NORSK POLARINSTITUTT
SKRIFTER NR. 146

B. FLOOD, D. G. GEE, A. HJELLE,
T. SIGGERUD, T. S. WINSNES

The geology of Nordaustlandet, northern and central parts

WITH GEOLOGICAL MAP 1:250 000

NORSK POLARINSTITUTT
OSLO 1969

DET KONGELIGE DEPARTEMENT FOR INDUSTRI OG HÅNDVERK

NORSK POLARINSTITUTT
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Manuscript received January 1969
Printed October 1969

Contents

Abstract

In 1965, Norsk Polarinstitutt sent an expedition to Nordaustlandet, geologically the least known part of the Svalbard archipelago. This paper contains the results of the reconnaissance in which the five authors took part, and includes data from previous works in an attempt to provide a general account of the Hecla Hoek complex of the island.

Northern and central parts of Nordaustlandet contain a geosynclinal sequence of pre-Carboniferous rocks, over 15 km thick, comparable with that described from neighbouring areas to the west. Beneath the Carboniferous unconformity, and intruded by Cretaceous(?) dolerites, the following succession has been established, with Cambrian and late Pre-Cambrian strata: Kapp Sparre Formation (Cambrian dolomites, limestones and shales, c. 800 m); Sveanor Formation (tillites and shales, c. 250 m); Murchisonfjorden Supergroup, composed of three groups, the Roaldtoppen Group – Ryssö Formation (dolomites, c. 1000 m) and Hunnberg Formation (limestones, c. 500 m), the Celsiusberget Group – Raudstup-Sälodd Formation (red and green marls and siltstones with subordinate dolomites, c. 500 m), Norvik Formation (grey-green silts and quartzites, c. 350 m) and Flora Formation (pink quartzites and subordinate red and green mudstones, c. 1250 m), and the Franklinsundet Group – Kapp Lord Formation (shales and quartzites, in part calcareous and with some limestones, c. 950 m), Westmanbukta Formation (red and green quartzites and mudstones, c. 600 m), and Persberget Formation (quartzites and subordinate grey shales, with a conglomerate at the base in the east, c. 400 m); the Botniahalvøya Group–Austfonna/Kapp Platen Formations (quartzites, pelites and limestones with minor amphibolites, c. 3000 m+), Brennevinsfjorden Formation (banded quartzites and pelites, conglomerate at the base in the west, c. 2000 m), and Kapp Hansteen Formation (volcanic rocks, c. 4000 m).

The lowest part of the succession is migmatized. In general, the Botniahalvøya Group was subject to greenschist facies metamorphism and this grade increases towards the contact with the migmatites with the incoming of biotite, garnet and, in one locality, andalusite and staurolite. The migmatite association, with accompanying syn-orogenic granitic rocks (quartz monzonite), contains supracrustal material which at least in part is derived from the Botniahalvøya Group, but apparently not from the overlying stratigraphic units. Gabbros and quartz porphyries intruded the Kapp Hansteen and Brennevinsfjorden Formations prior to the regional metamorphism and deformation.

After the deformation, granites intruded in two principal areas, Brennevinsfjorden and Rijpfjorden – Rijpdalen. None of these intrusive rocks have been recorded to penetrate the Murchisonfjorden Supergroup and overlying rocks, only the older groups and the migmatites.

The succession was folded in the Caledonian, developing a generally westerly asymmetric fold pattern, dominated by the following major structures: the Hinlopenstretet syncline, the Vestfonna anticline, the Lovén syncline and the Rijpdalen anticline. In the lower part of the Rijpdalen anticline, isoclinal folds exist which are folded by the anticline. It is possible that this earlier folding and accompanying metamorphism occurred prior to the deposition of the Murchisonfjorden Supergroup, implying the existence of a pre-Caledonian basement to the late Pre-Cambrian and Lower Palaeozoic sequences. A post-fold fracture pattern exists, including a system of major longitudinal faults and a conjugate system of WNW and WSW strike-slip faults.

Isotopic age-determinations from the area are discussed in relation to the new geological data.

General introduction

BY

T. SIGGERUD

In 1965 Norsk Polarinstitutt sent an expedition to Nordaustlandet in the Svalbard archipelago. The expedition's aim was to study the geology of the pre-Carboniferous areas, supposed to make up the bedrock over a greater part of the island (northern and central parts).

The geology of this area was only known to a limited extent, and in many areas the work had been based on material collected by expeditions on which no geologist took part. The most detailed information existed from the westernmost areas, where a stratigraphical scheme had been established for the sediments.

Nordaustlandet is the large island situated north-east of Spitsbergen.[1] For the purposes of this paper, we also include the surrounding smaller islands. The northern latitudes of the southernmost and northernmost points are 79°17′ and 80°50′ respectively. In longitude it reaches from 17°47′ to 27°22′ E. The surveyed area is about 15,000 km^2 (Fig. 1).

Discovery and topographical mapping

Nordaustlandet was probably seen by whalers in the seventeenth and eighteenth century. The first real expedition was W. E. PARRY's in 1827. Geographical investigations were carried out by the Swedish expedition in 1861 and the English (LEIGH SMITH) expeditions in 1871 and 1873. In 1873, after wintering in Spitsbergen, A. E. NORDENSKIÖLD sledged along the north coast of Nordaustlandet to 26°E and returned by the way of Wahlenbergfjorden.

Between the years 1898 and 1903, the Russian-Swedish Arc-of-Meridian Expedition surveyed the western coast of Nordaustlandet. In 1924 the Oxford University Arctic Expedition succeeded in making the first crossing of the ice-cap. A Swedish-Norwegian Arctic expedition (Sveanor) in 1931 studied the geology and made extensive sledge journeys. In 1935–1936, the Glen Expedition (the Oxford University Arctic Expedition) spent a year in Nordaustlandet surveying part of the island and its coast. The island was photographed from the air (obliques) by an expedition sent by Norges Svalbard- og Ishavs-undersøkelser in 1938. Based on all the available material and sketches from the air-photographs,

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[1] Formerly Vestspitsbergen; the name of the island has bee changed to *Spitsbergen* in 1969.

