Norges Geologiske Undersøkelse No. 212e.

INTERNATIONAL GEOLOGICAL CONGRESS
XXI SESSION NORDEN 1960

# THE NAPPE AREA OF THE CALEDONIDES IN WESTERN NORWAY

Guide to excursions no. A 7 and no. C 4

by

ANDERS KVALE

Editor of Norwegian guide-books:

JOHANNES A. DONS,

secretary to the

NORWEGIAN GOVERNMENT'S ORGANIZING COMMITTEE

for the

INTERNATIONAL GEOLOGICAL CONGRESS

OSLO 1960

# CONTENTS


| | Page |
|---|---|
| Introduction | 3 |
| Topography | 4 |
| Climate | 5 |
| Population | 5 |
| Stratigraphy | 6 |
| Precambrian | 6 |
| Cambro-Silurian | 7 |
| Finse–Sogn | 8 |
| The Norheimsund Area | 11 |
| The Bergen Arcs | 13 |
| The Northwestern Migmatite Area | 17 |
| The Western Gneiss Area | 18 |
| Anorthosites and related Rocks | 19 |
| Structural Geology | 20 |
| Tectonic Units | 20 |
| The Upper Jotun Nappe | 21 |
| The Upper Bergsdalen Nappe | 22 |
| The Lower Bergsdalen Nappe | 23 |
| Anorthosites and related rocks in the Bergen Arc System | 24 |
| Structures | 25 |
| Structural Patterns | 26 |
| Age of the Overthrusting | 31 |
| Outline of Geologic History | 31 |
| Road Log | 35 |
| Literature | 43 |


2 figures in the text. 2 plates enclosed.
Key map: see back cover.

Excursion A 7: Aug. 5th.–Aug. 14th., 1960.
Excursion C 4: Aug. 26th.–Sept. 4th., 1960.

*Excursion leaders:*


PROFESSOR DR. ANDERS KVALE,
Geologisk institutt, Joachim Frielesgt. 1, Bergen, Norge.

VITENSKAPELIG ASS. JOHAN NATERSTAD,
Geologisk institutt, Joachim Frielesgt. 1, Bergen, Norge.

## Introduction

The excursion will provide cross sections through the nappe area of the Caledonides of Western Norway. The main purpose of the excursion is twofold:

1. To give a summary of our present knowledge of the tectonic history of this area.
2. To demonstrate the various types of structures occurring and their relation to the movements which produced them.

Although the structural problems are considered to be most important, stratigraphy and petrography are dealt with to provide a sufficient foundation for a study of the structural problems.

The excursion will begin at Finse and Hallingskeid (see Fig. 2 and Pl. 1), where the Precambrian basement is undisturbed, and where Cambrian basal conglomerate has been preserved undeformed in pockets. The basement is overlain by the Phyllite Formation (Cambrian and Lower Ordovician), which in turn is overlain by the highest tectonic unit of the area, the Upper Jotun Nappe.

The excursion continues to Flåm and Aurland, where partly deformed Precambrian basement appears in a window. From there the excursion goes to the north side of the Sognefjord, crossing the nappe area and reaching the completely recrystallized basement at Grinde. In this region a new stratigraphic and tectonic unit, the Valdres Sparagmite, appears between the Phyllite Formation and the Upper Jotun Nappe.

The nappe area is crossed a second time from Vik to Voss and Ulvik. In this section the Upper Bergsdalen Nappe appears below the Upper Jotun Nappe. The Valdres Sparagmite has disappeared. At Ulvik the Precambrian basement is reached.

From Ulvik the excursion continues to Granvin and further along the Hardangerfjord to Norheimsund. At Granvin and Lussand the uppermost part of the Precambrian basement has been deformed during the Caledonian orogeny. From Lussand southwestward, the Phyllite Formation and the overlying Upper Bergsdalen Nappe are crossed. At Fyksesund a formation of phyllites and volcanics below the nappe is encountered. These rocks of Ordovician, (mainly lower Ordovician), age are studied between Fyksesund and Kvamskogen west of Norheimsund, where the most complicated structures of the area occur. From Kvamskogen westward the Upper and the Lower Bergsdalen Nappes are crossed in succession, and the Bergen Arcs are encountered east of Tysse.

The last two days of the excursion are spent in the Bergen Arc district, an area of interesting stratigraphic, petrographic and structural geology.

**Topography.**

The main area of the excursion lies between the two largest fjords of Western Norway, the Sognefjord to the north and the Hardangerfjord to the south. The Sognefjord is about 200 km long and nearly 1300 m deep in its central part, while the depth at the mouth is only about 200 m. Its general trend is E—W and it follows partly the strike of the rocks and partly joint systems. The Hardangerfjord is about 160 km long. It trends northeast and follows in the main part of its course the boundary between the Cambro-Silurian rocks and the Precambrian basement. While the distance between the mouths of the two fjords is 150 km, the difference in trend reduces the distance between two of the innermost arms to 30 km.

Throughout the area, neighbouring mountains reach a general level, the elevations increasing from 2—300 m near the coast to 1800 m at Finse. Peaks of the alpine type are not present. The general surface of the land may be compared to a shield, into which valleys and fjords have been eroded. Because of the penetration of the fjords into the interior of the shield, the distance to the sea is nowhere great. Therefore the valleys and fjords become narrower and steeper towards the interior of the country. The rivers are short, with numerous waterfalls. The longest river, Vosso, is 60 km long and runs westward through the central part of the peninsula.

The topography and geomorphology around Bergen is particularly interesting. The rocks of the Bergen Arc System change in direction of strike from north-west in the northern part over north to north-east and partly east in the southern part. The dip of the strata is generally steep, and valleys and fjords are eroded along the softer beds or along joint systems which are radial to the curvature of the arcs.

**Climate.**

The coastal areas have a mild and wet climate, while the eastern part of the area has warmer summers, colder winters and less precipitation. The isotherms are generally parallel to the coast and, to some extent, also to the major fjords. The mean temperature for February decreases eastward from + 2° C at Bergen to — 2° C at the innermost arms of Sognefjord and Hardangerfjord. The mean temperature for July increases from 13° C at Bergen to 15° C at the inner fjords.

The annual precipitation is about 1300 mm at the coast. It increases eastward with the increasing elevation of the mountains, is about 2000 mm at Bergen and reaches a maximum of more than 3000 mm 50—70 km from the coast. Further eastwards it decreases, and at the innermost branches of the Sognefjord it is below 500 mm. This distribution is due to the fact that most of the precipitation comes from the west or the southwest, and when the clouds reach the inner parts of Western Norway most of their rain or snow has already fallen.

**Population.**

Until the beginning of the present century, farming provided the means of living for the great majority of the population within the area of the excursion. Fishing added to the income of the people living near the sea as did hunting to the people living on the mountain farms. During the last 50 years great changes have occurred. Farming and fishing are still important, but hunting has declined, while fruit-growing gives a fairly good income to farmers in Hardanger and Sogn. The forests are being better utilized than in the old days, and every year hundreds of thousands of new trees are planted. But the greatest change has been caused by the building of hydroelectric power plants. The lakes in the high mountains form natural reservoirs, and because of the fjords, the distance from the dam to the sea is nowhere great. Electrometallurgic and electrochemical plants have been built in several places along the Sognefjord and the Hardangerfjord (Ålvik). The textile industry, which around Bergen is more than 100 years old, has been expanding rapidly in recent years thanks to cheap electricity, and various minor industries have grown up, especially factories for making furniture.

The best farming districts are found where phyllite forms the subsoil (Voss), or where large post-glacial terraces occur (Vik at the Sognefjord and Steinsdalen west of Norheimsund).

At Voss a quartz schist is quarried as roofing slate. Talc is mined by A/S Norwegian Talc at Framfjord on the south side of Sognefjord, a few kilometers west of the excursion route. Serpentine is quarried for road metal at Fyksesund and in Samnanger. The electrometallurgic plant at Ålvik operates a quarry in quartzite on the east side of the Hardangerfjord opposite the factory. Low grade titaniferous iron ore occurs in connection with anorthosite in the Bergen Arc system, but attempts at mining the ore have hitherto been unsuccessful.

Although communication between the various parts of the district always has been fairly easy, owing to deeply penetrating fjords and good mountain paths, a number of different dialects have developed in former times. At present these dialects are gradually disappearing. So are many of the old customs, as well as the costumes for everyday wear. The typical national costumes, which were used on special occasions, are, however, still popular.

Nearly all houses are built from wood, as is the case throughout the country, with the exception of the larger cities. Relatively few houses are more than one hundred years old, but at Voss are two of the oldest wooden secular buildings in Norway, Finneloftet and Lydvaloftet, both from the first half of the thirteenth century.

At Vik two old churches, a stone church from about 1150 and a "stavkirke" from the 14th century, are too small for present day use. The stone churches at Voss (from 1260) and at Fana near Bergen (13th century) are still the main churches of the communities.

Ruins of an old monastery (13th century) are seen at Lysekloster south of Bergen.

## STRATIGRAPHY

The rocks of Western Norway may stratigraphically be divided in the following main divisions:

1. Precambrian rocks.
2. Cambrian, Ordovician and Silurian rocks in varying degrees of metamorphism and deformation, caused by the Caledonian orogeny.
3. Devonian rocks. Metamorphism and deformation generally insignificant. These rocks are not met with on excursions A 7 and C 4.

### Precambrian.

Precambrian rocks occur over large areas in Southern Norway. Towards the north and north-west these rocks are overlain by Cambro-Silurian rocks, but they crop out in a few windows near the border of the Caledonian orogen. During the excursion the contact between Precambrian and overlying rocks will be studied in several localities, one in the window at Aurland.

The oldest preserved Precambrian rocks in Western Norway are probably the supracrustal rocks of the Telemark Suite. They occur on both sides of the Sørfjord, a southward trending branch of the Hardangerfjord. This area is not visited during the excursion, but as "Telemark rocks" probably occur in the Bergsdalen nappes, they shall be briefly mentioned here. (*Kvale* 1946. Bergens Museums Årbok Nr. 5.)

The sediments are quartzite, quartz schist and quartzite conglomerate. Argillaceous sediments occur in the type area in Eastern Norway, but are not met with in Hardanger.

The volcanic rocks are metabasaltic, metadacitic and metarhyolitic. They are partly lavas, partly tuffs. The age relations are not clear, but probably the metavolcanics are generally older than the sediments. The supracrustal rocks have been invaded by intrusions of gabbros (generally saussuritized), quartz diorites and granites. The thickness of these rocks in the Sørfjord area has not been determined. In the Bergsdalen nappes the total thickness of the supracrustal rocks is more than 3000 m. The metavolcanics are surrounded by granitic rocks of somewhat varying composition and texture, rocks which everywhere seem to be younger than the metavolcanics. The most common of these granitic rocks is a coarse-grained granite with larger crystals of feldspar reaching 5 cm. It will be seen at Finse and Hallingskeid. Quartz diorite is seen at Granvin. Along the excursion route the metavolcanics are found only as remnants lying in and penetrated by granite. They occur in several places between Granvin and Lussand. Near Lussand is a body of medium-grained granite.

## Cambro-Silurian.

Two distinctly different series of Cambro-Silurian rocks are found in the area. In the central and the north-eastern parts phyllite is completely dominating, and only small zones of other rocks are found. Along the Hardangerfjord south of Ålvik (Norheimsund area) and in the Bergen Arcs, large masses of volcanic rocks occur as well as arenaceous rocks and conglomerates. Fossils are scarce, and because of the intense deformation, stratigraphic sequence and thickness are often difficult to determine. Table 1. may therefore have to be revised as investigations proceed, but it gives a summary of our present knowledge. Rocks which are not seen during the excursion, are in parentheses. Rocks where fossils have been found are in italics. Separate tables are given for the Norheimsund area and for the Bergen Arcs because of differences in sequence and difficulties in correlation.

