambrian cores with thin mantles of supracrustal rocks. He claimed that evidence of an original discordant position was still discernable.

There is no reason to question O. Holtedahl's and N.-H. Kolderup's contensions that the *western* part of the Gneiss region of West Norway to a large extent is made up of altered Cambro–Ordovician and Eocambrian rocks, but the *eastern* margin has proved to be Precambrian and has been indicated as such on all geological maps (Bjørlykke 1905, Werenskiold 1915, O. Holtedahl 1944, Holtedahl & Dons 1953, revised 1960). Rekstad (1914 p. 12–14) published figures which indicated even angular unconformity below the schists, Goldschmidt (1941 p. 198) noted the presence of conglomerate above the true Precambrian basement and Landmark (1949 p. 42, 48, 57, also referred to by Strand 1960 p. 238) demonstrated that migmatitization processes in the gneisses took place in the Precambrian and that the basement was affected only by mylonitization, shearing and sheeting during Caledonian movements. Recent studies of the eastern margin of the Gneiss region (Banham & Elliott 1965, Banham 1968) confirmed the Precambrian age of the gneisses and Strand (1966, 1969 and personal information) was able to map a possible contact between the basement and younger metamorphic supracrustals at Grotli within the basal gneiss region. A true Precambrian Rb–Sr isochron age (1.000 $\pm$ 150 m.y.) was obtained by Brueckner et al. (1968) for corresponding basement gneiss at Tafjord. The complex structural relations at Grotli indicate that the basement has been deformed in Caledonian time, similar to that anticipated by O. Holtedahl (1944) on his tectonic map of the Norwegian Caledonides.

N.-H. Kolderup's maps (1928, 1960) and the most recent geological map of Norway (Holtedahl & Dons 1960) show a number of isolated outcrops of Cambro-Silurian and Eocambrian rocks in the western part of the basal gneiss region. A line drawn at the easternmost extension of these outcrops must be located near the contact between the «caledonized» Precambrian basement and the assumed Caledonian supracrustals (Wegmann 1959 p. 56, Bryhni 1966 p. 10), but its validity is dependent on the correctness of the age assignment given to these supracrustals.

The relations in the northern part of the basal gneiss region were studied by Birkeland (1958) who demonstrated that two distinct tectonic units were present in western North Trøndelag: (1) an old Precambrian basement complex and (2) a younger Caledonian system of transformed early Paleozoic geosynclinal rocks with intrusives. The younger system rests on the older with a profound unconformity. Supracrustal rocks were present in the Precambrian basement. These important results were reinterpreted (Holtedahl & Dons 1960) or overlooked in later maps or regional geological studies.

The «basal granites» of North Norway have offered the same problems as the basal gneiss of South-West Norway. Vogt (1942) considered that many, perhaps most of the granites were Precambrian and was supported by Kautsky (1946) and Gustavson (1966) who contended that the gneiss-granite in the coastal areas were thrust sheets which had been recrystallized and mobilized during the Caledonian orogeny. Rutland & Nicholson (1965) found that the Precambrian basement had rather taken part in plastic nappe tectonics comparable to that of the Pennine zone in the Alps. The main transport of the nappes was accomplished at an early stage before the main metamorphism and the slides between the nappes consequently show concordant structures on either side.

Present study.

The contact between Caledonian cover rocks and their «caledonized» basement is at present very difficult to define unambiguously in the coastal districts of West Norway, although an important attempt has been made on the MÅLØY map at scale 1 : 250 000 (Kildal 1970). Mica-schist and feldspathic quartzite in this part of the country are usually referred to as Cambro-Silurian or Eocambrian rocks. This is an assumption which should be tested — may be the metamorphic supracrustals rather belong to the Precambrian basement? The problems met with in the MÅLØY map area made it clear that detailed studies in selected areas with simpler basement/cover relations were desirable. Only by integrated interpretation of such small areas can a reliable stratigraphic-tectonic map of regional scale possibly emerge.

The present report is still at the reconnaissance scale. It gives results of a study of the contact relations between rocks of assumed supracrustal derivation and a complex of massive gneisses in an area west of Breimsvatn, Sogn og Fjordane Co. and some data on the lithologic succession in this area. Botanic studies (Nordhagen 1954) had indicated that schists and carbonate rocks were present and this was confirmed by one of the present writers (Bryhni as assistant for Prof. N.-H. Kolderup) at Blåvatn—Måsvassdalen in 1956 and Vonen—Årdalskupa in 1957. The reconnaissance indicated that the schists formed synforms above massive granitic gneisses, and the area therefore appeared promising for a closer study of general basal gneiss problems.

Fig. 2 gives the main results of the present study. Two major rock units have been distinguished:

1. An inhomogeneous complex of calcareous schist, meta-arkose, feldspathic quartzite, mica-schist and gneisses of assumed supracrustal origin. Significant amounts of meta-anorthosite, banded gneiss and amphibolite occur interlayered with these rocks, and ultrabasite and an «eclogite-like rock» do also occur.

2. A relatively homogeneous complex of massive two-feldspar gneiss, migmatite and augen gneiss.

The two units correspond respectively to the Fjordane and the Jostedal complexes of Bryhni (1966). The homogeneous complex of essentially granitic gneisses represent «infracrustal» rocks (Windley et al. 1966) which may be related to the supracrustals by sedimentary superposition, basement reactivation or by granitization/migmatization. The term «infracrustals» for these rocks is especially useful as long as the age of the supracrustals is unknown.

Lithologic succession.

Our geological mapping was performed on rather old and inaccurate maps at scale 1 : 100 000 for the major part of the about 500 km² area, and the tectonic or stratigraphic problems encountered in the field would certainly require more detailed studies to be properly solved. We have, however, studied some characteristic sections and established a tentative rock succession which could be a basis for later discussion of stratigraphy and structure of the area.

A description of the major rock units in the area around Storevatn follows below:

VII. *Ommedalen gneiss and meta-anorthosite.* This is structurally the uppermost unit which is exposed in the upper part of Ommedalen and in the mountain plateau south of Storeskarseggen. Massive anorthosite and schistose meta-anorthosite with layers or tectonic inclusions of amphibolite are the most common rocks together with augen gneiss.

VI. *Storeskarseggen meta-arkose.* This unit is well exposed south of Storeskarseggen where it occurs as a division several hundred meters thick of light gneiss with minor feldspathic quartzite and mica-schist. The light gneiss is essentially an epidote-muscovite-feldspar-quartz rock (minerals listed in order of encreasing amounts).