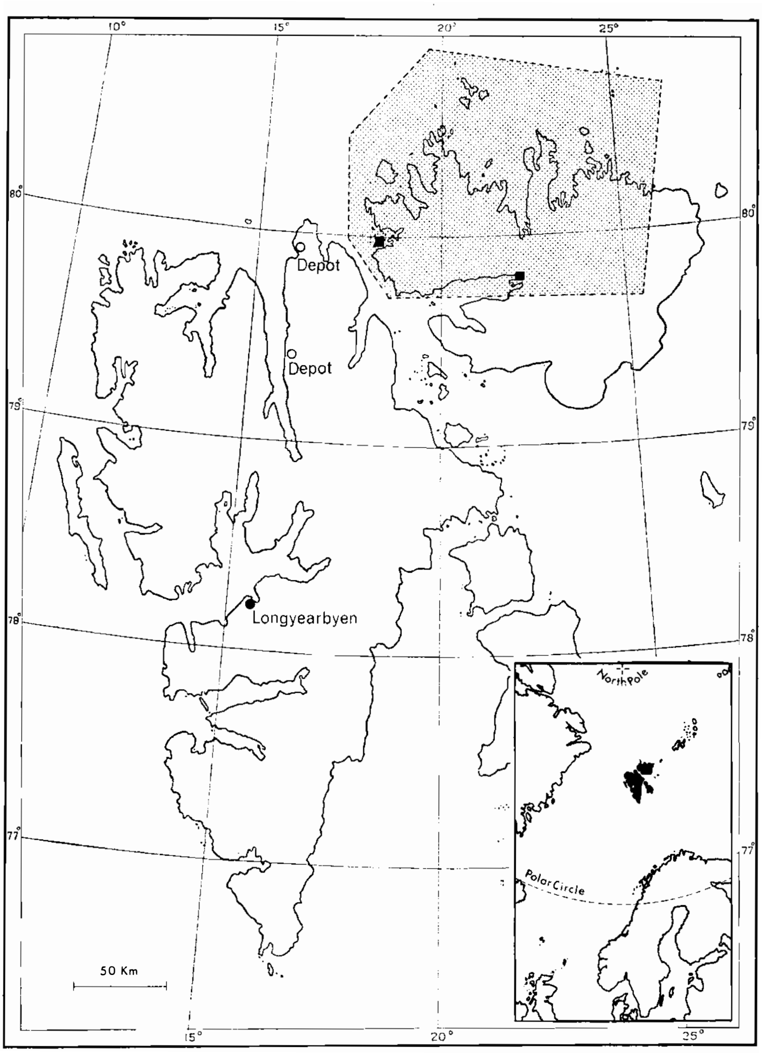


Fig. 1. *Map of Svalbard*; *dotted area shows the part covered by this paper.*

Norsk Polarinstitutt has compiled the first 1:100,000 scale maps of Nordaustlandet and named all the more prominent features. This work was finished in a preliminary edition in 1967, but most of it was available for the 1965 expedition.

Geographical description

The greatest distances across Nordaustlandet, including the surrounding smaller islands, are about 200 km east-west and 175 km north-south. In the east and south, the island shows a fairly smooth rounded coastline, whereas in the north and west the landmass is dissected by a number of fjords mostly of approximately longitudinal orientation. From the west, two fjords (Murchisonfjorden and Wahlenbergfjorden) cut into the land in an east-west direction. Nordaustlandet is covered by three ice-caps, two large and one small (Vestfonna, Austfonna, and Glitnefonna), and smaller glaciers. In the coastal areas, especially in north-west and central peninsulas, are found quite large regions not covered by permanent ice or snow. These areas are topographically more flatly rolling with elevations up to 700 m (a.s.l.). However, the peninsulas end in steep escarpments towards the sea in the north.

Depending on the type of bedrock and the gradient, the ground is covered by unconsolidated material, talus, moraines etc. The lowlands in the north-west are to a great extent covered by gravel and beach deposits.

The vegetation is mostly very scarce; an account of the flora is recently published (A. H. NEILSON 1968). A number of reindeer manage to live here throughout the year. There are some rookeries with migratory birds and some seals around the coasts. Polar bears live in the area the whole year. In general the vegetation and animal life are much more sparse than in Spitsbergen.

The ice and weather conditions greatly hinder travelling to and around in Nordaustlandet. The pack-ice is never far from the shore in the north and east and most years it extends south to Nordaustlandet even in summer time, with a little open water here and there depending on the wind directions. The fjords are covered by winter ice which usually breaks up in the summer but not always (e.g. in 1965). Temperatures are usually just above freezing in summer time and snowstorms occur all the year round.

Very few trappers have been wintering there. Except for the hut of the Glen Expedition and the large camp of the Swedish-Finnish-Swiss Expedition during the international geophysical year 1957—58, there are no buildings in Nordaustlandet.

Earlier geological work

Although several expeditions have visited Nordaustlandet, geologists have only taken part in a few of them. Prominent in the history of geological exploration are the Swedish geologists A. E. NORDENSKIÖLD and O. KULLING, and the British geologist K. S. SANDFORD.

NORDENSKIÖLD visited Nordaustlandet on his expedition in 1861 (NORDENSKIÖLD 1863, 1866) and classified seven geological formations in the area. The oldest, No. 1, he called gneiss with granite veins and dykes; No. 2, the crystalline limestone and dolomite; No. 3, the Hecla Hoek Formation; No. 4, the Ryssö Formation. On top of these came the fossiliferous formations; No. 5, the Cape Fanshaw Formation (supposed to be Carboniferous); No. 6, the Brachiopod Formation; and then No. 7, the Hyperite Formation, i.e. the younger dolorites.

NORDENSKIÖLD's formation No. 1 is what we on our map have referred to as migmatites and syn-orogenic granitic rocks. It perhaps also included the post-orogenic granitic rocks. His formation No. 2, the crystalline limestones and dolomites, is mostly found in Spitsbergen on the western side of Hinlopenstretet. No. 3, the Hecla Hoek Formation, is described by NORDENSKIÖLD as quartzites, shales and limestones, occurring in the western part of Nordaustlandet on both sides of the granitic area on Laponiahalvøya. He thought that the sediments had been subjected to folding, i.e. were compressed, and that fold repetition occurred. No. 4, the Ryssö Formation, was found striking north-south through the western part of Nordaustlandet. He described it as pure yellow dolomites and limestones showing little stratification. He also gave a description of the stromatolites in them without realizing what they were.

In 1866, NORDENSKIÖLD published a survey of the Spitsbergen geology, and he then included the Ryssö dolomites and limestones in the lowest part of the Carboniferous Formation, and the crystalline limestone and dolomite on the west side of Hinlopenstretet were included in the Hecla Hoek Formation.