*Table 1.*

| System | Epoch | Oslo Area | Bergen Arcs | Norheimsund Area | Finse–Sogn |
|---|---|---|---|---|---|
| Silurian | Lower | 7 a<br>6 c | *Phyllite*<br>*Phyllite*<br>Sandst.+qz.cgl. | | |
| | Upper | 5 a | Phyll.+*limest.* | (Phyll. with limestone and qz.sch.) | Valdres Sparagmite (NW) |
| | | | Polymictic cgl.<br>Graywacke | Polymictic cgl. | |
| Ordovician | Middle | | | | |
| | | | Green schist<br>Limestone | Green schist (with limest. and phyll.) | |
| | Lower | | | (Lime silic.sch.) | |
| | | | Phyllite or mica sch. | Phyllite | Phyllite<br>(Limestone)<br>(Dark quartzite) |
| | | 2 e | Phyllite or | Phyllite | *Alum shale* |
| | Upper<br>Middle | | mica schist | Phyllite | Alum shale |
| Cambrian | | | | | |
| | Lower | 1 bβ | | | Quartz sch.<br>*Basal cgl.* |
| Pre-cambrian | | | Granitic gneiss? | Granite (Telemark suite) | Granite (SE) (Telemark suite) (SE) |

*Finse—Sogn.*

*Basal conglomerate* is found in several pockets in the Precambrian basement near the railway stations Hallingskeid, Finse and Ustaoset. They contain well rounded pebbles of quartzite in a fine-grained brown matrix. Fossils are found in two localities, Sandådalen, 4 km NW of Finse *(Torellella laevigata)* and at Ustaoset *(Strenuella),* determining the age as upper part of Lower Cambrian (1 bβ in the Oslo scheme) *(Goldschmidt* 1912).

One locality of this conglomerate is visited near Finse.

*Quartz schist* lies above the conglomerate or directly upon the basement. It is usually white and may be intensily deformed. In many places it is lacking.

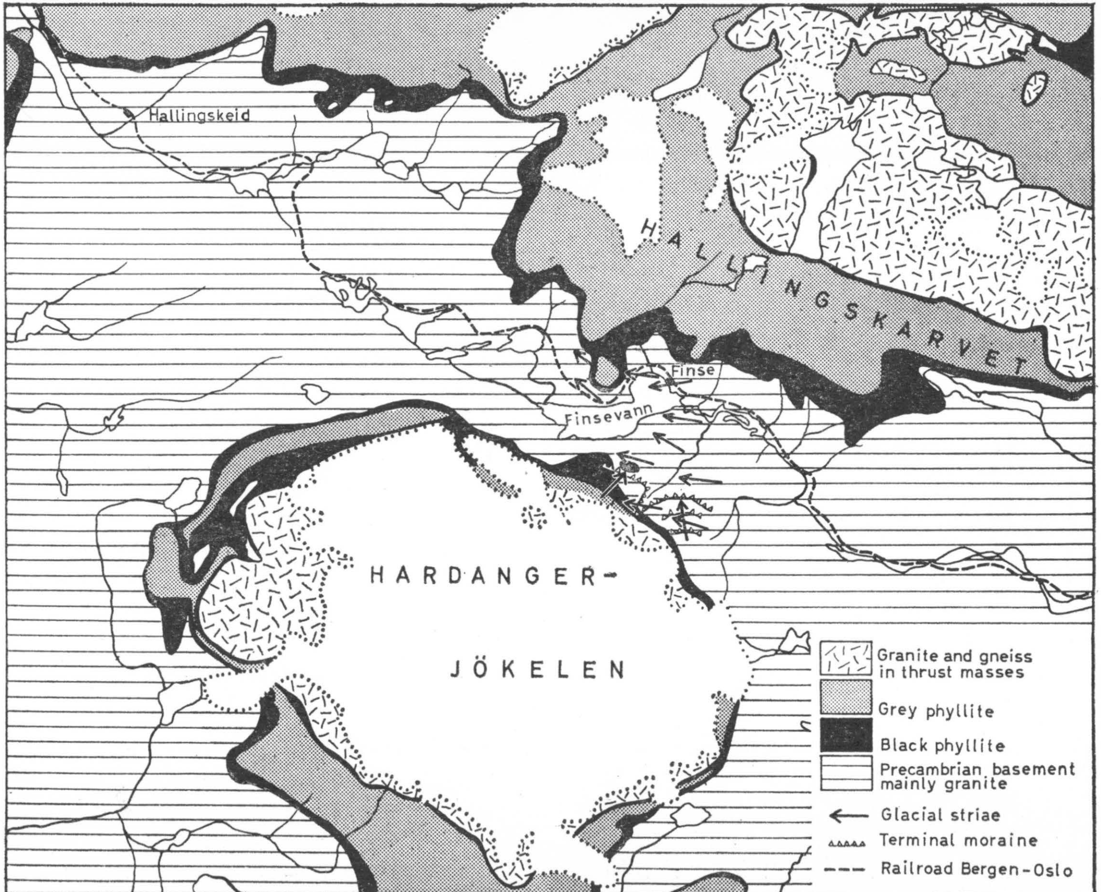



*Fig. 1. The Finse–Hallingskeid area. (Map reproduced from H. Holtedahl: Guidebook d, for excursions A 6 and C 3.)*

*Alum shale,* which commonly is altered to phyllite, lies above the quartz schist or directly upon the basement. *Dictyonema* (Lower Ordovician or 2 e in the Oslo scheme) has been found at Holberget 50 km S of Finse. This shale probably represents Middle and Upper Cambrian as well as the oldest strata of Lower Ordovician.

*Dark quartzite* occurs in many places south of the Finse district, but not in the excursion area.

*Limestone* occurs above the quartzite in some places south of the excursion area.

*Phyllite* (usually quartz-muscovite-biotite phyllite) is the predominating Cambro-Ordovician sediment in the north-eastern half of the area. The colour varies with the amount of graphite from gray to black. In some places layers rich in quartz or carbonates mark the bedding, but generally bedding is destroyed by intersecting flow cleavage. Folding and thrusting have caused repetition of strata. All determinations of thickness are therefore uncertain. Minimum figures are 250 m in the Finse district and 300 m in Sogn.

In Sogn the phyllite generally lies directly upon the basal gneisses, the foliation of which is parallel to the contact. Beds of alum shale phyllite occur within the phyllite. North of the excursion area (in Bøverdalen) the phyllite contains limestone beds having a thickness of more than 200 meters.

No fossils have been found in the phyllite. This series probably represents Lower Ordovician and parts of Middle Ordovician.

*Valdres Sparagmite* consists of arkose and graywacke, both rock types with conglomerate beds (quartzite and gabbro conglomerate respectively). The type area lies about 100 km ENE of Finse. Here the thickness probably exceeds 1000 m. No fossils have been found, but the age is probably Upper Ordovician or Lower Silurian. According to *Strand* (1940) it is deposited on the Lower Jotun Nappe, which was also the main source of the material. Later the Upper Jotun Nappe was thrust above the Valdres Sparagmite.

Within the excursion area, the Valdres Sparagmite is found only in Sogn, from Målset south of Vik northward. The best exposures are Fatlaberget east of Hermansverk (*Skjerlie,* 1957 p. 35—40). The series consists of a lower group and an upper group. The rock type in the lower group varies somewhat, but is mostly a pale, greenish or grey blastopsammitic arkose. The upper group consists of a uniform, fine-grained to dense, greyish-blue rock.

The potash feldspar in these rocks seems to be identical with the potash feldspar in the rocks of the anorthosite kindred, which are the predominant rocks in the two Jotun nappes. This similarity supports *Strand's* theory that the Valdres Sparagmite mainly consists of detritus derived from the Lower Jotun Nappe.

*Igneous* rocks are very scarce in the Cambro-Silurian sediments in this part of the excursion area. A few small zones of green schist, quartz porphyrite (metadacite) and trondhjemite occur in the phyllite between the two Bergsdalen nappes southwest of Voss. Several bodies of serpentine, which to a large extent are altered to talc, lie in the lower part of the phyllite at Framfjord south-west of Vik. Other small bodies of igneous rocks may be found when the whole area is mapped in great detail, but on the whole the igneous rocks are insignificant, in sharp contrast with the Norheimsund area and the Bergens Arcs.

## *The Norheimsund Area.*

*(Kvale, 1946.)*

No fossils have been found in this area. A detailed correlation with the sequence in the Bergen Arcs, where three fossil horizons are known, is therefore difficult. In both areas the stratigraphic sequence is incomplete because of tectonic movements, but it seems clear that some of the strata occurring in the Bergen Arcs are missing in the Norheimsund area and vice versa. (See Table 1.)

The only relatively undisturbed section in the Norheimsund area is found south of Norheimsund, where in a large syncline the green schist is overlain by younger rocks. This area will not be visited during the excursion.

*Phyllite.* The oldest Cambro-Silurian rocks in this area are those of the basal zone of phyllite, which from Lussand continues below the sea to the east side of the Hardangerfjord, where it can be traced from south of Ålvik to south-east of Norheimsund. Between the phyllite and the Precambrian basement, thin layers rich in quartz or calcite occur in some places. The phyllite crosses the Hardangerfjord again 10 km south of Norheimsund, where the basement is exposed in the hill Ljonesåsen.

A zone of gneiss and quartzite, which is most likely a continuation of the Lower Sheet of the Upper Bergsdalen Nappe, lies above the phyllite on the east side of the Hardangerfjord. The prominent peak of Samlenuten consists of this gneiss, while the valley east of it is eroded in phyllite. West of Ljones this zone of gneiss and quartzite lies in the basal phyllite. It is strongly deformed, and it varies in thickness from 100 to 300 m.

In the western part of the Norheimsund area several zones of phyllite occur. They may belong to the same stratigraphic zone, which may correspond to the basal phyllite described above. The base of the phyllite is, however, nowhere exposed, and tectonic movements have made reliable correlations difficult. The occurrence of several bodies of serpentine supports the idea of the old age of the phyllite, as serpentines are known to occur only in the older horizons of phyllite in the Caledonides of Norway.

The rock type in this zone of phyllite is a quartz-biotite-muscovite schist, containing garnets in many localities.

The thickness of this zone probably exceeds 200 m.

*Lime silicate schist.* In the peninsula between Øystese and Fyksesund a zone of quartz-hornblende-epidote-calcite schist, at least 200 m thick, lies above the lower zone of phyllite. It will not be visited during the excursion.

*Green schists* cover about two thirds of the Norheimsund area. The thickness is probably more than 1500 m. The series probably consists of lavas and tuffs, but primary structures, such as amygdules, are found only in a few localities.

There is no reason to doubt that these schists are equivalent to the green schists in the Bergen Arcs and to the Bymark group in the Trondheim area, thus being of Lower Ordovician age.

*Conglomerate* with a basic groundmass occurs in two, possibly three horizons. The maximum thickness is 40 m in one horizon, and only a few meters in the others. The pebbles consist of trondhjemite, various types of saussurite gabbro, green schists and occasionally some rhyolite. It corresponds in composition to the Moberg conglomerate in the Bergen Arcs, which probably is contemporaneous with the Volla conglomerate in the Trondheim area, and which is of Upper Ordovician age. The age of the conglomerates in the Norheimsund area is, however, uncertain.

*Limestone.* A white and grey limestone reaching 5 m in thickness lies in the middle of the green schist series south of Norheimsund. It is accompanied by a zone of phyllite having a maximum thickness of 10 m.

*Upper phyllite.* A zone of quartz-muscovite-chlorite schists with a thickness of more than 300 m lies above the green schist series in two high mountains south and north of Norheimsund. It is partly rich in quartz, and south of Norheimsund a 50 m thick zone of quartz schist lies in the phyllite. Here there is also some calcareous schist and a narrow zone of limestone in the highest part of the phyllite.

This zone of phyllite is less metamorphosed than the lower phyllite. No traces of igneous rocks have been found in the zone. Most likely these schists are the youngest sedimentary rocks in the area. If the conglomerate is equivalent to the Volla conglomerate, the younger phyllite must be of Upper Ordovician age.

*Intrusive rocks.*

*Serpentine* occurs in several bodies in the lower phyllite in the western part of the area and near Fyksesund, where it is partly altered to talc.

*Rhyolite* (quartz porphyry) occurs partly in the green schists and partly in the lime silicate schist. Whether the beds are sills or lava flows cannot be determined.

*Saussurite gabbro* occurs in several small bodies, most of them in the lower phyllite. One of them can be seen near the road to Burkeseter.

*Trondhjemite* (p. 21) occurs in numerous sills in the green schists and in the lower phyllite. The largest sill is 15 km long and has a maximum thickness of 100 m. The main minerals are quartz, albite ($An_{0-10}$), hornblende, biotite, muscovite, epidote, chlorite, garnet.

## *The Bergen Arcs.*

*(C. F. and N.-H. Kolderup* 1940.)

The Bergen Arc System consists of two arcuate areas of Cambro-Silurian schists and intrusives, between which is an arcuate area mainly containing rocks belonging to the anorthosite kindred, the majority of which have a gneissic appearance. West of the arc system is the Western Gneiss Area, consisting of migmatite and plutonic rocks. The arc system is curved around an eastward protrusion of the Western Gneiss Area, the Lyderhorn peninsula, which lies south-west of Bergen.