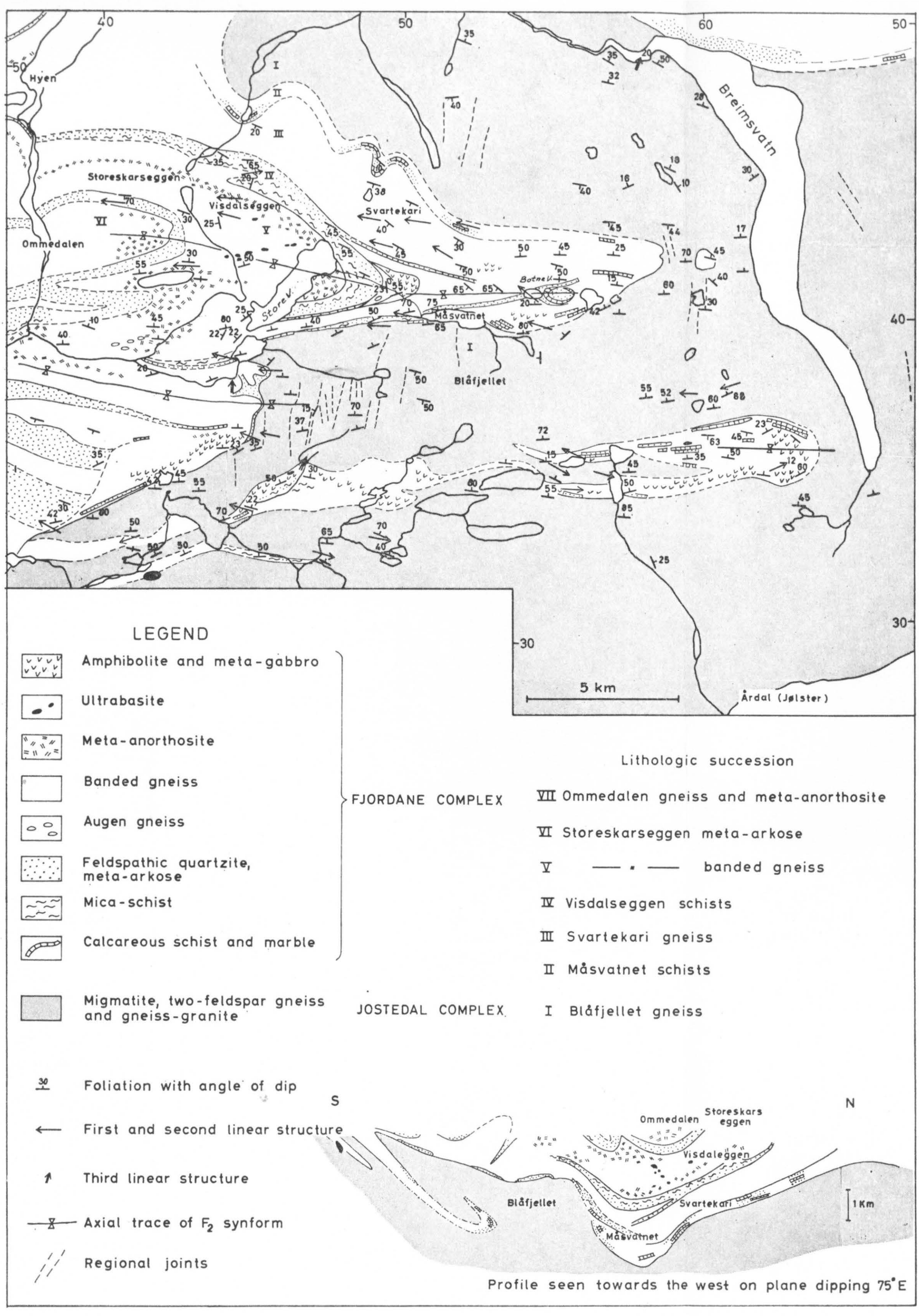

Fig. 2. Geological map, lithologic succession and tectonic profile of the area to the west of Breimsvatn. The profile is hypothetical in the southern part of the area where the fold axis has very variable trend and plunge.

Fig. 3. Interbanding of biotite-plagioclase gneiss and meta-anorthosite. Mountain plateau south of Storeskarseggen (LP 405/455), looking east towards Visdalseggen where a larger body of white meta-anorthosite can be seen.

V. *Storeskarseggen banded gneiss.* Most of the area west of Storevatn belongs to this unit, which is several hundred meters thick. The lithology is rather varied with banded biotite-plagioclase gneiss and meta-anorthosite, big bodies of anorthositic rocks, amphibolite, augen gneiss, and other gneisses with two feldspars. Several small bodies of serpentinite have been recorded within this unit. A small occurrence of «eclogite-like» plagioclase-garnet-clinopyroxene rock from amphibolite east of Storevatn also appear to be located within this unit. Small scale banding of biotite-plagioclase gneiss, meta-anorthosite and amphibolite (with anorthositic layers less than 10 cm thick) has been recorded at the mountain south of Storeskarseggen (Fig. 3).

IV. *Visdalseggen schists.* The upper part of this unit is a characteristic garnet-quartz-mica schist with up to 15—20 % rather euhedral garnets ½—2 cm in diameter. The schist is well exposed at Visdalseggen and at the south-western part of Måsvassdalen. Layers of feldspatic quartzite 0.1—5.0 m thick are often present in this mica-schist and amphibolite is found at places. The thickness of the unit is from a few hundred metres to less than 50 metres.

Fig. 4. Svartekari gneiss with characteristic white quartz-dioritic layers and lenticles. Svartekari (LP 500/440).

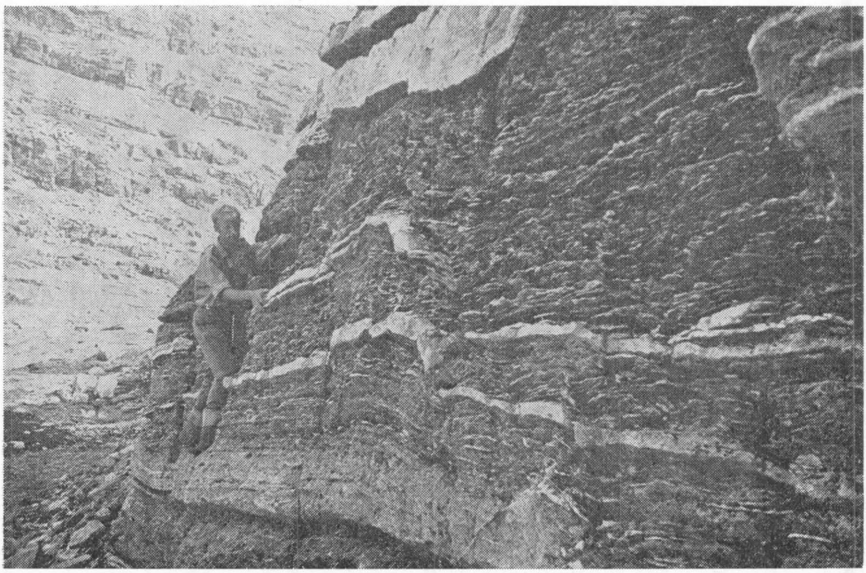

Fig. 5. Calcareous two feldspar-quartz-mica schist with layers of meta-arkose in which plagioclase is the dominant feldspar. Above Smørløysa west of Langevatn (LP 490/460).

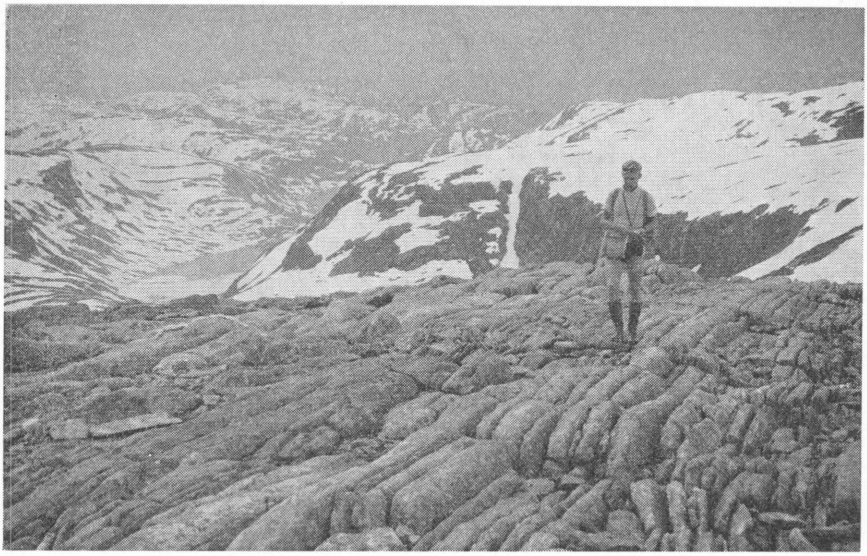

Fig. 6. Massive gneiss-granite with steep foliation (Blåfjellet gneiss). Blådalsfjell (LP 575/380).

Below the garnet-quartz-mica schist is a formation of meta-arkose 50—200 meter thick with minor feldspathic quartzite. White mica is often concentrated in layers between more massive benches in this rock.

Calcareous mica-schist with layers of impure, grey phyllonitized marble less than 1 meter thick is well exposed below meta-arkose east of Storevatn but has not been recorded elsewhere. The grey, fine-grained marble contains big books of white mica and is thus similar to marble in the Måsvatnet schists further down in the succession.

Massive augen gneiss with up to fist-size augen of potash feldspar occurs at the bottom of the Visdalseggen schists at the nose of the Måsvassdalen synform.

III. Svartekari gneiss. This is essentially a gneiss unit with banded biotite-plagioclase gneiss and biotite-quartz-two feldspar gneiss. It is present in characteristic development at the mountain Svartekari between Måsvatnet and Langedalsvatn where it has an apparent thickness of more than 1000 meters. White layers and lenticles of quartz-dioritic or of granitic composition can frequently be seen in the gneiss (Fig. 4). Pegmatitic layers and veins are especially found in the area to the east of Svartekari. Layers or isolated inclusions of amphibolite and hornblendite are rather common while quartzite and mica-schist are rare within this unit. A big body of amphibolite with relict gabbroic texture is present in Måsvassdalen.

II. Måsvatnet schists. Rocks within this unit were first referred to by Nordhagen (1954) who called attention to mica-schist and calcareous rocks at Måsvatnet. The rocks are well exposed at the south-western and at the eastern end of this lake, where they overlie the assumed basement (Blåfjell gneiss). The rocks which occur are: gneiss, amphibolite, garnet-quartz-mica schist, meta-arkose, feldspathic quartzite and calcareous mica-schist with interlayers of marble (Fig. 5). The marble is a white, pure calcite marble at Botnevatn east of Måsvatnet, but has often been mechanically transformed into a grey, fine-grained «limestone». White mica of the impure marble layers occurs as books up to several centimeters wide.