During 1898–1902, the large Swedish–Russian Arc-of-Meridian measuring expedition worked around Hinlopenstretet. GERARD DE GEER (1923) was the leader of the expedition in the summer of 1901 and managed to do a little geological work. He was inclined to think that the Ryssö dolomite was of Silurian age and that the Caledonian mountain folding also affected these rock types. He thought that the crystalline rocks were Archean. A. G. NATHORST in his work on Spitsbergen geology (1910) discussed the question of the ages, and he said that the Silurian age for the whole Hecla Hoek Formation was very doubtful. He suggested that they might contain Cambrian and older rocks.

The work done in the north-western corner of Spitsbergen by O. HOLTEDAHL (1926) demonstrated that there was a transition from Hecla Hoek phyllites, mica-schists, and quartzites to granite and gneiss, and that the granites were younger (instead of older) than the Hecla Hoek rocks. This evidence influenced the later interpretations of comparable lithologies in Nordaustlandet.

K. S. SANDFORD took part in an expedition in 1924, working in Wahlenbergfjorden and the north-west corner of Nordaustlandet, and dealing mainly with the stratigraphy and tectonics of the Hecla Hoek rocks and with Pleistocene geology. SANDFORD's work is mentioned in detail below.

In 1931, O. KULLING took part in a Norwegian-Swedish expedition to Nordaustlandet (as a geologist), working on both sides of Hinlopenstretet, in Nordaustlandet particularly in the area between Murchisonfjorden and Brennevinsfjorden. This most important work resulted in the establishment of a detailed stratigraphy in the area (KULLING 1934). The youngest member he called the Kapp Sparre Formation, made up of dolomites, slates and quartzites with a fossiliferous horizon near the top. The fossils were mostly brachiopods of Cambrian age. Below came the Sveanor Formation, including tillites. Then follows the Murchison Bay Formation, made up of dolomites and limestones, slates and sandstones with the calcareous rocks in the upper part and the clastic rocks in the lower part. Below these he described the Cape Hansteen Formation, made up of porphyry with agglomerate, conglomerate, and tuffs, and rearranged products of these. Rocks underlying the Cape Hansteen Formation were not found.

The Murchison Bay Formation was by KULLING subdivided into the Ryssö, Hunnberg, Sälodd, Raudstup, Norvik and Flora Series (youngest listed first). These units have been retained by us and their main features are summarized below by WINSNES (p. 19). KULLING considered that part of the succession within the Murchison Bay Formation was repeated by isoclinal folding. KULLING discussed in great detail the probable structures of the Murchisonfjorden area, dominated by synclines and anticlines with fold axes running N–S. He also found the continuation of the strata from Murchisonfjorden north to Franklinsundet.

On the east side of Lady Franklinfjorden, he described what he called the Cape Hansteen Formation. He apparently thought that there was a transition in the central part of Gerardodden between the fine-grained tuffs of his Cape Hansteen Formation and the quartzose sandstones of the Murchison Bay Formation. KULLING specified that the volcanic Cape Hansteen Formation underlay the Murchison Bay Formation. He did not find a clearly defined boundary, e. g. a basal conglomerate between the two formations.

KULLING also visited the west coast of Laponiahalvøya, Kontaktberget, and Depotodden and found a beautiful contact between the Cape Hansteen Formation and the Brennevinsfjorden granite at Kontaktberget. He recorded that the granite intruded the folded phyllites but apparently without affecting it. He assumed the deformation to be Caledonian and therefore referred the granites to a late Caledonian age. KULLING did not go east of Kontaktberget, but in his paper he compared his descriptions in west Nordaustlandet with the descriptions given by NORDENSKIÖLD and H. W. AHLMANN from further east (NORDENSKIÖLD 1863, AHLMANN 1933). He regarded the lithologies of Kapp Platenhalvøya as comparable with his Murchison Bay Formation. He repeated NORDENSKIÖLD's observations that the area east of Kapp Platen was extremely monotonous, consisting everywhere of gently undulating gneisses and mica-schists, resting on a white-greyish granite.

KULLING also investigated the area on the west side of Hinlopenstretet and made comparisons with Nordaustlandet. In general it can be said that he found comparable lithologies to those in Nordaustlandet.

In Nordaustlandet KULLING thought that the Murchison Bay Formation and the younger rocks of the Sveanor and Kapp Sparre Formations together were c. 4,000 m thick. He demonstrated the main changes of facies occurring during the deposition of the rocks. The Cape Hansteen Formation was built up in a period of volcanic activity. On top of this series of pyroclastic and effusive lithologies followed a series of shallow water clastic sediments which gave way upwards into a dominantly carbonate facies. This was followed by a complete change in the conditions of the deposition, and extensive glaciation resulted in the deposition of the Sveanor Formation. The overlying Kapp Sparre Formation with shales and dolomites reflects the beginning of a return to a dominantly carbonate facies, which is more extensively developed further west in Ny Friesland. Towards the end of his paper, KULLING discussed the geology of the area around Hinlopenstretet and compared it with the geology of Spitsbergen and other places in the world. This part of his paper is important in that he was one of the first to review the evidence for a wide-spread glaciation immediately before the Cambrian in North Europe and in the Arctic.

K. S. SANDFORD, like KULLING, visited Nordaustlandet once, in 1924. The results of this work were published in 1926. Subsequently, on the basis of his own material and that collected by later, largely non-geological expeditions, he published several reviews of local and regional Nordaustlandet geology (SANDFORD 1926, 1950, 1956, 1963).

In 1950, SANDFORD summarized KULLING's stratigraphy for west Nordaustlandet and compared this with new data obtained by the Glen Expedition in 1935–1936 from central and eastern areas. On the basis of this comparison he moved away from the concept that the gneisses and granites of Nordkapp and Duvefjorden were of Caledonian age (a view he favoured in 1926) and considered them to be part of a basement complex conformably underlying the sediments. Thus he clearly distinguishes between the post-(Caledonian) tectonic granites of the Brennevinsfjorden type, as described by KULLING from Kontaktberget, and the granitic rocks of this basement.

In 1956, he reviewed the evidence for this basement complex, having had access to Norsk Polarinstitutt's collection of oblique air-photographs. In the same paper he described the variations in Hecla Hoek stratigraphy across Nordaustlandet and noted in particular the apparent change in facies within the Cape Hansteen Formation, volcanic rocks giving way eastwards to argillaceous sediments. He suggested that structurally there was no relationship between the Hecla Hoek complex and the metamorphic complex beneath. Running north-south around Duvefjorden, SANDFORD postulated a fracture belt, "the Dove Bay fault", cutting the complexes and with the older metamorphic complex making up the whole eastern area.