The Minor Arc of Cambro-Silurian schists borders the Western Gneiss Area. It forms the bedrock in the city of Bergen, and it will be studied on the ninth day of the excursion.

The arc of anorthosite and related rocks curves around the Minor Arc. Parts of it are seen on the eighth and tenth days of the excursion.

The Major Arc lies conformably around the arc of anorthosite and related rocks. Its convex side borders in the northern part a large area of migmatitic gneisses, in the southern part the nappe area. During the excursion two areas of the Major Arc will be studied, the Samnanger area on the eighth day and the Os area on the tenth day.

Part of the supracrustal rocks of the Major Arc is separated from the rest and lies between the two northern bodies of saussurite gabbro. (p. 16.) These rocks were named by *Reusch* the Lysekloster schists.

*Lower phyllite or mica schist.* In the Major arc the rocks of this zone are partly mica schist, partly phyllites. In the Minor arc only mica schists are found.

The base of this zone is not exposed in the Major Arc. The contact of the Minor Arc with the Western Gneiss Area was visible at Minde near the city limit of Bergen until a few years ago. The contact was sharp, and the lowest 1—2 meters of mica schist was rich in calcite. In the author's opinion this contact probably was a depositional contact, which had been deformed by tectonic movements.

The mica schist is a quartz-biotite-muscovite-garnet schist. Minerals indicating a higher degree of metamorphism have not been found. The phyllite lacks garnet, has less biotite, and is more fine-grained. In parts of the Major Arc diaphtoritic chlorite is abundant.

*Limestone.* A white medium- to coarse-grained limestone occurs in both arcs, the maximum thickness probably being about 40 m. Pebbles of this limestone occurs in the polygenic Moberg conglomerate. West of Hisdal in Samnanger (ninth stop on eighth day) the contact between limestone and conglomerate seems to be depositional.

*Green schists* (hornblende schists) occur with a thickness of a few hundred meters. Primary structures indicating volcanic or intrusive origin have not been found. Probably most of the schists are metavolcanics, including both lavas and tuffs.

*Rhyolite* (quartz porphyry) occurs mainly in a zone extending from the Samnanger area (seventh stop on eighth day) southward on the east side of the Samnanger fjord. In the field it looks like a quartzite or quartz schist, but a porphyritic texture can be seen in thin section. According to *Kolderup* (1940, p. 36) the zone probably comprises both lavas and tuffs.

The age relatively to that of the green schists is not known, but both rocks occur as pebbles in the polygenic conglomerate.

"*Chloritic sparagmite*" is a name given by *Reusch* (1882) to a clastic rock rich in chlorite, which occurs near the large bodies of saussurite gabbro in the arcs. Petrographically it is a graywacke containing small, scattered beds of conglomerate, mostly with pebbles of saussurite gabbro. The material is probably derived from the neighbouring basic igneous rocks. An exposure of this rock is seen in the Samnanger area (tenth stop on eighth day).

*Polymictic conglomerate. Reusch* gave the name Moberg Conglomerate to a polymictic conglomerate with a basic groundmass and having well rounded pebbles consisting mainly of various types of gabbroic rocks, trondhjemite, green schist and locally quartzite and white limestone. The type locality is at Moberg farm near Osøyri, but the best exposures are near Hisdal in the Samnanger area (ninth stop on eighth day), where the thickness is more than 200 m, and where a depositional contact with trondhjemite is exposed at the road.

The conglomerate has a striking similarity to the Upper Ordovician Volla conglomerate in the Trondheim district. The conglomerate is penetrated by a few dikes of trondhjemite.

The relative age of Chloritic sparagmite and Moberg conglomerate is not known.

*Middle phyllite with limestone.* A quartz-muscovite-calcite phyllite, about 100 m thick, contains several lenticular bodies of grey limestone, in which several fossils of Upper Ordovician age (5a) have been found. The fossils are corals, crinoids, gastropods and cephalopods. No intrusive rocks occur in this zone. In many localities the grey limestone and the older white limestone occur near each other, and the two types have not been distinguished during the mapping. The occurrence of white limestone pebbles in the Moberg conglomerate has caused some uncertainty regarding the age of the conglomerate. In the locality at Hisdal in Samnanger (ninth stop on eighth day) evidence is seen that there are two different zones of limestone, and that only the older limestone occurs as pebbles in the conglomerate.

*Quartzitic sandstone with quartzite conglomerate.* The type locality is Ulven in the Os district. The sandstone is quartzitic in appearance, having grains of quartz and some plagioclase cemented with calcite and quartz. Biotite, muscovite and chlorite occur in minor amounts. The conglomerate has well rounded pebbles of a white quartzite. Locally some pebbles of white limestone, green schist or mica schist are found. The conglomerate beds are lenticular in shape. The beds may be 10 m thick in some places, in other places thin beds of conglomerate and sandstone alternate. Cross bedding is seen in the sandstone at Ulven, but it has not yet been possible to map synclines and anticlines in the zone. The thickness probably exceeds 200 m.

A zone of chlorite-biotite-albite-epidote schist, probably about 50 m thick, lies in the central part of the sandstone. No primary structure is preserved, and the origin is not clear. This zone will not be seen during the excursion.

Zones of quartzite with quartzite conglomerate occur in the Minor Bergen Arc and in the gneisses north-east of the arc in Bergen. One of the zones is seen on the ninth day of the excursion. In some places the pebbles are strongly deformed, in other places they are as little deformed as those at Ulven. The zones in gneiss have been emplaced by tectonic movements. These rocks resemble the sandstone at Ulven, but their age is not known.

*Upper phyllite.* At Ulven a quartz-muscovite-chlorite-calcite schist having porphyroblasts of biotite occurs on both sides of the sandstone. Two horizons with Lower Silurian fossils have been found, corresponding to the 6 c and 7 a horizons in the Oslo area. The fossils are graptolites, trilobites, corals and brachiopods. The thickness is probably more than 100 m.

Fossils are scarce and generally poorly preserved. One fossiliferous locality will be visited during the excursion.

No intrusive rocks have been found in this phyllite.

It has not been possible to determine the relative age of phyllite and sandstone in the field. There is, however, some indirect evidence indicating that the sandstone is the older rock.

The Ulven conglomerate and sandstone are remarkably similar to the Lyngestein conglomerate and sandstone in the Trondheim area. For the latter strata a Lower Silurian age (6 in the Oslo scheme) seems to be well established. In the Oslo area sandstones and quartzites occur in uppermost Ordovician (5 b) as well as in lowermost Silurian (6a). The Valdres Sparagmite is most likely contemporaneous with these beds.

*Intrusive rocks.*

*Serpentine* occurs as numerous bodies in the lower phyllite and in saussurite gabbro. Olivine occurs as relics. The serpentine has frequently been altered to soapstone containing talc, chlorite and magnesite besides serpentine. These bodies were extensively quarried for building stone during the middle ages. A serpentine body at the highway west of Ådland in Samnanger was quarried for talc some years ago. The mine is now exhausted.

*Saussurite gabbro* covers large areas between Trengereid in the Samnanger area and the sea west of Os, an area which is 40 km long and 6 km wide. Here three large bodies of gabbroic rock occur, one south-east of the Ulven sandstone, the second between the Ulven sandstone and the Lysekloster schists, and the third north of the Lysekloster schists. Several minor bodies are found, both in the Samnanger area and in the Minor Arc.

The composition, structure and texture of the gabbroic rocks vary considerably.

In the southern body at Os, deformation and metamorphism are generally weaker than in the other bodies. Olivine gabbro occurs at Skeie (eighth stop on tenth day).

In the middle and largest body deformation is moderate in the northern part, belonging to the Samnanger area. In the southern part the rocks are partly saussurite gabbros and partly greenstones and green schist, (according to *Kolderup* (1940, p. 16) formed by tectonization of the gabbro). The northern zone also contains considerable amounts of green schists, which may resemble altered volcanic rocks.

*Trondhjemite.* The name trondhjemite was given by *Goldschmidt* (1916 p. 77) to intrusive rocks having quartz, plagioclase and biotite or hornblende as main constituents. When unaltered, the plagioclase is normally andesine, but it is frequently altered to oligoclase or albite.

Several large bodies and thousands of small dikes and sills of trondhjemite occur in the Bergen arcs. They vary considerably in structure and texture. The larger bodies are usually coarse- or medium-grained, while the dikes and sills usually are fine-grained. Because of deformation the rock often looks gneissic. A variety with large quartz grains was named quartz augen gneiss by *Reusch* (fifth stop on tenth day).

The small intrusions of trondhjemite have frequently caused injection metamorphism in green schists. Porphyroblasts of garnet and hornblende are developed in the schist as well as in the trondhjemite.

*Age of the intrusions.*

Serpentine occurs in the lower mica schist and in saussurite gabbro.

Saussurite gabbro occurs in the lower mica schist and the green schists.

Trondhjemite occurs in the lower mica schist, green schist, saussurite gabbro and polygenic conglomerate.

## THE NORTHWESTERN MIGMATITE AREA

In Sogn the phyllite formation lies conformably on a series of migmatitic gneisses, which belong to a large area of metamorphic and plutonic rocks, which covers at least 40 000 square kilometers in

Southern Norway. Due to a lack of good topographic maps, the detailed study of this area, which is the principal object of the excursions A 5 and C 2, has been undertaken only in recent years. All investigators agree that the present structures of the rocks were achieved during the Caledonian orogeny, but opinions are divided as to the origin of the rocks. Some geologists believe that all rocks are of Cambro-Silurian age, others that the area is a mixture of Precambrian basement and Cambro-Silurian supracrustal rocks, which during the Caledonian orogeny were thoroughly intermingled, penetrated by intrusives, partly granitized and recrystallized completely. To the former group of geologists belongs *F. J. Skjerlie,* who studied that part of the area which will be seen during the excursions A 7 and C 4.

According to *Skjerlie* (1957 p. 11) there are two generations of gneisses. The older gneisses are partly quartz-albite-biotite gneisses, which are supposed to be derived from mica schists by the addition of sodium and silica; partly quartz-albite to oligoclase-amphibole gneisses, which may have been derived from dioritic to quartz dioritic rocks by the addition of sodium and silica.

The younger gneisses have a granitic to granodioritic composition. They are believed to have been formed by the addition of potash and silica to the older gneisses.

All the gneisses are penetrated by innumerable dikes and veins of granitic pegmatite, which according to *Skjerlie* (1957 p. 26) have been formed by replacement.

Evidence for the alteration of mica schist to gneiss is found in a 1—2 m thick zone of mica schist, which towards the border shows a gradual transition to quartz diorite.

The contact between phyllite (quartz-biotite-garnet phyllite) and gneiss can be studied at Grinde. The phyllite contains some albite, but there is no gradual transition to the gneiss. The contact is, however, a tectonic one, and the absence of a gradual transition is therefore of little value for elucidating the problem of the origin of the gneiss.

## THE WESTERN GNEISS AREA

The Bergen Arc System borders to the west on an area of uniform grey gneisses, together with some bodies of granite, gabbro and amphibolite. There can be little doubt that the present structures are of

Caledonian age, but the age of the rocks is not known. They may be Precambrian rocks, Cambro-Silurian rocks, or a mixture of Precambrian gneisses and Caledonian intrusives. The contact between the basement and the lower mica schist at Minde (p. 16), which, unfortunately, is now covered by a granite wall, could in the opinion of the present author best be explained as a depositional contact, which would prove a Precambrian age of the basement. In the northern part of the Minor Arc, deformation is more intense. The arc is much smaller and deeper levels are exposed. According to *Kolderup* (1940, p. 113) it is in many cases difficult to distinguish here between mica schist and gneisses rich in mica. This fact does not, however, disprove a Precambrian origin of the gneiss.

## ANORTHOSITES AND RELATED ROCKS

These rocks occur in three tectonic units visited during the excursion: the Upper Jotun Nappe, the upper and middle sheets of the Upper Bergsdalen Nappe and the Bergen Arc System. A general description of the rocks of the anorthosite kindred in the Caledonides of southern Norway was given by *Goldschmidt* (1916). The rocks in the area of Sogn which is visited during the excursion, were described by *Skjerlie* (1957). The rocks in the district of Vossestrand, between Sogn and Voss, were described by *Hødal* (1945). The rocks in the Bergen Arc System were described by *C. F.* and *N.-H. Kolderup* (1940).