I. Blåfjellet gneiss. This unit consists of migmatites and gneisses with much potash feldspar, gneiss-granite and augen gneiss (Fig. 6). Pegmatite is rather common and often transgressive to foliation in the gneiss.

Infracrustals (Blåfjellet gneiss)

The gneiss occurring in the eastern part of our area has not previously been subjected to detailed studies. N.-H. Kolderup mentioned some related gneiss types (1928 p. 14—22 and 36) and demonstrated exposures during the Congress excursions in 1960 (Kolderup 1960). Kolderup noted that the rocks had a «sort of magmatic character» and that the gneisses were rich in potash feldspar or mica and sometimes had augen structure. The minerals reported were quartz, microcline or microperthite, albite, biotite, muscovite, garnet, epidote, sphene and black iron minerals. Myrmekite and chlorite also reported.

The area immediately west of Breimsvatn contains a variety of different rocks, among which the following structural types are prevalent:

Massive gneiss-granite.

Massive augen gneiss with abundant lensoid or folded pink augen ½—1 cm long.

Banded biotite-two feldspar gneiss with augen or lenticles of pink potash feldspar.

Migmatite with irregular coarse-grained quartzo-feldspathic veins and dykes.

The rocks are, however, rather homogeneous compared with those which occur structurally above them further to the west. The term «Blåfjellet gneiss» has been found appropriate for this unit. It is believed that the gneisses from Blåfjellet are continuous with rocks below the Jostedalen glacier to the east of our area and that they thus are representative of the infracrustal core of the Caledonides.

The massive augen gneiss of our area appear to have formed from original granitic rocks by penetrative shearing. The massive rocks have weakly developed foliation with widely spaced parting surfaces. A coarse layering or banding is, however, distinct when a cliff section is viewed at a distance. Lineation is omnipresent in the western part of the area where the gneiss has been subjected to shearing, and cross joints are very characteristic there. In fact, the infracrustal rocks in the western areas can be mapped from air photographs by their characteristic jointing.

Pegmatitic, granitic and white quartz-monzonitic layers or transecting veins are common. Amphibolitic intercalations veins occur more sparsely and have been transected by pegmatite. The most widely distributed rock is the gneiss-granite, which is essentially a magnetite-sphene-biotite-quartz-plagioclase-microperthite fels, and its sheared derivative, which is essentially a magnetite-sphene-white mica-epidote-quartz-plagioclase-microperthite augen gneiss (minerals listed in order of increasing amounts). Apatite, epidote-orthite, white mica, pyrite, and zircon are common accessory minerals and calcite, chlorite and red iron minerals occur secondarily. Fluorite and molybdenite have been found occasionally.

The most massive granitic rock is located at Førde in the south-east corner of our map. It is an unequigranular gneiss-granite or granite with 1—2 cm wide megacrysts of pink alkali feldspar which is partly intergrown with or mantled by plagioclase. Its ground-mass contains quartz and granulated plagioclase with grain-size mostly between 0.2—1.0 mm. This rock is, towards the west, progressively transformed into a foliated and lineated augen gneiss with flat or lenticular pink augen 0.5—2.0 cm long. The ground-mass is fine-grained with grains of granulated quartz and plagioclase 0.1—0.5 mm long.

Sections perpendicular to the lineation indicate that the alkali feldspar pophyroclasts have rotated relative to the matrix. The augen have remained relatively coherent during deformation while quartz and plagioclase broke down into granulated aggregates of very small grains which bend around the more resistant potash feldspar fragments.

Table I.

Modal composition of some samples from Blåfjellet gneiss. «x» indicates that the mineral is present in small amounts.

Compositions have been estimated by pointcounting thin section and stained slab of each sample.

Locality	Quartz	Alkali feldspar	Plagioclase	Myrmekite	Biotite	White mica	Chlorite	Epidote	Orthite	Sphene	Zircon	Apatite	Calcite	Black iron minerals	Red iron minerals	Pyrite
Gneiss-granite																
Førde, Breim, LP 66/34	24	32	33	x	7	x	x	x	x	2	x	1	x	1	—	x
Gneiss																
Sørsendalen, Breim, LP 58/42	31	41	18	x	5	3	x	1	x	x	x	x	—	1	x	x
Augen gneiss																
Blåfjellet, LP 48/37	22	41	26	x	5	x	x	4	x	x	x	x	—	2	x	x

Modal compositions of three selected rocks are given in Table I.

Quartz occurs in aggregates of lenticular grains 0.5—1.0 mm long with saccaroidal to interlobate contacts in the massive gneiss-granite and as aggregates of strongly elongated, strongly undulative grains 0.05 mm thick and 0.5 mm long with sutured boundaries in the augen gneiss.

Alkali feldspar is mostly an untwinned microperthite which at places has rods and veins less than 0.005 mm thick of fairly refrigent inclusions. The amount of these plagioclase inclusions varies from grain to grain and even within a single grain, but is usually less than a quarter of the total microperthite volume. The portion of plagioclase inclusions increases towards zones of granulated plagioclase which sometimes transects the microperthite. Undulative extinction and microcline twinning is distinct in some grains or parts of one grain. Myrmekite and aggregates of small plagioclase grains often occur in the marginal zone of the microperthite grains.

Plagioclase is obviously recrystallized in the gneiss-granite at Førde where it occurs as granular-saccharoidal aggregates of grains about 0.2 mm wide with some epidote. Plagioclase in augen gneiss have bent twin lamellae but is usually recrystallized into apparent untwinned grains. The composition of both the twinned and the recrystallized varieties of plagioclase is about An 30.

Biotite occurs as clusters of books 0.5—1.0 mm thick in the gneiss-granite and as «trains» of somewhat smaller books in very fine-grained micaceous folia in the augen gneiss. Pleochroism is: X pale yellow, Y, Z dark olive green or dark brown. Parallel intergrowths with chlorite are seen in a few grains within each thin section.

White mica is only present as tiny flakes in plagioclase aggregates in the gneiss-granite and as serictic aggregates together with biotite in augen gneiss.

Chlorite is always associated with biotite from which it appears to have formed by retrograde alteration. Pleochroism: X colourless, Y, Z green. Anomalous blue interference colours are usually seen. Many grains have acicular inclusions which probably are rutile.

Epidote minerals. Epidote occurs as tiny grains within plagioclase aggregates in the gneiss-granite and as grains 0.5—1,0 mm wide in the augen gneiss. Many grains in augen gneiss have a core of red-brown, almost isotropic orthite. Orthite sometimes occurs alone as inclusions in sphene and magnetite.

Sphene is very frequent and readily seen with the naked eye as red-brown grains 1—3 mm long. Polysynthetic twinning is often seen under the microscope.

Zircon is idiomorphic in the gneiss-granite at Førde from which it has been isolated as slender tetragonal prisms 0.2—0.3 mm long.

Magnetite is omnipresent and very characteristic for the gneiss-granite and the augen gneiss. The magnetic fraction of a crushed sample from Førde had abundant perfect octahedra 0.2 mm high which under the ore microscope were quite homogeneous.

Radiometric ages.

Two micas from pegmatite in the «Jostedalen complex» have previously yielded K/Ar ages of 590 m.y. (Ortevik, Sogn) and 582 m.y. (Loen, Nordfjord). Neumann (1960) who reported these radiometric ages assumed that they were probably lower than the true ages of rock formation because argon might have been expelled during a later period of Caledonian orogeny.

Older gneisses of Tafjord (Brueckner et al. 1968) have yielded a Rb/Sr isochron age of 1.000 (± 150) m.y. and a biotite age of 383 (± 12) m.y.

Biotite from a massive granite-gneiss at Førde south of Breimsvatn has been dated for the present study (Geochronological report No. FMK/692, 1969). A total degassing $^{40}Ar/^{39}Ar$ determination produced an apparent age of 398 (± 2) m.y. and a $^{40}Ar/^{39}Ar$ spectrum analysis gave an isochron age of 402 (± 1) m.y. Thus the last major phase of Caledonian orogeny in this area occurred around 402 m.y. and was of sufficient intensity to outgas and/or recrystallize almost all the biotite of the granite-gneiss.