In 1954, SANDFORD also published an account of the outcrops at the eastern margin of Nordaustlandet, i.e. Isispynten, an area not visited by the Norsk Polarinstitutt expeditions. Foliated mica-schists, amphibolites, and grey granites are found together with unfoliated quartz monzonites and diorites. Judging from the material in the moraines, SANDFORD assumed that the volcanics and sediments do not occur in this area and that large numbers of upper Carboniferous rocks are lying directly on the migmatite complex.

In 1963, he described the geology of the north side of outer part of Wahlenbergfjorden, based on material collected by the Holland Expedition in 1955. There is evidently a continuation of the Hecla Hoek rocks from the north and west side of Vestfonna down to Wahlenbergfjorden.

Finally in 1964, in co-operation with I. HAMILTON, he published the first isotopic age determinations from Nordaustlandet.

During the summers of 1962, 1963, and 1964, Russian expeditions visited Nordaustlandet, and a preliminary survey of their work has been given by A. A. KRASIL'ŠČIKOV (1965).

Norsk Polarinstitutt's geological work in Nordaustlandet has been confined to an expedition in 1957, when T. S. WINSNES, A. HJELLE, and B. FLOOD spent some weeks in the area, and 1962 when T. GJELSVIK visited north-west Nordaustlandet for a short period. On the basis of this work, WINSNES (1965) published a short account of the Nordaustlandet geology, and HJELLE (1966) gave a description of some of the granitic rocks.

During the 1965 expedition we were concerned almost exclusively with pre-Carboniferous rocks. These are unconformably overlain by Carboniferous limestone in Idunfjellet (north side of Wahlenbergfjorden). Most of the area south of that dealt with in this paper, i. e. the area south of Wahlenbergfjorden, is composed of Carboniferous, Permian, and Triassic rocks.

Dolerites intrude the sediments and are thought to be of Cretaceous age (R. A. GAYER et al. 1966).

The 1965 expedition of Norsk Polarinstitutt

The 1965 expedition of Norsk Polarinstitutt to Nordaustlandet had the following geologists taking part: B. FLOOD, D. G. GEE, A. HJELLE, and T. S. WINSNES, each with one assistant. T. SIGGERUD, chief of operations, worked part-time as a geologist. A botanist, A. H. NEILSON, with two assistants also took part on the expedition.

The expedition ship, M/S «Signalhorn», skipper BJARTE BRANDAL, had a crew of nine men. The two helicopters hired from the Royal Norwegian Air Force were operated by the pilots J. AUNE and S. MJAANES and the mechanics A. HENNING and H. VÅDAHL. There was also an extra assistant for operating the wireless set. Altogether 26 persons, including the crews and assistants, took part on the expedition.

The expedition started from Longyearbyen on July 15, arriving at Nordaustlandet on the 19th, and returned from Nordaustlandet in the afternoon on August 25. The helicopters flew directly to and from Longyearbyen via Verlegenhuken.

Logistics

Transport to and around Nordaustlandet was provided by the expedition ship and two Bell 47-G helicopters. Small open boats with outboard engines were used in sheltered areas and from the expedition ship to the shore. The expedition ship was the one that usually transports Norsk Polarinstitutt's expedition equipment to and from Svalbard, a 113 ft wooden ship, strengthened to operate in the pack-ice and with a 340 BHP engine. Primitive accommodation for sixteen men had been installed in addition to the crew compartments.

The two helicopters were rather small, but well maintained and equipped, among other things with fairly reliable wireless sets. The helicopters operated with floats. The Norsk Polarinstitutt chief of operations made the flight plans but the chief of the helicopter group was responsible for the safe conduct of the flying programme according to the conditions and the regulations for helicopter operations.

The ship, a sealer, had no helicopter deck and the helicopters had to operate from the beaches. All personnel lived on board, and spare parts and fuel were stored in the expedition ship. Fuel depots were established in Longyearbyen, in Wijdefjorden, and on Nordaustlandet to facilitate the ferrying of the helicopters to and from Nordaustlandet and to allow for possible emergency flights to Longyearbyen (Fig. 1). Because of radio difficulties on board the sealer, a wireless station was set up on the beach for contact with the helicopters. A continuous radio watch was maintained whilst the helicopters were out in the field, their movements were tracked and information was passed to them about the development of the weather conditions at the base etc. The helicopters were equipped so that the pilot and passenger would be able to survive if circumstances made it impossible to get back to the base.

Two helicopters proved to be a minimum number for such an expedition. On two occasions one of them had a break-down in the field and the other helicopter had to come to its assistance bringing out a mechanic and spare parts. In all, 250 hours were flown in Nordaustlandet under, at times, most difficult conditions without any accidents.

The working plan for the expedition was to use the sealer as floating base-camp, moving eastwards from fjord to fjord on the northern side of the island. To get out in the field and to get around on daily trips, the two helicopters and small open boats were to be used. It was supposed that since the distances from the base to the working areas would be short, the helicopters could operate on most days. If it was at all possible to do field work it should also be possible to fly, at least below a cloud blanket, to get on to the exposures.

According to this plan the geologists were to co-operate as much as possible, working as a team in each area.

Since the field work was conducted under much more difficult conditions than anticipated, the only solution was to establish field camps away from the base. Once the geologists had been put into these, they could work on foot, even if the weather hindered the helicopters from leaving the base-camp where they had to stay for maintenance and fuel.

This meant that the helicopters often had to work at very large distances from the base; not a very economical way of utilizing helicopters but necessary due to the ice conditions that made it impossible to advance the base eastwards as planned. Small fuel depots were flown out when no passengers accompanied the pilot going out from the base to the field parties.

The ice and weather conditions

In order to evaluate the results achieved, one has to take into consideration the circumstances under which the work was done, especially the ice and weather conditions. The summer 1965 was one of the worst for many years with regard to the ice situation around Nordaustlandet. In many fjords the winter ice did not melt at all and the pack-ice closed down on the north side of Nordaustlandet during the whole summer. Often a narrow strip of open water existed from the entrance of Hinlopenstretet and northwards to Sjuøyane but the condition was never stable and a northerly wind would close it.