There is a marked difference between the rocks of the anorthosite kindred which occur in the Upper Jotun Nappe, and those which occur in the Bergen Arc System. The former are generally massive igneous rocks. Deformation and metamorphism are restricted to the vicinity of the thrust plane and to shear zones within the nappe. Peridotites and pyroxenites are frequent, olivine gabbros and norites cover large areas. The feldspar in the anorthosites is labradorite or bytownite; (plagioclase with $An_{90}$ has been found). Most rocks of the anorthosite kindred in the Bergen Arc System have a gneissic appearance. Olivine is scarce, and the plagioclase of the anorthosites is andesine ($An_{52}$ being the most basic plagioclase found in these rocks). The rocks have been thoroughly deformed and have to a large extent recrystallized during the relatively late stage of the Caledonian orogeny when the Bergen arcs were formed.

Before that stage of deformation, they may have been equivalent to the rocks of the Upper Jotun Nappe. The anorthosites and related rocks of the Upper Bergsdalen Nappe have not yet been studied in detail outside the Bergsdalen quadrangle, where these rocks occur only in one small area. It is, however, evident that acid and intermediate rocks predominate, and that they often have a gneissic appearance. For these reasons detailed mapping, with distinction from gneissic rocks not belonging to the anorthosite kindred becomes a difficult and tedious task.

Both in the Upper Jotun Nappe and in the Bergen Arcs, a large variety of rocks belonging to the anorthosite kindred are found, ranging from ultrabasic over basic and intermediate to acid. Among the rocks of the Jotun Nappe the following types will be seen during the excursion:

Gneissic acid rocks near the thrust plane at Flåm.
Anorthosite 6 km NW of Kaupanger.
Diorite 3 km SW of Sogndal.

Rocks of the anorthosite kindred belonging to the middle sheet of the Upper Bergsdalen Nappe will be seen at Ytre Ålvik (ninth stop on sixth day), where mangerites and related rocks occur.

In the Bergen Arc System gneissic acid rocks of the anorthosite kindred will be seen 3 km W of Trengereid (eleventh stop on eighth day). A typical anorthosite with scattered crystals of garnet and pyroxene in white andesine is seen at the twelfth stop on the same day. Anorthosite metamorphosed to a white slaty rock, consisting mainly of albite, is seen during the first stop on the tenth day.

Mangerites and related rocks are seen during the second stop on the tenth day.

## STRUCTURAL GEOLOGY

### Tectonic Units.

The sequence of tectonic units varies from the north-western to the south-western parts of the excursion area. In Table 2 the relative positions of the units in three cross sections are given. In each cross section the differences between the north-western part and the south-eastern part are indicated.

*Table 2.*
*Tectonic units between Finse and the west coast.*

| NW | SE | NW | SE | NW | SE |
|---|---|---|---|---|---|
| *Sogn–Norheimsund* | | *Vik–Voss–Ulvik* | | *Sogn–Finse* | |
| | | Upper Jotun Nappe | | Upper Jotun Nappe | |
| | | Valdres Sp. | | Valdres Sp. | |
| | | Phyllite | Phyllite | Phyllite | Phyllite |
| | | | U.Bgd.N.III | | |
| | | | (Phyllite) | | |
| | U.Bgd.N.II | | U.Bgd.N.II | | |
| | (Phyllite) | | Phyllite | | |
| | U.Bgd.N.I | | | | |
| Phyllite | Phyllite | | | | |
| L.Bgd.N.III | and | | | | |
| (Phyllite) | Volcanics | | | | |
| L.Bgd.N.II | | | | | |
| (Phyllite) | | | | | |
| L.Bgd.N.I | L.Bgd.N.I | | | | |
| Phyllite | Phyllite | | | | |
| NW'ern migmatites | Precambrian basement | NW'ern migmatites | Precambrian basement | NW'ern migmatites | Precambrian basement |

U.Bgd.N.: Upper Bergsdalen Nappe.
L.Bgd.N.: Lower Bergsdalen Nappe.
(Phyllite): Thin zones between sheets in nappes.

In the following description the distribution of the nappes and the rock types occurring in them will be briefly mentioned.

## *The Upper Jotun Nappe.*

This nappe covers more than 5000 km$^2$ in the north-eastern part of the excursion area. It is separated into two parts west of Hallingskeid, where erosion has cut through the nappe and into the phyllite below. The thickness of the nappe is unknown. The highest mountain, Fresvikbreen, is 1660 m. Between Aurland and Hermansverk the thrust plane disappears below sea level for a distance of 30 km. The angle of dip is about 30° on both sides. The maximum depth which is reached by the thrust plane is not known, but it seems likely that the thickness of the nappe exceeds 3000 m.

Rocks of the anorthosite kindred are completely predominant. Whether other rocks occur in this nappe within the excursion area, has not been definitely established. The main reason for this uncertainty is that the true character of the rocks near the thrust plane is very difficult to recognize because of intense deformation.

### *The Upper Bergsdalen Nappe.*

*Upper Sheet.* This sheet lies south of and below the Upper Jotun Nappe, from which it is separated by a narrow zone of phyllite or mica schist. Its thickness probably exceeds 2000 m, and it wedges out northward below the Upper Jotun Nappe. The sheet has been split into two parts by erosion of the valley leading southward from Vossestrand to Voss. The western part, which contains the prominent mountain of Lønahorgi (1412 m), consists exclusively of quartzite, quartz schist and metarhyolite. The eastern part has a more varied composition. In addition to the rocks of the western part, gneisses, amphibolites and granites occur, probably equivalent to the rocks of the Lower Sheet of the nappe. Intermediate and acid rocks of the anorthosite kindred occur in some places, but neither the distribution of these rocks nor their relation to the other rocks are known at present.

*Middle Sheet.* This sheet lies below the Upper Sheet from north of Ulvik to north of Voss. They are separated by phyllite or mica schist, which varies considerably in thickness. North-east of Ulvik the Upper Sheet is absent and the Middle Sheet lies below the Upper Jotun Nappe. Also between Voss and Vossestrand the Upper Sheet disappears, and the phyllite between the Middle Sheet and the Upper Jotun Nappe attains a considerable thickness. From Voss southward the Middle Sheet has been greatly reduced by erosion and is found in 12 separate areas.

The minimum thickness of the Middle Sheet is estimated to be 1000 m. In the Voss-Ulvik district also this sheet wedges out northward.

The rock types occurring are the same as those in the Upper Sheet. In the northern parts quartzite, quartz schist and metarhyolite predominate, although some metabasalt and saussurite gabbro occur. South of the excursion route, granite and gneisses of metarhyolitic composition are most important. Rocks of the anorthosite kindred are found only in the area which extends from Ålvik westward and which disappears north of Norheimsund.

*Lower Sheet.* This sheet is found in two large areas and several smaller areas. One large area extends from Voss northwards. The sheet becomes gradually thinner, and the phyllite above and below becomes thicker, until the nappe wedges out south-west of Vik. The other large area extends from a point north-east of Granvin westward and south-westward to the sea, east of the Samnanger fjord. Only one of the small areas needs to be mentioned. It lies above the phyllite on the east side of the Hardangerfjord and continues across the fjord to Ljones, where it forms an irregular mass, 100—300 m thick, in the lower phyllite. The gneisses along the road between Ytre Ålvik and Fyksesund probably belong to this sheet.

The greatest development of this sheet is found around the head of the Fyksesund. The mountains reach 1300 m above sea level, and the thrust plane lies at a considerable depth below sea level. A minimum thickness of 3000 m should be a safe estimate.

The greater part of this sheet consists of supracrustal rocks which, in the author's opinion, belong to the Telemark suite. The "Telemark rocks" in this sheet are quartzite and quartz schist with quartzite conglomerate, metarhyolite, metadacite and metabasalt. Quartz diorite and saussurite gabbro are believed to be of Precambrian age, while the granite, which occurs in several plutons, is considered to be of Caledonian age. Between Ålvik and Fyksesund feldspar augen are locally developed in gneissic rocks of this sheet. The phyllite between the Lower and Middle Sheets is, in most places, only a few meters thick, as is also the case with the phyllite between the Middle and Upper Sheets. The phyllite below the Lower Sheet is generally several hundred meters thick, especially in the Voss district.

### *The Lower Bergsdalen Nappe.*

*Upper sheet.* This sheet occurs mainly in an area extending from the highway between Samnanger and Norheimsund northward to a point 15 km NW of Voss, where it seems to disappear. The mapping north of Vosse-elvi is incomplete, but it is known that at least three minor bodies of alien rocks lie in the phyllite further north and in the approximate continuation of the nappe.

Towards the south this sheet disappears underneath the Upper Bergsdalen Nappe, but reappears 5 km further south in a window around the lake Gjønavatn.

The maximum thickness of this sheet is about 5000 m.

The rock types are the same as in the Lower Sheet of the Upper Bergsdalen Nappe, but they occur in different proportions, and the degree of metamorphism is higher. In the upper nappe most of the rocks belong to the epidote amphibolite facies, whereas in the lower nappe they are in the amphibolite facies or in transitional stages between these two facies. In the upper nappe the plagioclase of most rocks has the composition $An_{0-10}$, while in the Upper Sheet of the lower nappe the composition is $An_{20-30}$.

*Middle Sheet.* This sheet is separated from the Upper Sheet by a mica schist, which in most places is less than 2 m thick and which may be absent. Other zones of mica schist of similar thickness occur less than 1 km from this zone, and its importance as a thrust plane was not recognized within the Bergsdalen quadrangle. In the author's papers on this quadrangle the Upper and the Middle Sheet are therefore treated as one sheet. Mapping north of the Bergsdalen quadrangle, however, has brought out the existence of this thrust plane.

The Middle Sheet extends about 10 km further north than the Upper Sheet. An isolated body of gneissic rocks further north probably belongs to this sheet.

The maximum thickness of this sheet is about 3000 m.

Metadacite and metabasalt predominate, but other rock types of the Upper Sheet occur in minor amounts.

*Lower Sheet.* This sheet is separated from the Middle Sheet by a zone of mica schist, which varies in thickness from 10 to nearly 100 m, and which can be traced continuously for nearly 50 km until the Lower Sheet wedges out. The sheet is separated from the north-western migmatites below by a zone of mica schist having about the same thickness.

The maximum thickness of this sheet is about 1000 m (within the Bergsdalen quadrangle 700 m).

Metadacite is the most important rock type, but metabasalt and granite also occur.

### *Anorthosites and related rocks in the Bergen Arc System.*

*Reusch* (in Reusch and Kolderup 1902) presented two alternative cross sections through the Bergen Arc System. In one section the two arcs of Cambro-Silurian rocks were assumed to be synclines in the basement. The basement was generally accepted to be of Precambrian age. In the second cross section the two arcs were united underneath the rocks between them, which in that case would become a nappe. *Reusch* did not state which explanation be preferred. The present author has favoured the second explanation (1948) and subsequent research has strengthened his belief. A detailed discussion is outside the scope of this paper, but the main reasons may be briefly stated:

1. The rocks of the anorthosite kindred are absent in the Western Gneiss Area as well as in the adjoining parts of the North-Western Migmatite Area south of the Sognefjord.
2. A small body of anorthosite and related rocks lies in a syncline of

phyllite along the eastern border of the Major Arc in the Samnanger area.

3. The rocks of the Minor Arc most likely bend southward under the sea and join the schists of the Major Arc.

Although the majority of the rocks between the two arcs of Cambro-Silurian rocks belong to the anorthosite kindred, there are a few exceptions. East and south of the Minor Arc is a zone of gneisses, mainly of granitic composition, which show no relation to rocks of the anorthosite kindred. In these gneisses are two zones of quartzite with conglomerate, which have been thrust or folded into their present positions. Along part of the boundary between the anorthositic rocks and the gneisses a zone of mica schists is developed. Minor zones of mica schist occur also within the rocks of the anorthosite kindred.

In the Bergsdalen nappes several similar zones of mica schist occur, which do not represent zones of thrusting, but which have been pressed or folded into the nappes.

## Structures.

In 1936 the author began his studies of the petrography and the structures in the Bergsdalen quadrangle. Special emphasis was given to the types of linear structures occurring and their trends. He tried to correlate patterns of the linear structures with the movements of the tectonic units, movements which could be deduced from other evidence. He arrived at certain principles regarding the relation of movements to the trends of the linear structures which were formed during those movements (1948 pp. 196—205).

Petrofabric studies were begun simultaneously with the field studies. The fabric diagrams were, however, of little help in analyzing the tectonic movement in the area. When, however, the regional mapping of the linear structures was completed, they gave useful additional information.

The publication of the petrofabric investigations had to be postponed for various reasons. Meanwhile the author found it desirable to extend his studies northward and southward until the whole nappe area south of the Sognefjord and west of Finse was covered. This was done partly to try if the principles mentioned above would prove valid when applied to other areas, and partly to obtain a better understanding of some of the structural problems encountered in the Bergsdalen area. The studies are incomplete in some parts of the area, but it is believed that enough material has been collected to give the general pattern of the existing structures. In this paper only the main results can be given. As a general conclusion it can be stated that the results of recent years support the ideas set forth in the papers on the Bergsdalen quadrangle.