It is well known that biotite ages are easily reset by later metamorphic events. It is seen clearly by the ages reported from Tafjord and it is also well demonstrated at Eidsfjord, Hardanger (Progress Report 1967 and 1968) where Precambrian rocks with very little petrographically perceivable Caledonian influence and Rb/Sr ages above 965 m.y. yielded biotite Rb/Sr and K/Ar ages of about 380 m.y. Work in progress will probably produce evidence that the infracrustal rocks around the southern end of Lake Breimsvatn are originally Precambrian like the older gneisses at Tafjord.

Supracrustals and Associated Rocks.

Cambro-Ordovician and older rocks which can be identified as original supracrustals occur extensively on the west coast of Norway (N.-H. Kolderup 1928, 1960). Various gneisses and rocks can be related to the «Anorthosite Kindred» (Kolderup & Kolderup 1940, p. 69); meta-anorthosite, amphibolite, mangerite syenite, etc., are associated with the supracrustals, and Bryhni (1966) assigned them all to a «Fjordane complex» distinct from an assumed Precambrian basal complex («Jostedal complex»).

Banded gneisses.

A distinct tectonic/stratigraphic unit with calcareous and other metamorphic sedimentary rocks (Måsvatnet schists) separates the gneisses now to be described from the infracrustal gneisses.

High content of mica — biotite and at places also muscovite — is characteristic, and glittering rock surfaces can often be seen because

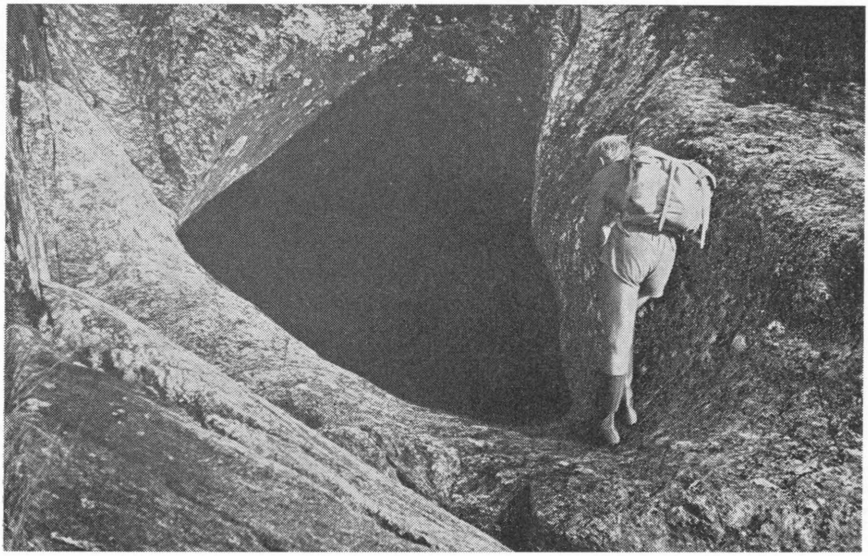

Fig. 7. One of the pot-holes carved out in massive augengneiss in ***Måsvassdalen*** *(LP 490/419).*

of mica-rich layers in the gneiss. The content of quartz varies much, but lenticles of pure quartz are frequently found. Many gneisses have plagioclase as the single feldspar although two-feldspar gneisses and even augen gneisses with much potash feldspar also occur.

Modal composition of some characteristic rocks is given in Table II.

Biotite-quartz-two feldspar gneiss.

Potash feldspar is present especially in the northern part of our area, in the unit termed «Svartekari gneiss». The structure of the potash feldspar bearing gneisses is usually characterized by alternating dark and light layers with white quartz-dioritic and sometimes even granitic bands often present. The amount of potash feldspar is variable, but usually small and confined to coarse layers and augen. Plagioclase is thus the dominant feldspar except in a variety of augen gneiss and in rare granitic and pegmatitic layers and veins. Augen gneiss with potash feldspar as the dominating mineral has been recorded in Måsvassdalen where it occurs in the contact zone between a feldspathic quartzite/meta-arkose and amphibolite and on the mountain plateau south of Storeskarseggen where it is associated with meta-anorthosite. The augen

Table II.

Estimated modal composition of various banded gneisses. «x» indicates that the mineral is present in minor amounts. «—» indicates that the mineral not been observed in the thin section.

Locality	Quartz	Potash feldspar	Plagioclase	Biotite	White mica	Chlorite	Garnet	Kyanite	Epidote	Orthite	Amphibole	Scapolite	Sphene	Zircon	Apatite	Black iron minerals	Red iron minerals	Pyrite
Åstølfjellet, LP435/377	20	20	45	10	3	—	—	—	2	x	—	—	x	x	x	x	x	—
NW Svartekari, LP 485/450	25	10	40	10	10	—	—	—	5	x	—	—	x	x	x	—	x	—
Svartekari, LP 500/440	20	10	60	10	—	x	—	—	x	x	—	—	x	x	—	—	—	—
Svartekari, LP 500/440	40	—	10	30	—	—	—	—	20	x	—	—	x	x	x	—	x	x
Svartekari, LP 500/440	20	—	55	12	—	3	—	—	10	—	x	—	x	x	x	x	—	—
N. Bergstølen, LP 407/367	22	—	33	17	x	2	24	x	x	—	x	—	—	x	—	2	x	—
N. Bergstølen, LP 407/365	20	—	60	16	x	x	2	—	x	—	—	x	—	x	—	2	x	—
N. Bergstølen, LP 407/365	30	—	10	10	43	x	x	—	x	x	—	5	x	x	x	2	—	—
Myklandsdalen, LP 613/362	20	—	46	26	—	—	—	—	x	—	1	—	1	x	x	6	x	—
E. Kupevatn, LP 563/353	38	—	19	18	—	1	2	—	15	—	7	—	—	x	x	x	—	—

gneiss at Måsvassdalen is an exceptionally massive (Fig. 7) and tough rock in which fine potholes have been carved out. The banding in the most widely distributed gneiss is due to alternation of epidote-quartz-biotite and biotite-potash feldspar-quartz-plagioclase layers (minerals listed in order of increasing amounts). The content of muscovite varies within wide limits, – from highly micaceous rocks similar to mica-schists to rocks devoid of white mica.

Amphibole, apatite, chlorite, limonite, orthite, pyrite, magnetite, sphene and zircon occur as accessory or secondary minerals.

Quartz usually occurs as granular aggregates and rarely as component of myrmekite.

Plagioclase (An 20) is strongly sericitized, saussuritized and sometimes even contains biotite inclusions. It has recrystallized into grains without inclusions at places, sometimes within the same thin section where other plagioclase grains are full of inclusions.

Potash feldspar is microperthitic with tiny plagioclase-component inclusions formed as rods and as veins. Inclusions have high relief and locally zoisite indicative of an original anorthite content. Irregular inclusions of potash feldspar in plagioclase or intergrowths between the two feldspars have also been noted.

Biotite (X pale yellow, Y, Z olive green or brown) and *muscovite* are often intergrown or aggregated with epidote and sphene.

Chlorite has formed from biotite at places.

Epidote is zonar with highest interference colours at rims. A core of red-brown *orthite* is sometimes present.

Sphene sometimes occur as mantles around black iron minerals.

Zircon is present as rather round grains.

Biotite-plagioclase gneiss.

A grey gneiss with much biotite and with plagioclase as the sole feldspar is the most widely distributed rock above the infracrustal complex. It often occurs with potash feldspar bearing gneisses in the unit termed «Svartekari gneiss» but is also present in higher tectonic/stratigraphic levels interbanded with mica-schist, feldspathic quartzite, amphibolite and meta-anorthosite.

The structure of this gneiss varies from rather homogeneous and massive «dioritic» types to banded and schistose rocks, and it can sometimes be demonstrated that this variation is related to mechanical deformation and accompanying neomineralization (phyllonitization). The most massive varieties are equigranular and medium-grained while the banded and schistose types are fine-grained and granulated with extensive sericitization of feldspar and biotitized or chloritized garnet. Massive rocks are essentially biotite-quartz-plagioclase felses while the sheared rocks are essentially white mica-epidote-quartz-plagioclase gneisses and schists.

Any of the minerals amphibole, epidote, garnet, kyanite and scapolite are locally characteristic constituents. Apatite, black iron minerals, orthite, pyrite, red iron minerals, sphene, zircon and zoisite occur as accessory phases.

Quartz is strained in the most massive rocks and granulated into aggregates of smaller, unequidimensional grains with sutured outlines in the sheared rocks.