On arriving in Nordaustlandet on July 19 (after a two days' visit to NORDENSKIÖLD's type section for the Hecla Hoek in North Ny Friesland), it proved impossible for M/S «Signalhorn» to get to the shore at any place because of the ice (see ice maps, Fig. 2). After two days a route was found to Søre Russøya in Murchisonfjorden and some helicopter fuel was taken ashore there. The ice then closed off the beach again and a small fiberglass boat had to be hauled over the ice and be used in the open water between the ice flows to get ashore to the helicopters.

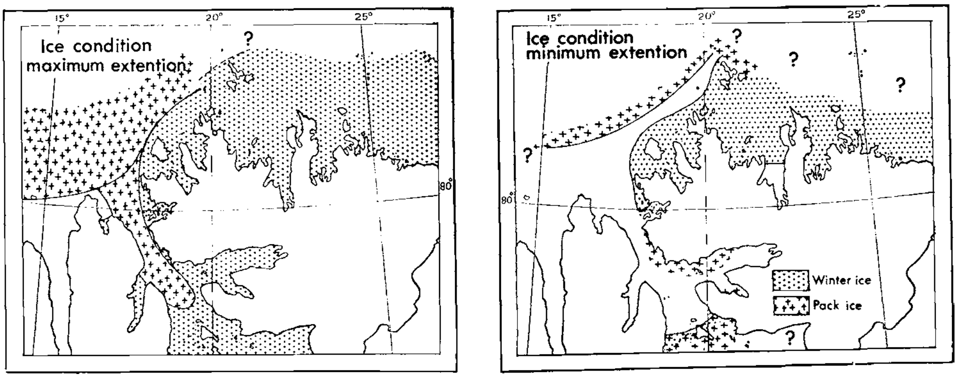


Fig. 2. *Maximum and minimum of sea ice during the field season 1965.*

Hinlopenstretet was open in the northern part whilst being completely blocked south of Wahlenbergfjorden. Around the beginning of August, helicopter reconnaissance showed that it was possible to get into Wahlenbergfjorden and the base was then moved to Bodleybukta at the head of the fjord. Wahlenbergfjorden was later blocked in the outer part when the ice broke up in Hinlopenstretet, but cleared sufficiently for the departure of the expedition on August 25 (but it would have been impossible without a good ice-strengthened ship).

The typical weather conditions for the summer was a low cloud ceiling with fog banks, occasionally down to the ground in the lower valleys and fjords. The flight of the helicopters to the north side of Nordaustlandet, from the base-camps in both Murchisonfjorden and Wahlenbergfjorden, was often impossible due to the clouds touching the ground in the passes.

Precipitation in the form of rain, sleet and snow occurred irregularly throughout the summer. Usually there was hardly any wind and only two severe gales hindered the work. Except for the snow falls and gales, the weather permitted the field work to be conducted, at least on foot, nearly all the time. More wintery conditions started soon after the middle of August.

The geological field work

The field work was conducted bearing in mind that the intention was not so much to make extensive studies of particular problems as to make a reconnaissance of the geology of the whole area north of a line along Wahlenbergfjorden. The pre-Carboniferous geology was to be surveyed, particular attention being paid to any phenomena of economic importance.

It was not always possible to do what was most interesting geologically but the geologists had to get the most out of the opportunities to visit as many localities as possible using the helicopters. Figs. 3 and 4 show which area each geologist worked in (actually there was some overlapping). Fig. 5 shows to what extent the ground was "covered", where the geologists have been doing their field work, i.e. where they have made traverses, short visits by helicopter landings, etc. It is evident from this map that the geological work in many areas could have been much more extensive. On Fig. 6 is shown the areas worked in 1957, when HJELLE

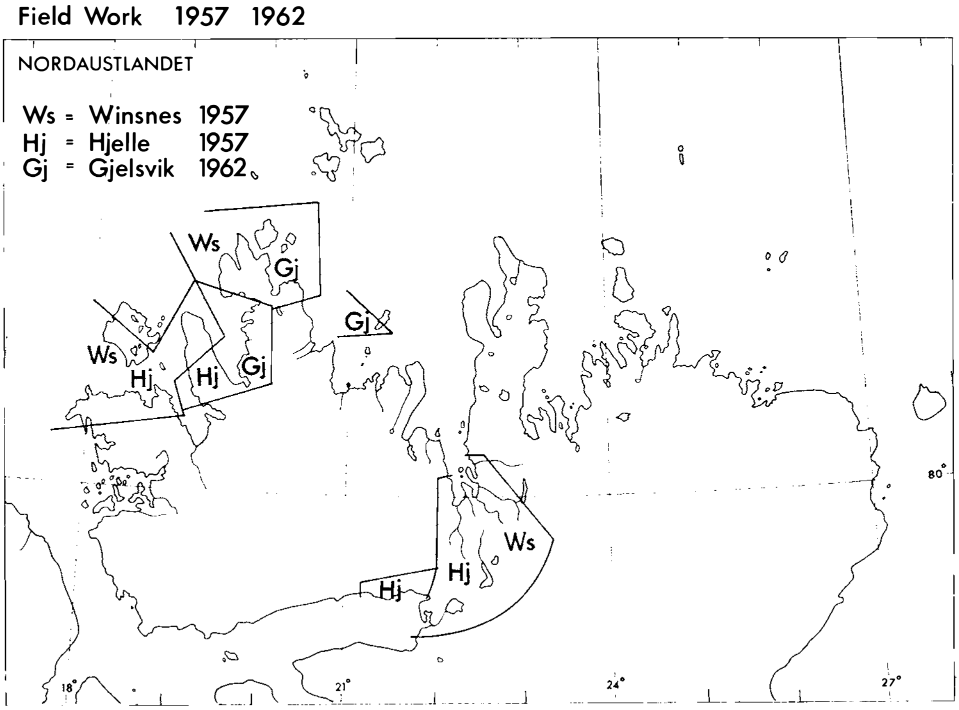


Fig. 3. *Areas visited by geologists from Norsk Polarinstitutt in 1957 and 1962.*