The author has used the term "Linear structures" to include all linear structural elements which can be found in rocks, the term thus being synonymous with the term "Lineation" as defined by Ernst Cloos. Feeling the need for a descriptive classification of linear structures in metamorphic rocks, he has found the following groups useful for field work as well as for further studies: Lineation, striae on slickensides, fold axes, intersections between planar structures.

*Lineation* is used for parallell orientation of minerals, stretching of conglomerate pebbles, amygdules, fossils etc., that means structures which were formed during a recrystallization of the whole or the major part of the rock.

If a parallell orientation of minerals having a trend different from that of the main lineation in the rock is found on some surfaces or in narrow zones a few millimeters in thickness, the term secondary lineation has been used. It is believed that this structure was formed at a stage when movement and recrystallization affected only a small fraction of the rock, and that it in general is younger than the main lineation, but older than the slickensides.

In many cases the surfaces of quartz veins and lenses exhibit a distinct linear element, which by studies of thin sections is revealed to be caused by a parallel orientation of quartz grains. This lineation may or may not be parallell to the lineation of the rock. In the latter case it tends to be parallel to the secondary lineation. The author considers it likely that in many cases it is younger than the main lineation.

*Intersections between planar structures* generally are intersections between flow cleavage or bedding and fracture cleavage.

The construction of $\beta$ axes, based on field observations of planar structures, has not been carried out.

## Structural Patterns.

On the map of lineation (Pl. 2.) the simplest pattern is found in the area from Finse westward to Lussand at the Hardangerfjord. In this area we may speak of three main tectonic units: 1) the Precambrian basement, the surface of which around Finse is gently undulating, but from Hallingskeid westward dips 10°—30° NW; 2) the phyllite zone, which provided lubrication for the movements; 3) the nappes, consisting of massive rocks having a total thickness of at least 5000 m.

There is ample evidence indicating that the nappes were thrust over the basement for probably more than 100 km. There is also evidence that the general trend of the movements in this orogen as in others was away from the central parts of the orogenic zone towards and above the foreland, *i.e.* a trend in the quadrant between east and south. A contour map of the base of the Cambrian indicates that the movements took place over a gently undulating surface which provided no serious obstacles. We might therefore expect to find a fairly regular pattern in the structures which were formed during these movements. Actually the map of lineations shows a remarkable parallelism in the trends, both in the basal parts of the nappe, in the phyllite, and in the deformed parts of the basement. This general trend is east-southeast, almost parallel to the direction of thrusting.

More direct evidence of direction and mechanism of movements is seen in several localities. At Hallingskeid the foliation in the basement, (strike north—south, dip vertical for at least 100 m below the contact), is bent eastward in a 1 m thick border zone to the phyllite. This bent zone has a distinct lineation trending east-southeast, which is not seen at deeper levels. The outcrop gives evidence of movement towards east-southeast. About 40 m to the east the lineation in the top of the basement maintains the east-southeast trend, but here the foliation has been deflected west-northwest. Traces of relative movements in the phyllite at both localities generally indicate that the upper layers moved towards west-northwest. In other localities there are further indications of movements towards west-northwest as well as east-southeast. Southeast of Hermansverk on the northwest side of the nappe area, *Skjerlie* (pp. 60—64) found evidence of movements towards northwest. These movements he interpreted as being caused by isostatic compensation after the main thrusting.

The problem of the opposite directions (senses) of movements needs further study. The present author believes that the movement towards west-northwest or northwest probably was the later one. If the overthrusting was connected with convection currents as outlined in *Griggs'* theory of mountain building, the thrust planes would, during the over- (or rather under-) thrusting, dip towards northwest. When the movements halted one might therefore expect some down-dip sliding of the nappes, giving evidence of movement in the opposite sense of the main movement.

Along a profile from Ulvik to Voss and northward to Vik at the Sognefjord, the trend of the lineation in all tectonic units changes gradually from east-southeast through southeast to south-southeast. Usually only one trend is present in any one area except in the northernmost part, where in addition to the south-southeast lineation also a lineation trending northeast occurs in the phyllite and in the northern part of the Upper Bergsdalen Nappe. In the migmatite gneisses lineations trending both northeast and southeast are found, the former being the most important.

In the southwestern part of the nappe area, southwest of Ålvik, the pattern of the lineation is more complicated. This difference in pattern agrees well with the assumption that the movements proceeded less smoothly, which can be demonstrated by means of geologic maps, profiles, and structure contour maps. Between the overthrust rocks and the basement lie in this part of the nappe area not only the phyllite, but also the thick series of green schist, rhyolites, conglomerates and intrusives of gabbro and trondhjemite. The thickness of this "green schist formation" was perhaps ten times that of the phyllite. That this thick series of mostly competent rocks provided no lubricant for the overthrusting is best seen by studying structure contour maps of the base of the nappes in the two parts of the excursion area. The nappes resting on phyllite dip rather uniformly north or northwest. The contact between the Upper Bergsdalen Nappe and the green schist formation is highly irregular, the angle of dip being mostly 70° to 90° and changing in strike direction at short intervals. The continuation of the nappe on the east side of the Hardangerfjord and at Ljones may imply that the whole northern part of the green schist formation lies as a huge fold in the nappe.

In the southwestern part of the nappe area a lineation trending parallell to the local strike of the thrust plane is seen on either side of the thrust plane. Where the strike of this plane differs from east-southeast, a local lineation trending east-southeast is found, partly in the rocks, and partly in quartz veins and lenses. Folding on axes parallel to the strike of the thrust plane is common, and in several cases this folding is clearly younger than the east-southeast trending lineation. Proceeding westward from the thrust plane between the Upper Bergsdalen Nappe and the green schist formation, *e.g.* along the road between Norheimsund and Samnanger (seventh and eighth days of the excursion), one finds a prominent lineation trending east-southeast and strictly parallel in the two Bergsdalen nappes and in the phyllite between them.

These observations can, in the author's opinion, only mean that the east-southeast lineation was formed during the overthrusting and parallel to the direction of movement. During the later stages of the overthrusting, when the movement halted due to the resistance of the green schist formation, the rocks near the thrust plane were folded on axes being approximately parallel to the local strike of the thrust plane.

The conspicuous difference between the structural patterns in the northeastern and the southwestern parts of the area may be explained as the result of two different types of movement. In the northeastern part, the movements proceeded relatively unhampered because of the lubrication effect of the Phyllite Formation. This type of movement was predominantly laminar, with one layer sliding above the other. As a result of such movements the direction of maximum elongation parallels the direction of movement, and in this direction the lineation was formed. In the southwestern part of the area the green schist formation offered considerable resistance to the overthrusting, causing an intense folding of the rocks. The type of movement was here rotational. The direction of maximum elongation was parallel to the strike of the steeply dipping thrust plane — and to the fold axes — consequently the lineation was formed in this direction.

The pattern of the main lineation in those areas which will not be visited during the excursion shall only be briefly mentioned. In the Northwestern Migmatite Area (north of Bergen, south of Sognefjord) the dominating trend of the lineation is northeast. East of the migmatite area the trend of lineation in the three sheets of the Lower Bergsdalen Nappe change gradually, being northeast in the lower, western, part and east-southeast in the upper, eastern, part. In the zones of mica schist, which have served as thrust zones, the lineation trends, however, east-southeast. This above mentioned change in trend in the lower nappe is difficult to explain. The author believes that the lineation was formed during the thrusting of the upper nappe, and before the thrusting of the lower nappe.

The pattern of the secondary lineation is—throughout the excursion area—very simple, being predominantly east-southeast and independent of the trend of the main lineation. This trend is found even in the northwestern migmatites.

The pattern of the lineation trends in quartz veins and lenses is also quite simple. An east-southeast trend is found over the whole excursion area, but lineation conforming to the main lineation of the rock is also found.

The striae on slickensides give a less regular pattern, but more than half of the observations give trends about east-southeast in all tectonic units. This trend is found on slickensides showing great variation in strike and dip, although the majority strike about northeast.

In the Western Gneiss Area (west of Bergen) a prominent lineation trending about east-southeast is found nearly everywhere. Fold axes have the same trend.

In the Bergen Arc System the structural patterns are complicated and investigations are as yet incomplete, but some facts are clear. The main lineation is parallel to the local trend of the arcs. Lineation trending east-southeast to southeast is found in many localities, and at least in some cases it is the older structure. The contact between the arc system and the nappe area is a thrust plane, generally steep and irregular in shape. Near the thrust plane, below as well as above it, lineation trending east-southeast has been folded on axes parallel to the strike of the thrust plane. East of the Samnanger area the strata in the nappes dip gently westward until about 100 m from the thrust plane, where they become steeper until they are vertical at the contact. Evidence of relative movements in the nappes show that the lower part has moved relatively eastward during movements which caused a folding on axes trending from north to northwest and being parallel to the contact between the Bergen Arc System and the nappe area. This direction (sense) of movement is in good agreement with the steepening of the strata near the thrust plane.

It seems likely that the Bergen Arc System during a late stage of deformation was moved eastward towards the nappe area.

The author takes the observations of trends of the various types of linear structures as evidence that the main direction of tectonic transport throughout the deformation was east-southeast. During the earlier stages of movement, when the rocks recrystallized completely and the main lineation was formed, local variations in resistance to movement and in competency of the rocks, together with differences in the evenness of the Precambrian peneplain, caused variations in the type of movement and in the trends of the structures formed during the movements. During later stages, when the rocks were more solid, and the movements were restricted to narrow zones, the movements and the resulting structures became more uniform.

The petrofabric studies are not yet completed, but a few facts are clear.

Wherever a megascopic lineation can be observed, the B axis of the mica is parallel to the lineation. If only one megascopic lineation is found, the B axis of quartz has the same direction. Where a secondary lineation is developed, the quartz pattern is more complicated. In some cases a more or less distinct girdle, having the secondary lineation as a B axis, is seen. The orientation in some of the quartz diagrams is remarkably good.

### Age of the Overthrusting.

Regarding the age of the various movements the following can be said.

The thrusting of the Upper Bergsdalen Nappe commenced before the thrusting of the Lower Bergsdalen Nappe, and during subsequent deformation the two nappes moved together.

The thrusting of the Upper Jotun Nappe probably took place after the thrusting of the Upper Bergsdalen Nappe, if otherwise the wedging out to the north of the upper and middle sheets of this nappe below the Jotun Nappe is difficult to explain.

The formation of the Bergen Arc System was later than the thrusting of the two Bergsdalen nappes. It was probably also later than the thrusting of the Upper Jotun Nappe, as the middle part of the arc system may be a part of a nappe (it has the same petrographic composition as the Upper Jotun Nappe).

The formation of the Bergen Arcs began after the deposition of the Lower Silurian sediments, and was completed before the deposition of Middle Devonian sediments.

No formation corresponding to the Valdres Sparagmite has been found in connection with the Bergsdalen nappes. Thus there is no evidence of a considerable time interval between the thrusting of the various nappes. This implies further that although the identity of the Upper Jotun Nappe in the excursion area is clear, the correlation of the other nappes with nappes in Eastern Norway is at present very uncertain.

## OUTLINE OF GEOLOGICAL HISTORY

*Precambrian.*

Deposition of sediments and volcanics of the Telemark suite. Intrusion of plutonic rocks. Widespread granitization destroying the base of the suite and large volumes of supracrustal rocks. Uplift and erosion producing a peneplain.

*Eo-Cambrian.*

No deposition of sediments in the excursion area.

*Cambrian.*

Towards the end of Lower Cambrian times slow marine transgression southward on sub-Cambrian peneplain. Deposition of 1—2 m of basal gravel in pockets, then deposition of a few meters of arenaceous sediment. Subsequent deposition of argillaceous sediments through Middle and Upper Cambrian.

*Ordovician.*

*Lower Ordovician.* Deposition of argillaceous material continued in the northeastern part of the area through most of the epoch. Arenaceous and calcareous sediments were formed during relatively short intervals.

Also in the southwestern part of the area the deposition of argillaceous sediments continued during the first stage of this epoch. Later a widespread and intensive volcanic activity began. The volcanics are mostly basic, but acid rocks also occur. During lulls in the volcanic activity argillaceous and calcareous sediments were deposited. Then followed a large-scale intrusion of plutonic rocks beginning with serpentines, continuing with gabbros and concluding with trondhjemites.