Plagioclase is a basic oligoclase to acid andesine in the most massive rocks and acid oligoclase in the schistose types. Tiny needle- or flake-like inclusions of biotite, white mica and zoisite cloud the plagioclase even in the most massive rocks. These inclusions are often concentrated in the contact zone between adjacent plagioclase grains. Granulation has started at the grain margins in the massive rocks and is complete in the sheared rocks. Twinning has been obliterated by the abundance of inclusions in plagioclase of the massive rocks, but is often distinct in some of the sheared and recrystallized varieties which have smaller unequidimensional grains of plagioclase without inclusions.

Biotite (X colourless, Y, Z brown or olive green) is fringed by small grains of amphibole in the massive rock types and intergrown with chlorite in the sheared rocks. Inclusions of zircon, black iron minerals or sagenitic rutile are sometimes present.

Amphibole is present only in the massive rocks as blue-green hornblende on the margins of biotite. More sheared or recrystallized rocks have pale-green poikiloblastic actinolitic amphibole.

Epidote of the epidote-rich rocks has vivid interference colours with highest birefringence at the rims. Brown orthite occurs in some specimens and clinozoisite with normal low or anomal blue interference colours is sparsely present.

Garnet has round, xenomorphic outline or has been broken up into irregular fragments. Numerous inclusions are usually present. Biotite and chlorite have formed along cracks oriented perpendicular to foliation.

Kyanite occurs in layers with much garnet as fibrous masses.

Scapolite has sometimes very irregular outlines indicating interstital growth. Inclusions of black iron minerals are common. Yellow-brown alteration products are present along the rim and on cracks in the scapolite grains.

Apatite and *sphene* occur very sparsely, and sometimes fail to show up in one thin section.

Zircon is present as round or lenticular grains mostly less than 0.2 mm wide and is surrounded by pleochroitic halo when inclosed in biotite.

Chlorite is usually of a type with high refringence, normal low or anomalous brownish interference colours, weak pleochroism: X, Y pale green, Z colourless and negative elongation possibly corresponding to prochlorite. It has inclusions of sphene. Another type, often a retrograde product of garnet, has very lov, anomalous Berlin blue interference colours.

White mica is present as tiny inclusions in plagioclase of the relatively massive rocks and as sericitic aggregates in the sheared rocks.

The two types of gneiss described in this section are related by similar appearence and occurrence in the field, similar association with amphibolite and metamorphic sedimentary rocks and by similar properties of many of their minerals as seen in the microscope.

The gneisses are in some respects like those which occur in outer Nordfjord (Bryhni 1966 p. 17—32). The biotite-plagioclase gneisses of our area are, on the other hand, also similar to metamorphic dacites which occur in thrust slices above a migmatitic basement in the Bergsdalen area (Kvale 1946a p. 47—52 etc.).

Close association with quartzitic rocks and mica-schist indicates that the gneisses may have formed by metamorphism of original sedimentary and volcanic rocks although local interlayering with anorthosite and evidence of phyllonitization from original massive rocks make this explanation difficult to apply for *all* the biotite-plagioclase gneisses. It is possible that *some* gneisses have formed from more massive but flow banded plutonic rocks which by mechanical processes and neomineralization become schistose — like what can be seen in the overthrust masses of central Norway — while *others* have been produced from dacitic and rhyodacitic volcanics or from greywacke sediments.

Mica-schist, micaceous gneisses, meta-arkose and quartzitic rocks (Meta-pelites and meta-psammites).

Mica-schist, muscovite-rich gneisses, meta-arkose and feldspathic quartzites are interbanded and grade lithologically into one another. A characteristic example of interlayering of mica-schist and feldspathic quartzite is illustrated in Fig. 8 where the quartzitic layers are 5—200 cm thick.

Tight internal folding and armouring by quartz segregated into lenticles or fold-cores have rendered some varieties of mica-schist rather tough and massive. Small rounded topographical features are characteristic for them. Carbonate is locally present as lenticles with brown colour on weathered surfaces. The mica-schist is garnetiferous at places with abundant garnets up to 1 cm wide. Feldspar locally shows up as big, round porphyroblasts and the rock then grades into augen gneiss. Pyrite and tourmaline are mesoscopically discernable in some mica-schist and micaceous gneisses.

The meta-arkoses and feldspathic quartzites are white or grey rocks with much potash feldspar and white mica. Potash feldspar is usually

Table III.

Estimated modal composition of some mica-schists, micaceous gneisses and feldspathic quartzites. «x» indicates that the mineral is present in minor amounts. «—» indicates that the mineral was not observed in thin section
[1]) And rutile.

Locality	Quartz	Potash feldspar	Plagioclase	Biotite	White mica	Chlorite	Garnet	Epidote	Orthite	Amphibole	Sphene	Zircon	Apatite	Calcite	Tourmaline	Black iron minerals	Red iron minerals
N. Storevatn, LP 474/433	35	—	5	x	45	—	15	—	—	—	x[1])	x	x	—	x	x	—
Årdalskupane, LP 551/360	50	—	5	5	40	—	—	x	x	—	x	x	x	x	—	x	x
S. Storeskarseggen, LP 410/450	45	15	25	x	10	x	—	3	x	—	x	x	x	—	—	2	—
NW Vaslivatn, LP 405/430	40	20	10	1	26	x	—	2	x	—	x	x	x	—	—	1	x
Årdalskupene, LP 564/350	35	20	5	x	37	x	—	x	x	—	x	x	x	—	—	3	—
Ryg støl, LP 610/365	56	29	—	—	15	—	—	—	—	—	x	x	x	x	—	—	—
Gjengedal, LP 390/415	73	21	—	—	6	—	—	x	—	x	x	x	x	—	—	x	x
Årdalskupene, LP 564/346	71	17	—	—	12	—	—	—	—	x	x	x	x	—	—	x	x

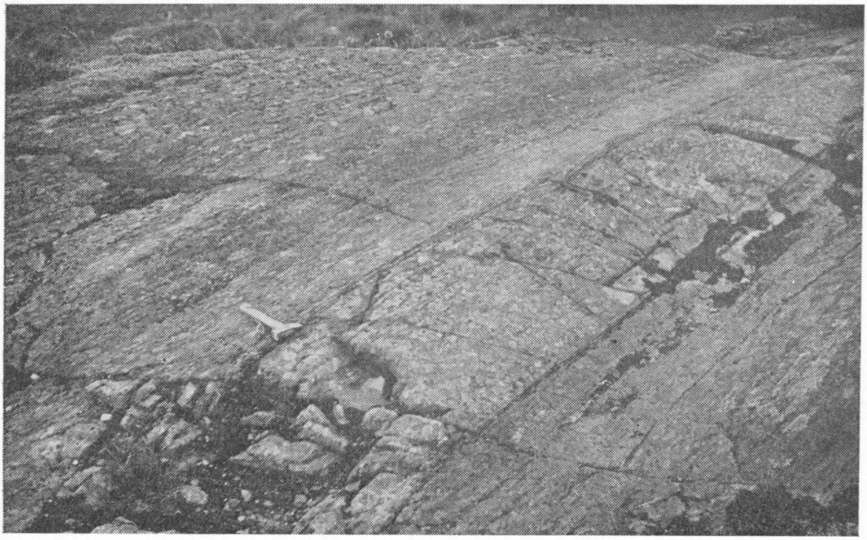

Fig. 8. Interlayering of feldspathic quartzite and mica-schist. Nesstøylen (LP 450/330).

dominating – sometimes the only feldspar present, but one sample (from Storeskarseggen meta-arkose) has more plagioclase than potash feldspar.

Apatite, black iron minerals (hematite, magnetite and ilmenite), orthite, sphene and zircon occur as accessory minerals.

Modal composition of some samples is given in Table III.

The texture of the mica-rich rocks is characterized by twisted books of white mica and by lenticular feldspar grains in a very fine-grained matrix of granular-sutured quartz. The quartzitic rocks are also usually very fine-grained with unequal-dimensional grains of strongly sutured quartz elongated in the foliation surface.

Potash feldspar has sometimes microcline «grill» but is mostly without twinning. Grains with irregularly distributed veins of plagioclase have been noted in micaceous gneiss but feldspar is usually non-perthitic. Potash feldspar of some quartzitic rocks is «dusty» due to very small brown inclusions.

Plagioclase is usually untwinned and never contain inclusions of potash feldspar. Albite has been noted in one thin section and basic oligoclase in another.

White mica often forms books up to 5 mm wide which may be externally granulated into sericite. Mantling by fine-grained biotite has been noted in a non-feldspathic calcite-bearing mica-schist. White mica of the quartzitic rocks has a green tint indicative of high iron content.

Biotite is always present in much lower amounts than white mica. Pleochroism is:

X colourless, Y, Z dark green, olive green or dark brown. Chloritization of biotite has been noted in one sample.