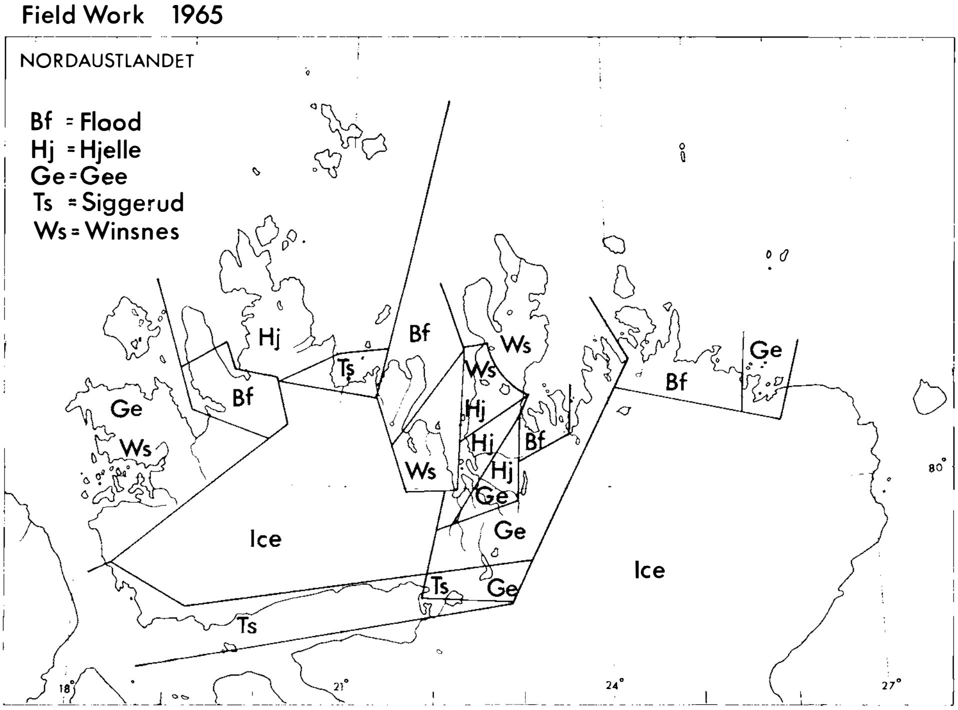


Fig. 4. *Areas visited by geologists on the 1965 expedition.*

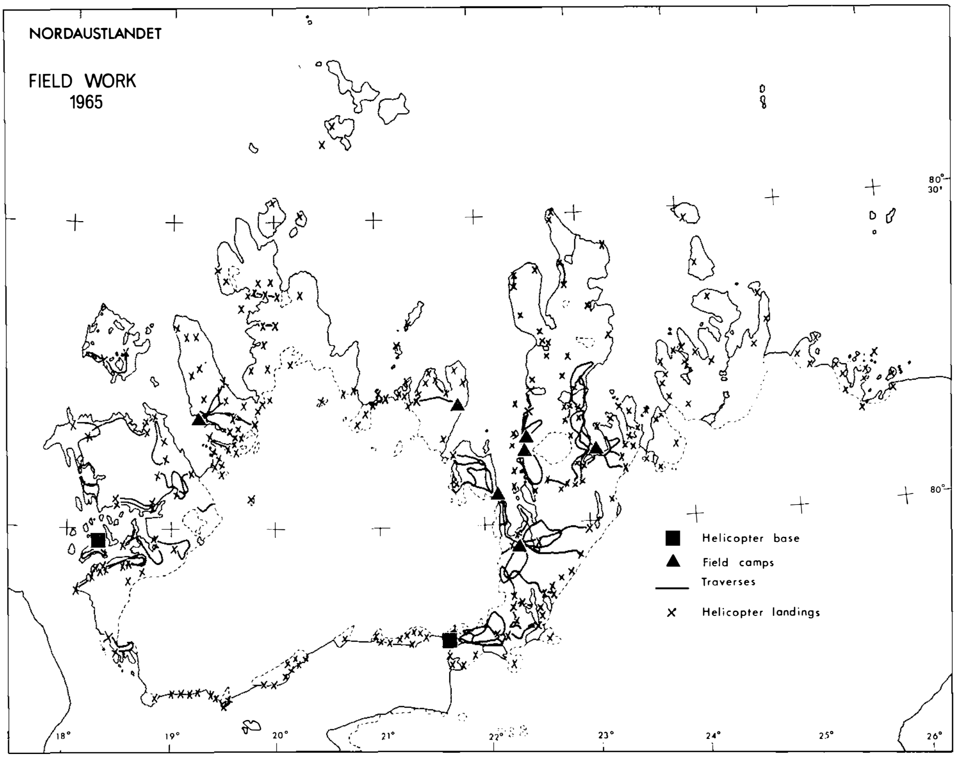


Fig. 5. *Map showing the localities visited by the geologists in 1965. Areas between the helicopter landings were studied from the air, flying at a low altitude.*

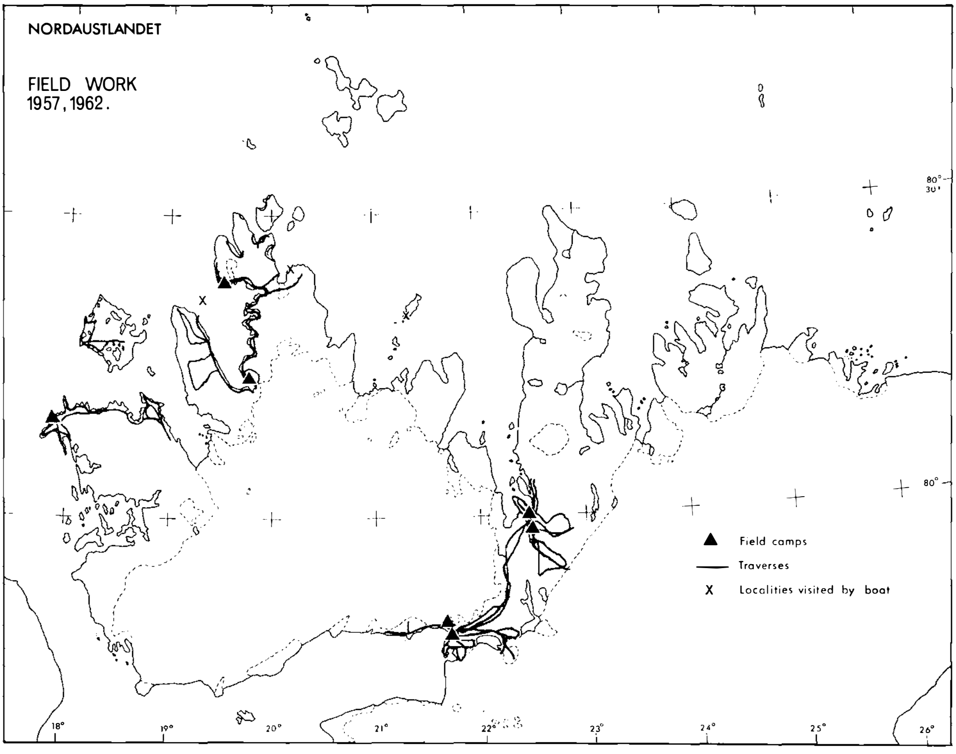


Fig. 6. *Map showing the localities visited by geologists from Norsk Polarinstitutt in 1957 and 1962.*

and WINSNES spent some time in Nordaustlandet. The results of this expedition have not been published before and are included in the present work.