*Middle Ordovician.* A period of deformation and metamorphism began in the upper part of Lower Ordovician or in the lower part of Middle Ordovician. Argillites were altered to phyllites, limestones to marbles, basic volcanics to green schists etc. Whether the deformation was accompanied by thrusting in addition to the downfolding is not known. Nor is it known whether any deposition of sediments took place.

*Upper Ordovician.* Uplift and erosion of the metamorphosed Lower Ordovician rocks resulted in the formation of the polygenic Moberg conglomerate, and probably the "Chloritic sparagmite" in the Bergen arcs. Later argillaceous material was deposited. In the southwestern part of the area coral reefs were common. In the northeastern part neither conglomerate nor limestone occurs, and it is not known whether deposition of argillaceous materiel took place.

*Silurian.*

*Lower Silurian.* Only events in the southwestern part of the area can be deciphered to some extent. Renewed uplift and erosion caused the deposition of sand and quartzite pebbles of unknown origin. Later followed deposition of argil lasting at least into the middle part of Lower Silurian times.

*Middle and Upper Silurian.* During these epochs the thrusting of the three nappes took place, probably also the formation of the Bergen arcs. Further events during these epochs were the thorough deformation of the basement, accompanied by granitization and emplacement of granitic plutons. (Whether and eventually to what extent deformation of basement, granitization and intrusion of granite took place during the Middle Ordovician orogenic phase is not known at present.)

After deformation and metamorphism a very extensive uplift followed, which probably began in Upper Silurian and lasted into the Middle Devonian.

*Devonian.*

*Lower Devonian.* This was an epoch of uplift and erosion. Sediments of this age are not known from Western Norway.

*Middle Devonian.* Uplift and erosion continued. Enormous quantities of gravel and sand were deposited. The total thickness is not known, but it has been estimated at more than 20 000 meters. These sediments which now are found in the coastal areas north of Bergen were in part deposited upon Caledonian gneisses, which during the Middle and Upper Silurian orogenic phase were deformed at depths probably exceeding 10 kilometers.

*Upper Devonian — Lower Tertiary.*

No record of the geological history is left. The country probably had a low elevation during most of this time, and both erosion and deposition were insignificant. By Middle Tertiary time a peneplain had been formed, which comprised most of the surface of the country.

*Upper Tertiary.*

In late Tertiary times the country was uplifted and tilted towards the east. In the coastal areas extensive faulting took place along fault lines parallel to the present coast. Most of the fault lines were of Caledonian age, some were Devonian, others may have been Precambrian. The uplift in the coastal areas exceeded 1000 meters, in Eastern Norway it was much smaller. Erosion began remodeling the landscape, cutting deep canyons in the old peneplained surface.

*Pleistocene.*

The country was covered with ice probably four times. The present surface has been sculptured partly by erosion during the glacial periods, and partly by erosion during interglacial times. Remnants of the old Tertiary peneplain are still visible in the central parts of the country, especially in Hardangervidda, which extends for about 100 km N—S and 100 km W—E.

Raised beaches and shore lines give evidence that the country was depressed by the load of the ice and that an isostatic upheaval followed. The post-glacial marine limit lies at 56 m in Bergen, 70 m at Tysse in Samnanger, 90 m west of Norheimsund and at 120 m at the innermost arms of the Hardangerfjord. The latter figure does not give the maximum uplift, as the terraces are younger than the highest terraces at Bergen, which were formed at a time when the inner part of the Hardangerfjord was covered with ice.

It is likely that the uplift in Western Norway has been insignificant during the last 700 years.

## ROAD LOG

1st. DAY, Aug. 5th., Aug. 26th. Contact between Precambrian basement and Cambrian phyllite at Finse. Basement undeformed, locally undeformed basal Cambrian conglomerate.

From Finse railway station (elevation 1222 m) by foot along marked trail 1500 m ENE to contact between Precambrian basement and Cambrian sediments (elevation 1420 m). In brook undeformed Middle Cambrian basal conglomerate (thickness 0.5 m). Above conglomerate quartz schist with mineral parallelism trending ESE.

Return to railway station. From there by foot 700 m NW to water reservoir. Contact exposed. Deformation of basal Cambrian beds and top of basement.

Return to railway station. By train through basement and Phyllite Formation to Hallingskeid.

Night quarters: Hallingskeid Fjellstove, Hallingskeid.

(For the night quarters the mailing address is given.)

2nd. DAY, Aug. 6th., Aug. 27th. Contact between Precambrian basement and phyllite at Hallingskeid. Deformation of basement.

From Hallingskeid railway station (elevation 1110 m) 1200 m walk northward to contact between Precambrian basement and Cambro-Ordovician sediments (elevation 1240 m) (p. 27). Precambrian surface undulating. Caledonian deformation visible 1—5 m downward. Bending of foliation in some places indicating movement towards ESE, in other places towards WNW. Drag folds etc. in phyllite indicating movement of upper layers towards WNW. Parallel orientation of minerals in Cambrian quartz schist and stretching of Precambrian feldspar in gneiss trend ESE. Later folding on axes trending N.

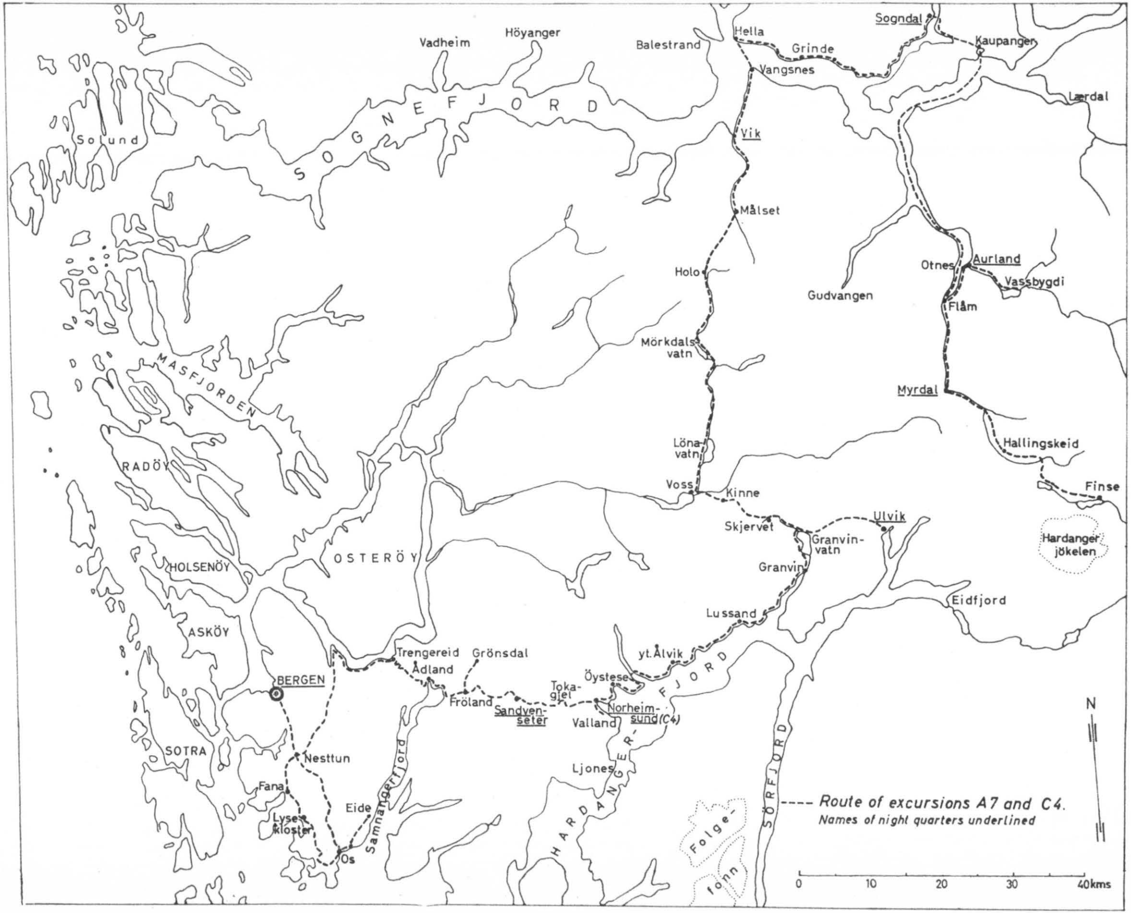



*Fig. 2. Map showing excursion route. First night quarters Hallingskeid, not Myrdal as shown on map.*

Return to railway station. By train to Myrdal, where change to the Flåmsdalen railway, which in 20 km descends to sea level through magnificent canyon. Upper part of canyon is eroded in Upper Jotun Nappe, lower part in Phyllite Formation. Near fjord the nappe is re-entered.

Night quarters: Wangen Hotell, Aurland.

3rd. DAY, Aug. 7th., Aug. 28th. Window with Precambrian rocks Aurland—Vassbygdi. Contact with phyllite and deformation of basement south of Aurland. Basal part of Upper Jotun Nappe at Flåm.

By bus from Aurland 10 km eastward to Vassbygdi. Road cuts in massive migmatite of Precambrian window 1000 m vertically below phyllite. No trace of Caledonian deformation. Return by bus to Aurland.

By foot 700 m from Aurland southward to Otnes. Basement rocks become less massive towards contact with phyllite. Contact exposed at shore in bay on south side of Otnes. Near contact, prominent mineral parallelism trending ESE in gneiss and phyllite. Structures in phyllite indicate relative movement of upper layers towards WNW. In gneiss feldspar phenocrysts reaching 5 cm occur 10—30 m below contact. Most phenocrysts undeformed.

By bus to road cut in phyllite 1 km from Flåm. Walk 500 m past unexposed contact with Upper Jotun Nappe to road cuts in basal portion of nappe. Gneissic rocks of anorthosite kindred display mineral parallelism trending ESE.

Walk 500 m to Fretheim Hotell. In hill east of hotel large potholes are seen in gneissic rocks of Upper Jotun Nappe having lineation as in previous locality.

Luncheon at Fretheim Hotell.

After luncheon by boat from Flåm to Kaupanger on north side of Sognefjord. Anorthosites and related rocks of Upper Jotun Nappe are seen on both sides of Aurlandsfjord.

By bus from Kaupanger to Sogndal. Stop at road cut near Valeberg 6 km from Kaupanger for study of anorthosites.

Night quarters: Hofslund Hotell, Sogndal.

4th. DAY, Aug. 8th., Aug. 29th. From Sogndal by bus westward along the Sognefjord through Upper Jotun Nappe, Valdres Sparagmite, Phyllite Formation and basement gneisses to Hella. Ferry from Hella to Vangsnes on south side of Sognefjord. Bus from Vangsnes through basement gneisses to Vik.

Stop at road cut 3 km from Sogndal for study of dioritic rocks of the Upper Jotun Nappe.

At Fatlaberget the road goes for 3 km (16—19 km from Sogndal) through the Valdres Sparagmite (p. 10), which lies below the nappe and above the Phyllite Formation. Consists of quartzite, arkose and graywacke, intensely folded. Mineral parallelism trending SE, locally NNE, axes of folds trending NNE, locally SE, drag folds indicating movement towards NW.

Below the Valdres Sparagmite, phyllite, mostly covered along the road to Grinde, where contact between phyllite and basement gneisses. Complete conformity as to structures on both sides of contact.

Between Grinde and Hella migmatitic gneisses (p. 17). Between Vangsnes and Vik migmatitic gneisses.

Night quarters: Hopstock Hotell, Vik i Sogn.

5th. DAY, Aug. 9th., Aug. 30th. From Vik through basement gneisses, phyllite, Upper Jotun Nappe and units of the Upper Bergsdalen Nappe via Voss to Ulvik, where the Precambrian basement southeast of the nappe area is entered.

*Stop 1.* Road curve near Holstad stølen 7 km from Vik. Phyllite with zone of quartz schist.

*Stop 2.* Målset 15 km from Vik. 200 m E of road exposure of Valdres Sparagmite. Lineation trending SSE.

*Stop 3.* Road cut 1 km south of Skjerlingevatn. Phyllite with quartz lenses.

*Stop 4.* Road curve 500 m north of Holo seter. Contact between phyllite and Upper Jotun Nappe (quartzose schists).

*Stop 5.* Near outlet of Myrkdalsvatn. Mangerites etc. of Upper Jotun Nappe in contact with phyllite.

After 1.5 km, road intersection at Vinje. Phyllite continues southward for 2.5 km to an anticline of underlying quartzitic rocks belonging to the Middle Sheet of the Upper Bergsdalen Nappe, which continues southward to Lønavatn.