Epidote-minerals. Brown, zonar orthite is the only epidote-mineral in some of the mica-schists. It is then sometimes intergrown with black iron minerals. Epidoterich rocks have orthite only as cores within highly birefrigent epidote.

Sphene sometimes forms big porphyroblasts, but is usually present as small isolated grains or clusters of small grains intimately associated with black iron minerals.

The black iron minerals are in some cases magnetite, in other ilmenite and hematite. A polished sample shows the latter two to be finely intergrown.

Calcareous mica-schist and marble.

The calcareous rocks in the area are usually easily recognized by the rusty weathered surface, cavernous weathering and by the natural rockgardens with Silene acaulis, Dryas octopetala and various types of Saxifraga (Nordhagen 1954).

The main rock type is a coarse-grained calcite-quartz-mica schist with layers less than 1 meter thick of white marble or grey, impure, fine-grained «limestone». Potash feldspar as well as plagioclase occur in some varieties of the schist, and quartzo-feldspathic rocks are locally interlayered with it. Lenticles of quartz and of calcite are frequent.

The combined thickness of the calcareous rocks is usually less than 20 meters and often as little as 2 meters although thickness above 50 metres are reached at Botnevatn where tectonic thickening has taken place.

White marble from the west end of Måsvatnet is rather coarse-grained calcite aggregate with only a few grains of quartz and graphite. An impure «limestone» from the SE side of Storevatn is gray on fresh surface, contains white mica in books up to 1 cm wide but is otherwise very fine-grained. It contains about 60 % calcite, 20 % quartz, 15 % muscovite and 5 % plagioclase and is microscopically much sheared with folded lamination, twisted books of mica and granulated grains of quartz and plagioclase in a very fine-grained matrix of calcite, black iron minerals, sericite, sphene and orthite. The rock gives a false appearance of low metamorphic grade because of the grain-size and gray colour, but it is rather an impure marble which has been granulated.

A layer of calcareous mica-schist in feldspathic quartzite at Sletteheia west of our area has about 50 % quartz, 25 % plagioclase, 15 % calcite and 10 % muscovite. The quartz is present as segregations or as granulated aggregates. Apatite, green biotite, chlorite, black iron minerals, limonitized pyrite and sphene occur as accessory minerals. The high content of plagioclase in this rock is remarkable, and indicates that there may be a lithological transition between impure marble and quartzo-feldspathic gneisses. Local presence of plagioclase and potash feldspar in some calcite-quartz-mica schists and interlayering of such schist with quartzo-feldspathic rocks are, in fact, indicative of an original sedimentary environment where calcareous and arkosic psammites were deposited together.

Ultrabasites.

Ultrabasites occur within the series of assumed supracrustal rocks. They are developed as serpentinized dunite, serpentinite, chlorite schist and as talc schist. Only the biggest body, at Nes in Naustedalen, has been mentioned in the literature previously (Kolderup 1928) but the ultrabasites in our area appear to be related to those described from an adjoining area to the north (Kolderup 1952a). The ultrabasites west of Storevatn form an aligned association in micaceous gneisses with anorthosite. The biggest body is about 200 m long and 75 m wide, while the smallest are only 5—15 m thick schistose bodies interlayered with the micaceous gneiss.

Asbestos occurs in irregular veins and talc is concentrated in layers up to 1 m thick.

The two bodies in upper Naustedalen are developed as serpentinite schist on the contact between amphibolite and micaceous gneiss or between calcareous mica-schist and feldspathic quartzite.

It is interesting that the ultrabasites are associated with amphibolite and anorthosite. The whole rock complex has been too much altered to give any indication about the original relations between these rocks, but the fact that similar rocks occur together in vast areas north of our area (Bryhni 1966 p. 48) points towards a genetic connection, possibly involving magmatic fractionation, flow differentiation or differential melting of an igneous basic body.

«Eclogite-like rock» and other basic inclusions.

A massive rock with garnets in a pale-green, fine-grained clinopyroxene matrix has been recorded from an ultrabasic part of amphibolite east of Storevatn. The garnets ($n = 1.742$) are marginally symplectitized and granulated while clinopyroxene occurs both as strained porphyroclasts and as fine-grained, granulated matrix, none of which appear to be symplectitized. Acid plagioclase (An 30) and quartz occur

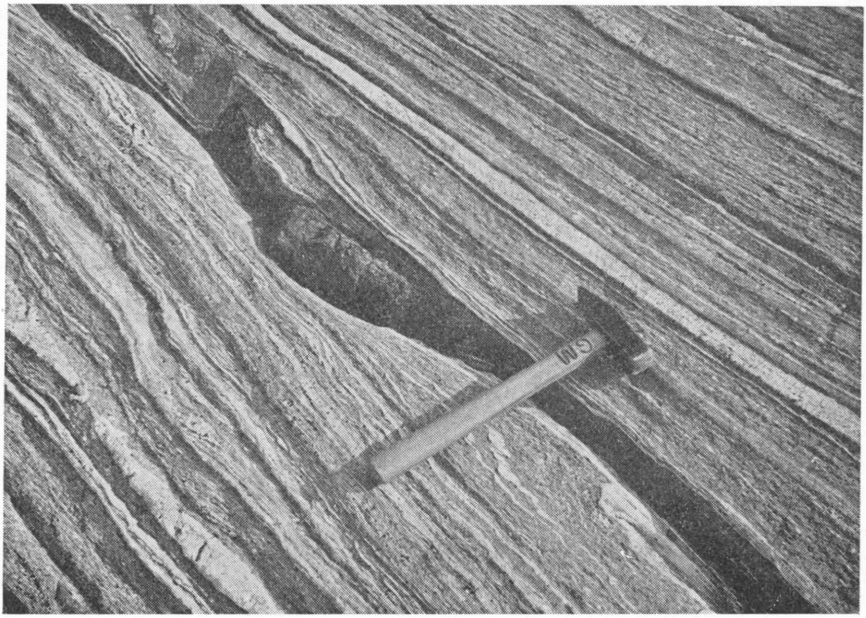

Fig. 9. Hornblenditic inclusions in Svartekari gneiss (LP 515/422).

rather subordinately as fine-grained, granular aggregates while rutile is a conspicuous accessory mineral.

The rock is «eclogite-like» in hand specimen and also microscopically similar to an eclogite except for the presence of minor plagioclase. It is possible that plagioclase has formed by recrystallization of a meta-eclogite, but it is more likely that the rock was metamorphosed in the boundary field between gabbro and eclogite, i.e. in the granulite stability region.

The two-feldspar gneisses east of Svartekari contain a variety of basic inclusions, which occur as isolated bodies, trains of small bodies or as layers, — much in the same way as the eclogites and associated rocks do in outer Nordfjord (Fig. 9). Many of the basic bodies consist essentially of coarse-grained hornblende, while others are garnet-hornblendites, garnet-epidote-hornblende felses and garnet amphibolites. A sample selected for microscopic examination was essentially a garnet-epidote-hornblende rock with minor muscovite, biotite, plagioclase, chlorite and rutile. Symplectites were not observed, and we have thus no proof that the basic inclusions can be related to the eclogites.

Amphibolites.

Amphibolites are very common associates of the micaceous gneisses and -schists. Relict gabbroic texture has anly been preserved in a large body in Måsvassdalen. All other amphibolites occur as layers with apparent thicknesses from less than one meter to at least 400 meters. Like other rocks, they are tightly similar-folded with axial planes almost parallell to lithologic boundaries. The highest figure of «layer thickness» is therefore due to tectonic thickening. Thin layers of amphibolite have often been deformed into boudins. Layers with rusty surface colour due to oxidized pyrite are very characteristic for the amphibolitic rocks. Several mineralogical and structural varieties occur: The most common type is a quartz-epidote amphibolite, but quartz-garnet-epidote amphibolites, biotite-amphibolites and white plagioclase-rich schists frequently occur as bands. Gneiss and white quartz monzonite may also occur as layers within amphibolitic rocks.

Only two specimens of quartz-garnet-epidote amphibolites have been studied in thin section, both representative of the south-eastern part of our area. They have granoblastic texture in plagioclase-rich or quartz-rich aggregates. Plagioclase has composition An 14, is untwinned and sometimes contains lenticular inclusions of quartz. Amphibole has pleochroism: X pale yellow, Y and Z blue-green, $2V_x = 78°$, $Z/C = 20°$.

Epidote, garnet and quartz make up about 15 %, 10 % and 10 % respectively of the bulk.

Biotite, apatite and zircon occur as accessory minerals.