The geological field work was partly based on the oblique air-photographs where most of the ground is shown at a rather small scale and many features have changed since 1938 because of the general retreat of the glaciers (and margins of the ice-caps).

The unpublished topographical maps in 1:100,000 are merely sketches based on earlier expedition maps and the oblique air-photographs. No modern maps have been constructed, and it has been difficult to plot geological observations accurately on the maps.

The topographical base for the published geological map includes corrections made during the 1957 and 1965 expeditions, in some areas considerable modifications have been made. But we do not think that the inaccuracies remaining in the topographical base-map influence in any important respect the presentation of the geology.

Type collections and detailed maps are stored in the archives of Norsk Polarinstitutt.

The geological map gives a generalized picture of the geology, and serves as an illustration to the text. For details the reader is referred to this paper.[1]

Acknowledgements

The work in Nordaustlandet was made possible only by the support of Luftforsvaret (Royal Norwegian Air Force) and the close co-operation of the helicopter crews. In addition, we were assisted in the field by the following students whose help we are glad to acknowledge: LUDVIG J. BECKMANN, J. CHRISTIAN KELLER, ØYSTEIN FÆSTØ, EINAR TVETEN, and PER WENDELBOE.

Norsk Polarinstitutt's director, Dr. TORE GJELSVIK, has read the manuscript and offered us much constructive criticism. He placed his field notes from Nordaustlandet (1962) at our disposal. Dr. K. S. SANDFORD helpfully commented on the structure (Part II). Cand. real. K. BJØRLYKKE read the Botniahalvøya Group stratigraphy (Part I). We are most grateful for the improvements of the paper that are due to their interest in the work.

For the geologists of Norsk Polarinstitutt the diagrams have been drawn by M. GALÅEN and some by R. ANDERSSON. One of us (D. G. GEE) thanks Mrs. S. JÄRNEFORS for drawing the diagrams in Parts II and V.

The manuscript has been edited by T. SIGGERUD and the English language has been corrected by D. G. GEE.

[1] All references to degrees in this paper refer to a 400 degree circle.

Part I.
Stratigraphy

Introduction to Part I

The stratigraphy of Nordaustlandet is based on the work by KULLING (1934). NORDENSKIÖLD (1863) on his expedition 1861 has contributed on the geology along Hinlopenstretet and the north coast of Nordaustlandet, and made the first attempt to define the regional stratigraphy.

In several works, SANDFORD (1926, 1950, 1956, 1963) also has contributed to the knowledge of the geology and the stratigraphy of the sedimentary sequences on the west and north coast and in Wahlenbergfjorden.

In 1957 two of the present authors (HJELLE and WINSNES) made some observations on the stratigraphy in the area near Langgrunneset and at the head of Wahlenbergfjorden and eastwards to Rijpfjorden. During 1965 observations on the stratigraphy resulted in the adding of new formations to the scheme of KULLING.

During this expedition (1965) the younger and western part was mainly investigated by WINSNES and the older and eastern part by FLOOD. For this reason the stratigraphy will be presented separately by WINSNES and FLOOD in two chapters.

The Kapp Sparre Formation, the Sveanor Formation, and the Murchisonfjorden Supergroup

BY

T. S. WINSNES

In the following descriptions of the formations, the type area of Murchisonfjorden and Franklinsundet is treated first and the sequences of KULLING and our own observations are presented. They are tabulated in Fig. 7 and their locations are seen in Fig. 8. Subsequently the areas of Wahlenbergfjorden and western Rijpfjorden are described.