*Stop 6.* Åsbrekke bru (bridge), 9.5 km south of Myrkdalsvatn. Quartzite with lineation plunging NNW.

At northern end of Lønavatn phyllite below the quartzite. Through phyllite southward to Voss, then 4—5 km eastward to Kinne, where *Stop 7* for demonstration of nappes around Voss.

*Stop 8.* Dalsleitet 15 km SE of Voss. Quartzite and quartz schist belonging to Middle Sheet of Upper Bergsdalen Nappe. Prominent lineation trending SE.
*Stop 9.* Skjervet 20 km SE of Voss. Gneissic rocks belonging to Upper Sheet of Upper Bergsdalen Nappe.

From Skjervet on winding road downward through Upper and Middle Sheets of Upper Bergsdalen Nappe to the lake Granvin-vatn, where phyllite zone SE of nappe area is reached. Then NE, E and SE to Ulvik. The road goes first through phyllite, then through Middle Sheet of Upper Bergsdalen Nappe, then downward through phyllite to Precambrian basement at Ulvik.

Night quarters: Ulvik Hotel, Ulvik.

6th. DAY, Aug. 10th., Aug. 31st. From Ulvik return to Granvin-vatn, then southward into Precambrian rocks near Granvin, then SW through Precambrian rocks to Lussand, through phyllite and Lower and Middle Sheets of Upper Bergsdalen Nappe to Fyksesund, then through the zone of phyllite and volcanics to Norheimsund.

*Stop 1.* Roadcut 2 km above Ulvik. Basement gneiss.

*Stop 2.* Espeland, half way between Ulvik and Granvin-vatn. Quartz schist of Middle Sheet of Upper Bergsdalen Nappe. Lineation trending ESE.

*Stop 3.* Near outlet of Granvin-vatn. Contact between phyllite and basement exposed.

*Stop 4.* Granvin. Massive Precambrian quartz diorite.

*Stop 5.* 6 km SW of Granvin (1 km SW of Folkedal). Metadacitic gneiss.

*Stop 6.* 1.2 km E of Lussand. Massive Precambrian granite.

*Stop 7.* Lussand. In brook, contact between Precambrian gneiss and phyllite.

*Stop 8.* 3.5 km SW of Lussand. Contact between phyllite and Lower Sheet of Upper Bergsdalen Nappe.

*Stop 9.* Ytre Ålvik. Mangerites and related rocks belonging to Middle Sheet of Lower Bergsdalen Nappe.

*Stop 10.* 3 km SW of Ytre Ålvik. Augen gneiss belonging to Lower Sheet of Upper Bergsdalen Nappe (p. 23).

*Stop 11.* Berge, 3 km SE of Øystese. Phyllite and polymictic conglomerate belonging to the series of phyllite with volcanics.
*Stop 12.* Valland, 2.5 km SE of Norheimsund. Metavolcanics with sills of trondhjemite.
Night quarters: A 7: Sandvenseter Turisthotell, Eikjedalsgrend, C 4: Sandven Turisthotell, Norheimsund.

7th. DAY, Aug. 11th., Sept. 1st. From Norheimsund westward through Steinsdalen and Tokagjel (Phyllite with volcanics) to Kvamskogen, the critical area of the nappe structures.

*Stop 1.* Lower end of Tokagjel canyon 5 km from Norheimsund. Phyllite.
*Stop 2.* Upper end of Tokagjel canyon. From here (elevation 350 m) by foot northward 2 km to contact between phyllite and Lower Sheet of Upper Bergsdalen Nappe (elevation 680 m). Along the path outcrops of phyllite, green schist, polymictic conglomerate and trondhjemite. Lineation and fold axes trending ENE predominant, southeasterly trend occurs locally. Metarhyolitic gneiss in nappe, folded on axes trending ENE.
Return to highway. By bus westward to Sandvenseter.
*Stop 3.* 3 km W of Tokagjel. Metarhyolitic gneiss of Upper Bergsdalen Nappe (Lower Sheet). Foliation and lineation dipping 20° ESE.
*Stop 4.* 4.5 km W of Tokagjel. Mica schist between the two Bergsdalen nappes in contact with metadacite of Upper Sheet of Lower Bergsdalen Nappe. Structures parallel with those of preceding locality.
*Stop 5.* 5.5 km W of Tokagjel. Alternating layers of metadacite and metabasalt.
*Stop 6.* Sandvenseter. Metabasalt.
Night quarters: Sandvenseter Turisthotell, Eikjedalsgrend.

8th. DAY, Aug. 12th., Sept. 2nd. From Sandvenseter westward through Upper Sheet of Lower Bergsdalen Nappe to Lower Sheet of Upper Bergsdalen Nappe at Frøland, where also junction with Bergen Arc system. From Frøland northward on side road to Grønsdalsvatn, where strongly deformed quartzite and conglomerate of Lower Bergsdalen Nappe. Return to Frøland and westward through Bergen Arc system to Bergen.

*Stop 1.* Brattefossen, 3 km W of Sandvenseter. Metadacite (Upper Sheet of Lower Bergsdalen Nappe) with prominent lineation and rodding trending ESE.

*Stop 2.* 1.5 km E of Frøland. Metadacite (Upper Sheet of Lower Bergsdalen Nappe) with lineation trending ESE and younger folding on axes trending NNW.

*Stop 3.* Bridge at Frøland. Metarhyolitic gneiss of Lower Sheet of Upper Bergsdalen Nappe, dipping gently westward.

*Stop 4.* 500 m NW of bridge. Phyllite and green schist of Bergen Arc system. Lineation trending ESE strongly folded on axes trending N. By foot 500 m to Frøland hydroelectric power plant, where demonstration of vertical contact between Upper Bergsdalen Nappe and Bergen Arc system.

*Stop 5.* Grønsdalsvatn. Quartzite with prominent lineation *(Kvale* 1945).

*Stop 6.* 1 km SW of Grønsdalsvatn locality. By foot 1 km to Seterhaug, where strongly deformed quartzite conglomerate.

Return to Frøland and westward to Tysse at Samnangerfjord. Contact with Bergen Arcs (unexposed) is passed 400 m W of road intersection at Frøland. From Tysse northward and westward along the fjord 5 km to roadcut in quartz porphyry at Bjørkheim, where *stop* 7 (p. 14).

*Stop 8.* Roadcut 1 km SW of Ådland on W side of Samnangerfjord. Phyllite.

*Stop 9.* Hisdal 3 km W of Ådland. Polymictic Moberg conglomerate with stretching plunging S. Contact with trondhjemite (p. 15). By foot 500 m along the road through trondhjemite and conglomerate to white coarse-grained limestone, which occurs as pebbles in adjoining conglomerate. West of white limestone, a grey limestone with Upper Ordovician fossils (p. 15).

*Stop 10.* Road tunnel 1.5 km S of Trengereid (4 km N of stop 9). Graywacke *(Reusch:* chloritic sparagmite).

*Stop 11.* Romslo, 3 km W of Trengereid. Gneissic rocks of anorthosite kindred. Lineation and fold axes trending N.

*Stop 12.* 1.5 km S of Garnes. Anorthosite with garnet and pyroxene (p. 19).

Night quarters: Bergen (A 7: Park Pension, Parkveien 22, C 4: Neptun Hotell, Walckendorffsgt. 8).

9th. DAY, Aug. 13th., Sept. 3rd. The morning will be allotted to visits to the geologic museum and institute, to shopping and sightseeing. In the afternoon excursion through the rocks of the Minor Bergen Arc and adjoining rocks.

From Bergen to Minde. During a walk of 500 m, outcrops with basal granitic gneiss (p. 14) and mica schist and gneiss of Minor Bergen Arc are studied. Near Storetveit church, quarry with hornblende schist, polygenic conglomerate and marble. Southward to Paradis past outcrops of marble, green schist, saussurite gabbro and mica schist. Northward past Natland with view of Bergen valley, eroded in softer rocks of Minor Bergen Arc between gneissic rocks in the mountains on both sides. Through the city to the old fortress, Festningen. By foot 500 m past outcrops of hornblende schist, mica schist and quartz schist.

By bus 500 m to outcrop of migmatitic gneiss east of Minor Bergen Arc.

Return to the city, night quarters in Bergen.

10th. DAY, Aug. 14th., Sept. 4th. From Bergen southward through Minor Bergen Arc, via Nesttun, then through arc with rocks of the anorthosite kindred and gneisses to Os, where a cross section of the Major Bergen Arc is studied. Return to Bergen via Ulven—Lyse kloster—Fana.

*Stop 1.* Bjørkåsen 1.5 km S of Nesttun. Saussuritized anorthosite.
*Stop 2.* Birkeland 3 km S of Nesttun. Mangerites and related rocks of anorthosite kindred.
*Stop 3.* Hetleflåtvatn 15 km S of Nesttun. Saussurite gabbro and other metamorphic basic rocks of Major Bergen Arc.

From Osøyri southward on road to Moberg.

*Stop 4.* 200 m S of Osøyri. Mica schist and green schist.
*Stop 5.* Moberg, 1 km from Os. Polymictic Moberg conglomerate. strongly deformed. Quarry in trondhjemite *(Reusch:* Quartz augen gneiss, p. 17).

By foot 800 m to outlet of Ulvenvatn. Phyllite with limestone containing Upper Ordovician fossils.

By bus to Solstrand, 1 km E of Osøyri, for luncheon.

*Stop 6.* Sea shore at Solstrand. Mica schist with sills of trondhjemite.

From Solstrand N and NE 5 km to Eide in Hegglandsdal, *(Stop 7),* where samples of fossiliferous limestone may be collected.

Return to Osøyri, then southward past Moberg to Grindavoll, then NW on road towards Hagavik.

*Stop 8.* Skeie 800 m NW of Grindavoll. Quarry in olivine gabbro (p. 17).

One km NW of Skeie right turn on road toward Ulven.

*Stop 9.* 200 m NE of road intersection. Lower Silurian phyllite (p. 16). 100 m eastward on path to contact with quartzite conglomerate, where poorly preserved fossils in phyllite can be found.

*Stop 10.* Ulven, opposite military camp. Lower Silurian sandstone with cross bedding. Zones of slightly deformed quartzite conglomerate (p. 16).

From Ulven 1 km NW to intersection, then 2 km northward, then SW past Lyse kloster (ruins of old monastery) to Lysefjord.

*Stop 11.* Lysefjord. Metamorphosed supracrustal rocks of Major Bergen Arc.

From Lysefjord northward on road to Fana, Nesttun and Bergen.

*Stop 12.* Fanafjell. Granite, probably Caledonian, with prominent lineation.

## LITERATURE


*Goldschmidt, V. M.:* Geologisch-petrographische Studien im Hochgebirge des südlichen Norwegens. I. Ein kambrisches Konglomerat von Finse und dessen Metamorphose. Vidensk.Akad. Oslo. Skrifter. Mat.-Naturv. Klasse Nr. 18, 1912.

– Geologisch-petrographische Studien im Hochgebirge des südlichen Norwegens. IV. Übersicht der Eruptivgesteine im kaledonischen Gebirge zwischen Stavanger und Trondhjem. Vidensk.Akad. Oslo. Skrifter. Mat.-Naturv. Klasse Nr. 2, 1916.

*Holtedahl, O.:* Norges Geologi I-II. Norges Geol. Undersøkelse Nr. 164. 1953.

*Hødal, J.:* Rocks of the anorthosite kindred in Vossestrand, Norway. Norsk Geol. Tidsskrift Bd. 24, pp. 129–243, 1945.

*Kolderup, C. F. and N.-H.:* Geology of the Bergen Arc System. Bergens Museums Skrifter Nr. 20, 1940.

*Kvale, A.:* Petrofabric Analysis of a Quartzite from the Bergsdalen Quadrangle, Western Norway. Norsk Geolog. Tidsskrift Bd. 25, pp. 193–215, 1945.

– Petrologic and Structural Studies in the Bergsdalen Quadrangle, Western Norway. Part I, Petrography. Bergens Museums Årbok 1945. Nat. rekke Nr. 1, 1946.

– Part II, Structural Geology. Bergens Museums Årbok 1946–1947. Nat. rekke Nr. 1, 1948.

– Noen bemerkninger om Telemarkformasjonen på Vestlandet. English summary. Bergens Museums Årbok 1945. Nat. rekke Nr. 5, 1956.

*Reusch, H.:* Silurfossiler og pressede konglomerater i Bergensskifrene. English Summary. 1882.

*Reusch, H. and Kolderup, C. F.:* Fjeldbygningen og bergartene ved Bergen. Summary in German. Bergens Museums Aarbog 1902, Nr. 10.