The occurrence of amphibolite as widely extended layers in micaceous rocks and their association with other supracrustal rocks indicate that they might be transformed basalts or other basic rocks originally formed at the surface. In some cases this might be true, but local preservation of gabbroic texture and association with anorthosite rather suggest that the amphibolite was produced from original igneous plutonic rocks.

Meta-anorthosites.

White, altered anorthosites occur intimately associated with amphibolitic rocks and with biotite-plagioclase gneisses. Augen gneiss is sometimes also associated with anorthositic rocks. Some of the gneisses are certainly related to the «Anorthosite Kindred» as defined by Kolderup and Kolderup (1940).

The Storeskarseggen gneiss unit west of Storevatn contains relict of only slightly altered anorthosites. The plagioclase of these rather massive rocks has locally retained its lilac colour and lustre on cleavage surfaces. Most anorthosites have been altered, however, to schistose, tightly shearfolded, very fine-grained rocks. The mineral association found in these rocks are:

plagioclase-zoisite-muscovite-chlorite

plagioclase-epidote-muscovite-biotite (amphibole-garnet).

The plagioclase is an andesine, — sometimes basic andesine (An 45), Bright-green chromian muscovite occurs in pockets and veins. Amphibolites are often associated with the altered anorthosites. Amphibolites in the south-eastern part of our area contain white rocks with less obvious relationship to the «Anorthosite kindred». The mineral associations found in these white bands are:

plagioclase-zoisite-actinolite-prochlorite

plagioclase-epidote-muscovite-biotite.

The first association was found in a specimen sampled in Årdalskaret east of indre Kupevatn. It has a very fine-grained granoblastic-sutured mosaic of plagioclase between extremely well oriented tablets of zoisite and amphibole. Bigger grains of plagioclase are twinned and externally granulated into very fine-grained mosaic of largely untwinned plagioclase.

The other association was found in a specimen sampled at Skjorta east of Myklandsdalen. This rock is also finegrained, but the texture in aggregates of plagioclase (An 40) is granoblastic-saccharoidal. The plagioclase aggregates are surrounded by epidote and muscovite in a felted mass of sericite and pale-brown biotite. Books of muscovite are often twisted and externally granulated into sericite. Inverse zoning is often seen in plagioclase.

The thin, white layers in amphibolite are composed of essentially andesinic plagioclase and epidote minerals and should be classified with the meta-anorthosites encountered further west and northwest in our area.

Presence of white meta-anorthositic layers in amphibolite and interlayering of gneiss and anorthositic rocks must be considered in any theory for the formation of anorthosites in our area. Such field relations are best explained by calling for an original heterogeneous igneous plutonic complex where each lithological unit became widely extended by original flow layering or secondary mechanical deformation with neomineralization.

Structure.

Contact between lithologic units.

Contacts between lithologic units are sometimes difficult to define because shearing and recrystallization in the contact zone has rendered the rocks on each side similar to each other. This difficulty is marked especially in the most important of them all: the contact between the infracrustal (Blåfjellet gneiss) and the supracrustal complexes (Måsvatnet schists). An old observation by Reusch (1881 p. 167) had shown that the «schists» contained a variety of rocks: light schists, mica-rich schists, augen gneiss and hornblende-rich schists while the «Archean» basement contained gneiss-granite and gneiss. We think that the *heterogeneous character* is characteristic for the rocks we have related to the supracrustals and that this is of diagnostic significance for the Fjordane complex in contrast to the monotony of the rocks of the Jostedal complex.

It is possible that the contact regions locally are influenced by «granitization» processes as inferred by Kolderup (1960) for the north side of Breimsvatn where gneisses and quartz schists have veins and apophyses of granitic substance. This possibility cannot be ruled out for the north-west shore of Breimsvatn either where granitic and pegmatitic bodies frequently occur as layers, dykes or as the filling of tensional fissures. We have, however, mapped this area as part of the infracrustals because we think that such structures are best explained by partial melting processes or by segregations in the infracrustal complex.

Growth of feldspar porphyroblasts has locally taken place in the supracrustals immediately overlying the contact. A feldspathic quartzite at Kupevatn has augen of red microcline and is even interlayered with augen gneiss west of the same lake. Such relations might be explained by smallscale «granitization» processes, but could just as well be explained by compositional variations in the original psammitic and pelitic sediments. The most interesting rock with respect to possible «granitization» processes in our area is probably an augen gneiss which occurs between our Svartekari and Visdalseggen units in the closure of the Måsvassdalen synform. The big posttectonic feldspar augen of this rock appear to have formed in the sheared, possibly granulated, contact zone of two major lithologic units in a low-pressure regime.

Acute shear folds and tectonically elongated pegmatite lenticles are locally characteristic for the infracrustal gneisses near the contact towards supracrustals. The contact zone is often crushed and a mylonitic banding has at places almost obliterated the original lithological banding of original psammitic rocks. Individual lithological layers have often been sheared out in the contact zone between major units. This is well displayed in the Måsvatnet schists where for example feldspathic quartzite/meta-arkose alone or feldspathic quartzite/meta-arkose underlain by garnetiferous mica-schist and carbonate schist occur above the contact. The thickness of this feldspathic quartzite/meta-arkose formation varies from virtually nothing to several hundred meters along the contact between Vonen and Måsvatnet. We think that the main shearing in the contact zone took place during or before the first discernable folding of the rock body, although some later movements have produced mylonitic rocks and deformed feldspar porphyroblasts at places.

Planar and linear structures.

Foliation is in some rocks very regular without apparent folding, but close inspection will often indicate the presence of very tight shear folds or isolated fold-hinges with axial planes subparallel to lithological banding and formational contacts.

Most rocks exhibit a penetrative lineation which is defined by preferred orientation of minerals. Infracrustal gneisses have pretectonic augen aligned with their longest dimension parallel to axes of tight shear folds. Mica-schists and other rocks have lineation defined by rods of quartz and small-scale crenulations.

Foliation, penetrative lineation and tight folding with axial-planes subparallel to foliation are all related to the first folding, F_1, in the area. Strong transposition must have taken place during this folding, and the thickness of a layer or rock unit is therefore unrelated to original stratigraphical thickness.

Axial planes of the first folds are folded in similar manner as the foliation, and curved axial planes can often be seen (Fig. 10). This is indicative of nonplane cylindroidal folding or due to a second folding episode, F_2, comparable to a superposed folding further to the west (Bryhni 1962 p. 336). Linear structures related to F_1 and F_2 both trend EW to ESE-WNW (Fig. 11). The plunge in the northern and major part of our area is towards the west while the plunge in the southern part is towards the east as well. NS joints in the Blåfjell gneiss area dip

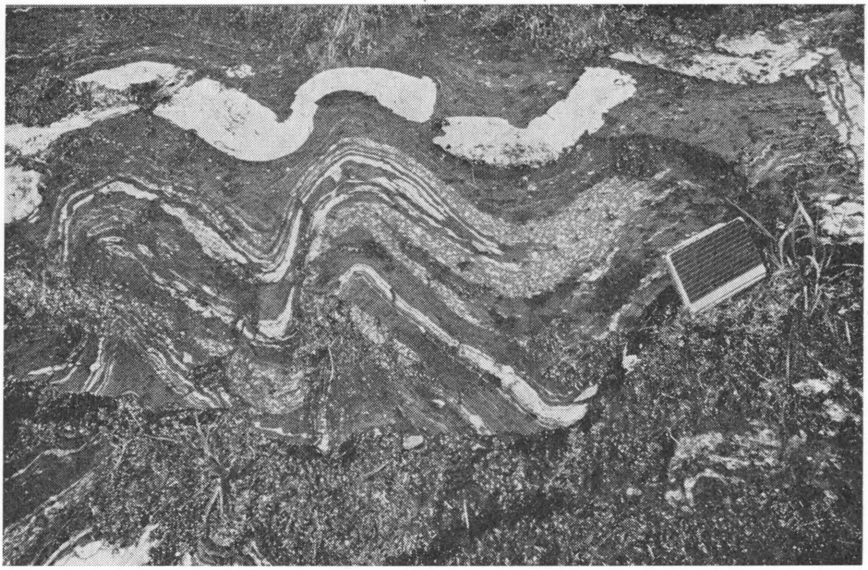

Fig. 10. Fold with curved axial plane. West side of Myklandsdalen near Rygg sl. (LP 375/605). Interpreted as F1-folds folded by F2.

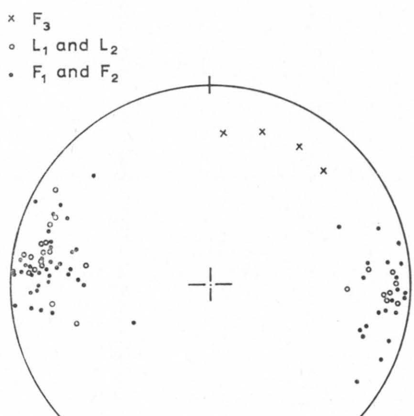

Fig. 11. Projection of linear structures in the area. Lower hemisphere, Schmidt net.

consistently to the east corresponding to their position as cross fractures for west plunging linear structures.

A few minor, open folds with axes trending NS to NNE-SSW and fracture cleavage with corresponding strike have been noted at places (e.g. at tributary to Slettelva, 700 m S of Dalevatnet). The folds have affected a lineation parallel to F_2 in quartz lenticles and must therefore be termed F_3. The fact that the first and second linear structures in the southern part of our area plunge both to the west and to the east can be attributed to this third folding.

Regional structure.

The geologic map and profile show a major synform at Måsvatnet which is bounded to the south by a major antiform. It is believed that the Måsvatnet synform is an F_2 structure comparable with the four «synclines» described by Kolderup from West Norway (1960 p. 8—13) and our supracrustal rocks can, in fact, be followed continuously with similar lithologic succession into his syncline IV north of Breimsvatn.

The supracrustals and the rocks associated with them have been folded in the same general way as the infracrustals, but have experienced more irregular folding with shorter wave-length as if decollement has taken place. The psammitic rocks in the Måsvatnet unit appear mesoscopically to strike perpendicularly to the NS-trending contact south of Dalevatn as if a discontinuity were present, but the relations have proved to be due to the west plunge of the fold axis and to the fact that the supracrustal rocks are deformed with tight folding while the infracrustal gneiss has been laid into broad, open undulations.

Discussion.

We think that the infracrustal rocks west of Breimsvatn are continuous with rocks which occur below the Jostedalen glacier and with rocks of established Precambrian age at the south-eastern margin of the Gneiss region. Infracrustal and supracrustal rocks of our area are, however, interfolded in such a way that age relations are not evident. The assumed basement shares all essential structures with its cover and the present conformity appears to be due to a deformation shared by both complexes.

The main deformation of the rock body in our area took place along EW to ESE-WNW axes. The linear structures formed during the first folding may have been rotated by the second folding, but we have no evidence that they originally diverged much from the axes of second folding. Nor do we have any evidence that the two folding episodes were separated by any significant time interval. We therefore provisionally suggest that the first and second linear structures are due to continued folding on essentially the same EW to ESE-WNW fold axis whereby initial axial planes become eventually refolded.

EW fold axes were found to be characteristic for the Precambrian basement at the south-eastern margin of the Gneiss region (Banham 1968), and one could argue that the supracrustals west of Breimsvatn were Precambrian as well. One has to remember, however, that EW folding is characteristic for large areas of the Norwegian Caledonides (Strand 1949) and has even affected rocks which are generally regarded as Eocambrian rocks and Cambro-Silurian rocks.

The deformation responsible for the second folding in our area probably left its imprint in the radiometric age of 402 m.y. and can perhaps be related to a late EW folding recorded by Banham & Elliot (1965) from the south-eastern margin of the Gneiss region.

The supracrustals west of Breimsvatn might well have a Precambrian depositional age. Birkeland (1958) has described metamorphic supracrustal rocks from a more northern part of the Gneiss area which he thinks were originally Precambrian, and Kvale (1946 b) has suggested that the metamorphic supracrustal rocks he encountered in Bergsdalen and which he related to the Precambrian «Telemark suite» have, in fact, a wide distribution in West Norway. The association of metamorphic psammitic rocks with amphibolite and biotite-plagioclase rocks in our area is not unlike the quartz-schist/metabasalt/metadacite association of Bergsdalen. The correspondence can be extended to include anorthositic rocks because such occur within the upper Bergsdalen nappe (Kvale 1960 p. 191). A possible argument against the assignment of the supracrustals and their associated rocks west of Breimsvatn with rocks of Bergsdalen and the «Telemark suite» is that the psammitic rocks are different. The Bergsdalen and Telemark metamorphic psammites are often ortho-quartzites and quartz schists with a very low content of feldspar while the psammitic types west of Breimsvatn are very feldspathic. The feldspathic quartzites and meta-arkoses west of Breimsvatn are in this respect more closely related to the Eocambrian of Norway (Kolderup 1928 p. 69—70), or to the particular feldspar-rich psammites of the Bandak group in the Precambrian Telemark suite (Bugge 1931 p.

162). Metamorphic supracrustal rocks identical with those which occur in our area are present in Oppdal, Nordmøre (Tingvoll group of Hernes 1965, 1967), Grotli (Strand 1966, 1969) and in the upper Gudbrandsdalen area (Strand 1964). The thick amphibolitic intercalations which occur west of Breimsvatn can then perhaps be correlated with the basic rocks present in flagstones and mica-schist of the Sethø complex at Oppdal (H. Holtedahl 1960, p. 13—17) which sometimes have formed from intrusive sills (Holmsen 1955, p. 138—139) and to gabbro and basalt associated with sparagmites of the Kvitvola nappe (Bjørlykke 1965).

Anorthositic rocks are generally regarded as Precambrian, and we have no reason not to accept this age for the metamorphic anorthosites west of Breimsvatn. At least three different mechanisms may account for the presence of Anorthosite Kindred rocks in our area:

1. Tectonic emplacement like in the central nappe region. A such mode of origin was suggested by Kolderup (1960 p. 11) and it is quite possible that nappes with Anorthosite Kindred rocks in West Norway and the central nappe region have a related tectonic position on each side of the Jostedalen culmination.

2. Intrusion of the Anorthosite Kindred rocks into the supracrustal series, differentiation by settling and later by flow layering to form extensive layers or bodies of contrasting composition.

3. Metasomatic derivation from original sedimentary rocks (Hietanen 1963, Korshinskij 1965).

Our data do not permit further eluciation of the problem of anorthosite formation, but we think that the area west of Breimsvatn lends support to the two first alternatives, and the true story of the formation of Anorthosite Kindred rocks in our area might involve both of them. The lithologic sequence given in Fig. 2 for the Fjordane complex is scarcely a normal stratigraphic succession. The Ommedalen and the Storeskarseggen units contain Anorthosite Kindred rocks similar to those which elsewhere in the Caledonides occur in thrust position. The wide extension of these units, their varied lithology with gneisses, anorthositic rocks, amphibolite and ultrabasite indicates that one is here dealing with plutonic rocks which first become intruded into metasediments, then strongly differentiated and deformed together with the enclosing rocks. Original intrusives would be phyllonitized or broken up into lenticular bodies congruently folded with the enclosing rocks. The mesoscopic style of folding indicates that recumbent F_1 folds are present. It is tempting, therefore, to relate our two anorthosite-bearing lithologic units with the two layers of anorthosite at Gloppen just to the north of our area and join Kolderup (1960, p. 13) in the interpretation of the area as composed of nappes. The Måsvatnet, Visdalseggen and Storeskarseggen schists and meta-arkose contain rather similar rocks and we think *that the Svartekari, Storeskarseggen and Ommedalen gneiss and/or anorthosite units are likely to form three individual thrust nappes. The schists and meta-arkose may then be the Precambrian or Eocambrian mantles between Precambrian fold cores.* Extension of our studies into areas to the west and more detailed mapping would be necessary to solve the structural problems, but we think that our tectonic profile (Fig. 2) indicates that large nappe structures of the type which was postulated by O. Holtedahl (1936) are likely to occur in the area west of Breimsvatn.

The existence of a complicated nappe system within the area west of Breimsvatn makes it plausible that rocks of very different ages were present. True Cambro-Ordovician rocks occur far to the west of our area, but are to our knowledge everywhere bounded by tectonic contacts towards lithologies which can be compared with the supracrustals west of Breimsvatn. We therefore would regard the rocks west of Breimsvatn as Precambrian or Eocambrian until more evidence is available to alter this opinion.

The rocks in our area are obviously polymetamorphic. Their grade of metamorpism corresponds generally to the almandine amphibolite facies although the presence of metamorphic varieties of the Anorthosite Kindred rocks and of Plag-Ga-Clpx «eclogite-like rocks» indicate that granulite facies has been attained at places. Later retrogression has caused saussuritization of plagioclase in gneiss, conversion of anorthosite into schistose meta-anorthosite and phyllonization of various rock types.

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ABBREVIATIONS:

N.G.T.: Norsk Geologisk Tidsskrift.
N.G.U.: Norges Geologiske Undersøkelse.

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