*Skjerlie, F. J.:* Geological Investigations between Fjærlandsfjord and Sogndalen, Sogn, Western Norway. Universitetet i Bergen, Årbok 1957. Nat. rekke, Nr. 10.

*Strand, T.:* Oversikt over fjellbygningen i Nordre Gudbrandsdalen. Norsk Geol. Tidsskrift Bd. 20, pp. 271–274, 1940.

*The reader is also referred to «Geology of Norway» edited by O Holtedahl. Norges Geologiske Undersøkelse No. 208, Oslo 1960.*

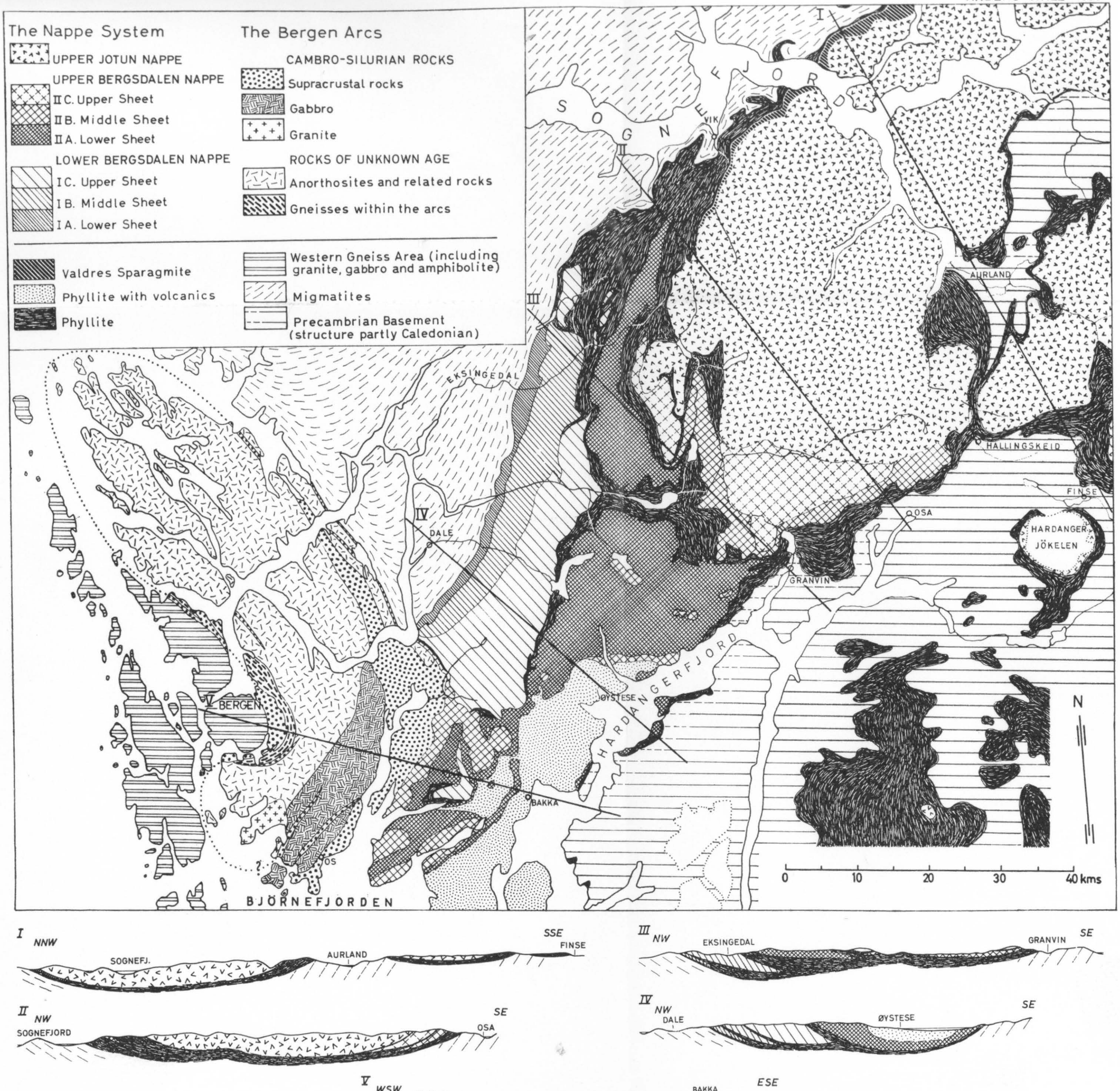
*Notes.*

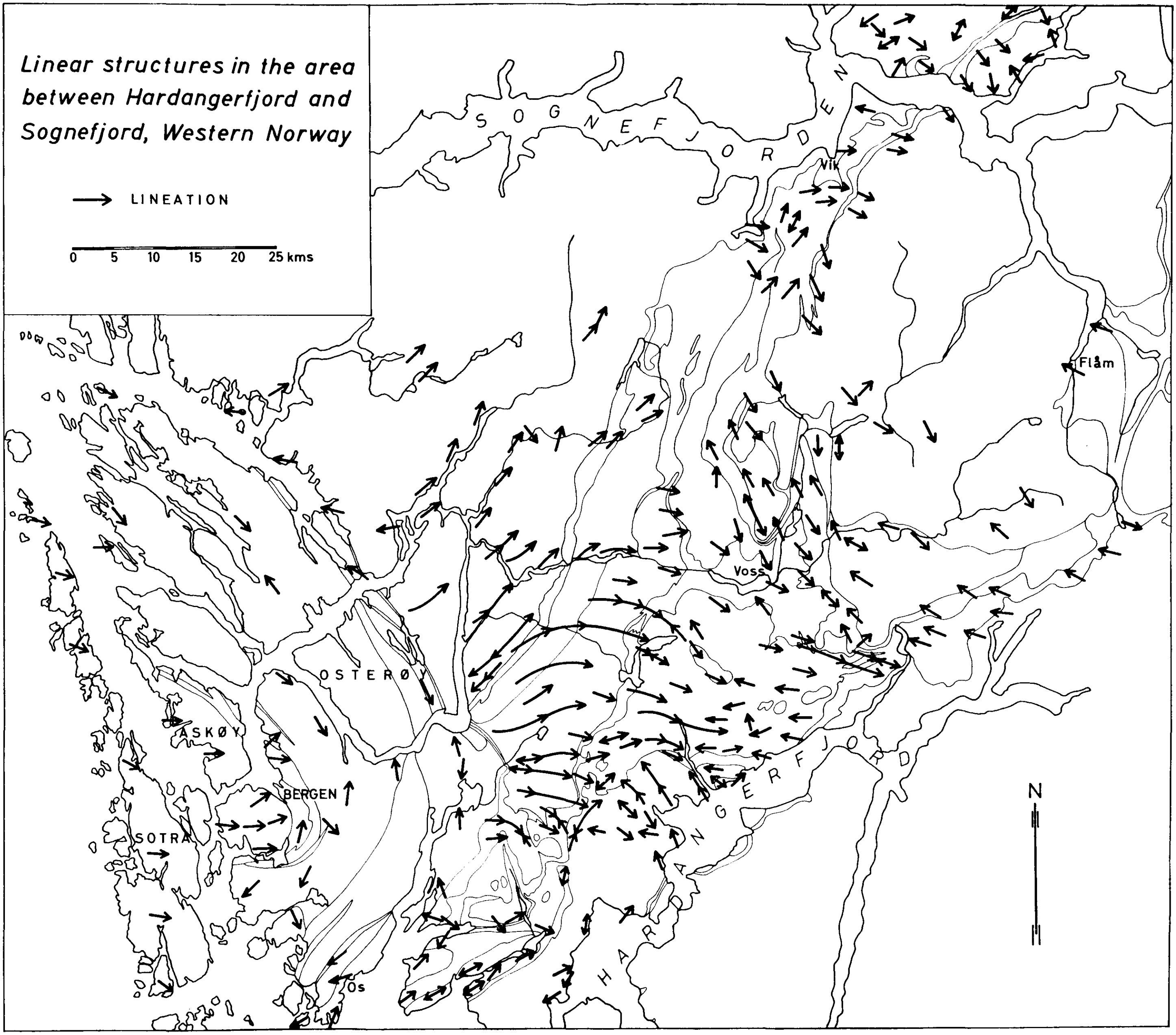
ANDERS KVALE 1959

Norges Geologiske Undersøkelse. No. 212 e. Pl. 1.

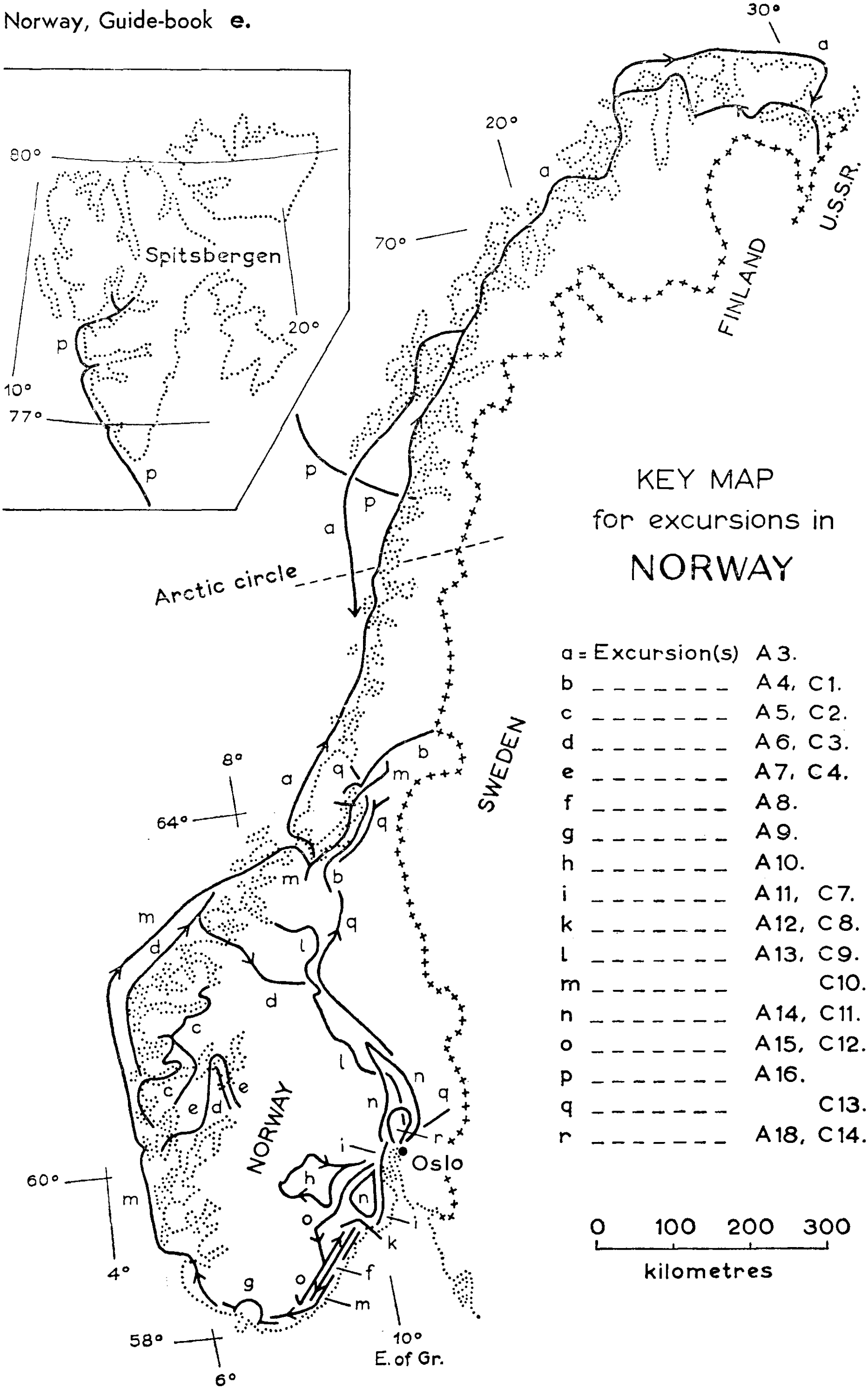
*Geological map of the area between Hardangerfjord and Sognefjord, Western Norway.*

*By Anders Kvale.*




Linear structures in the area between Hardangerfjord and Sognefjord, Western Norway
LINEATION
0 5 10 15 20 25 kms
SOGNEFJORDEN
Vik
Flåm
Voss
OSTERØY
ASKØY
BERGEN
SOTRA
Os
HARDANGERFJORD
N

Norway, Guide-book **e.**




WITTUSEN & JENSEN A/S, OSLO