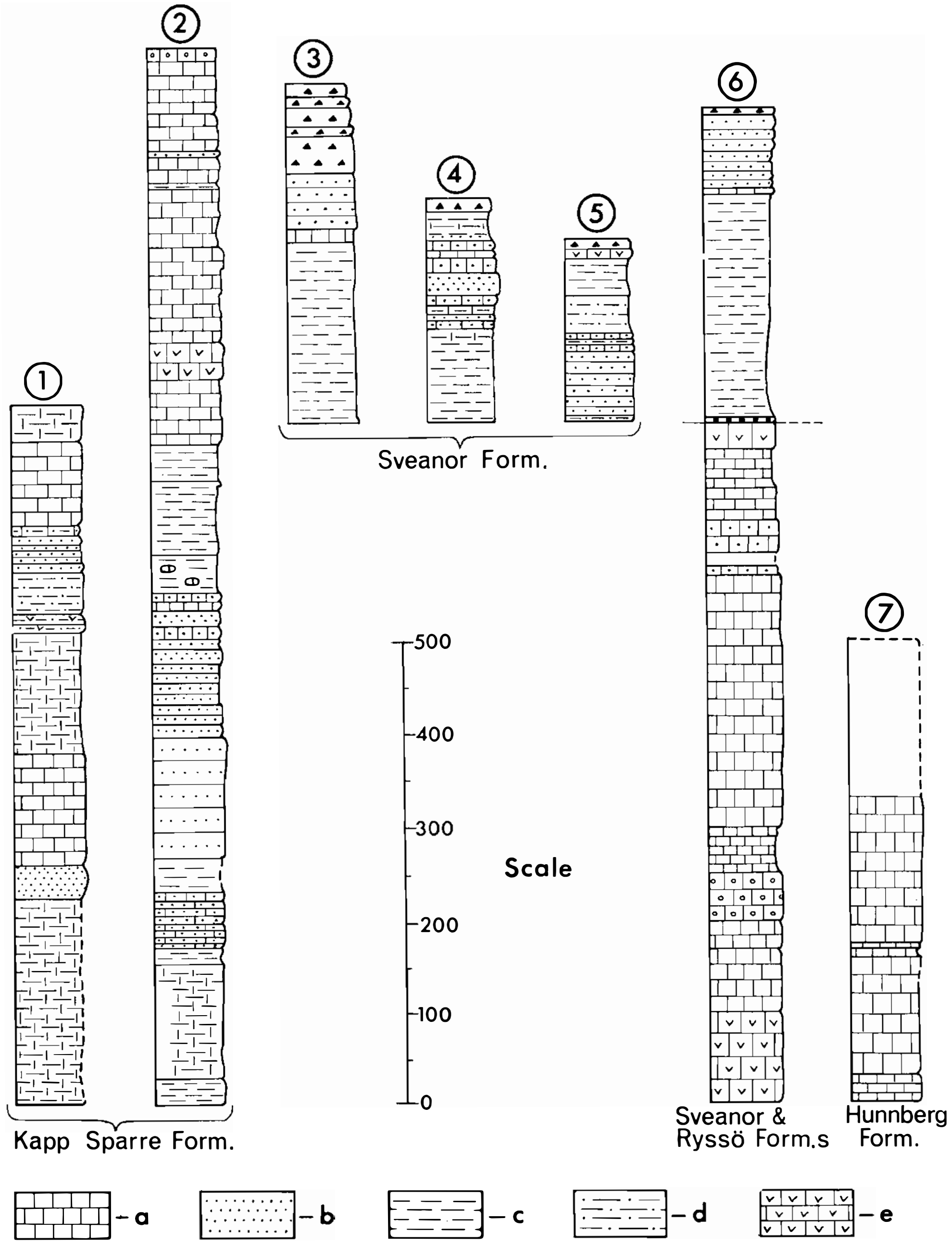
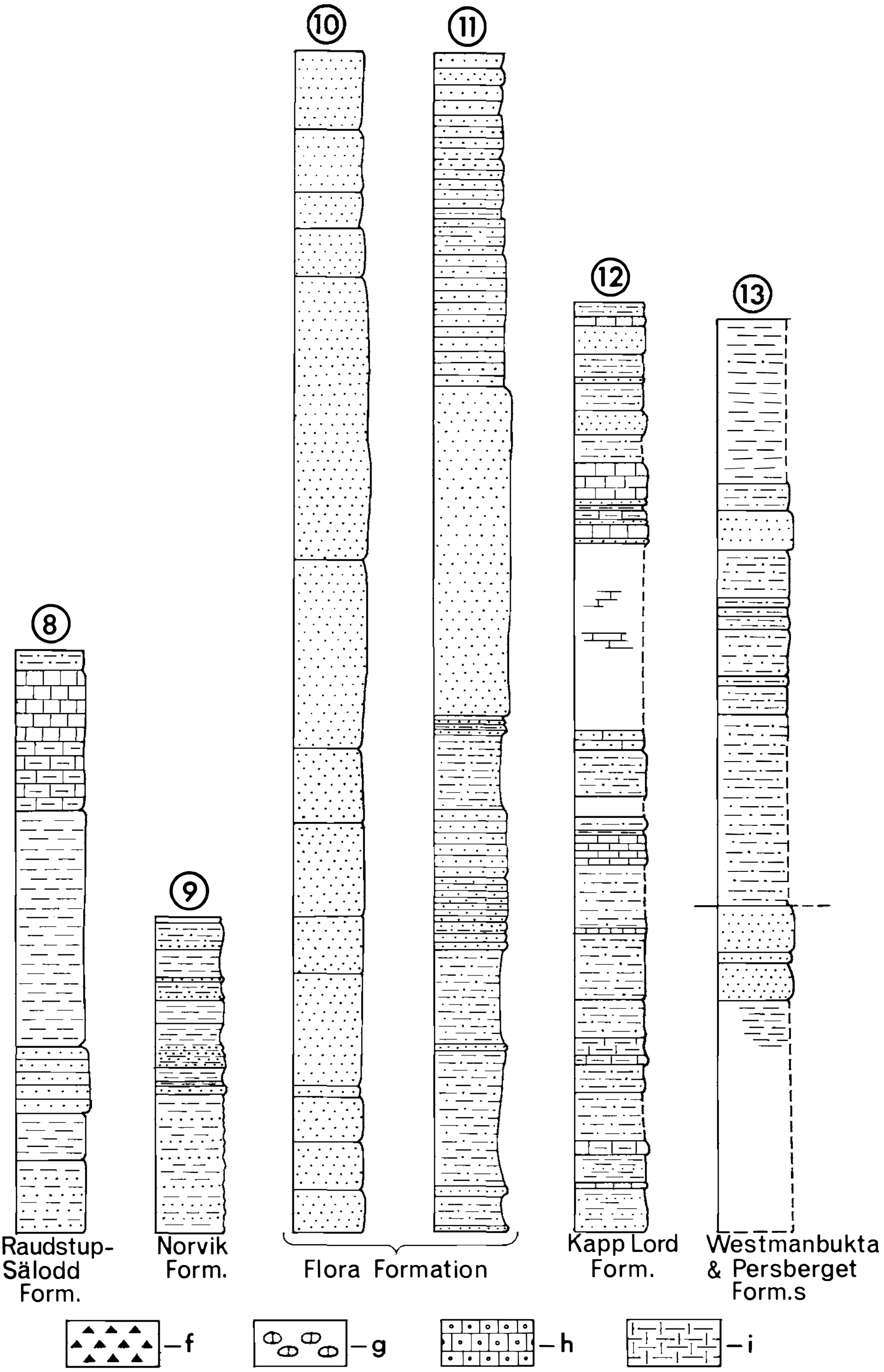


Fig. 7. (See next page too.) *Profiles through the sequences at Murchisonfjorden and Franklinsundet, Nordaustlandet. Locations are seen in Fig. 8.*

Profiles:

1. *The Kapp Sparre Formation, after* KULLING, *Sparreneset.*
2. » » » » *north of Bråvika.*
3. » *Sveanor Formation, after* KULLING, *south Murchisonfjorden.*
4. » » » *north of Bråvika.*
5. » » » *Langgrunneset.*
6. » » » *and Ryssø Formation, Søre Russøya.*
7. » *Hunnberg Formation, west of Snaddvika.*
8. » *Raudstup–Sälodd Formation, after* KULLING, *Franklinsundet.*



9. *The Norvik Formation, after* KULLING, *north Murchisonfjorden.*
10. » *Flora Formation, after* KULLING, » »
11. » » » *north Murchisonfjorden.*
12. » *Kapp Lord Formation, Franklinsundet.*
13. » *Westmanbukta Formation, the Franklinsundet and Persberget Formations, west of Søre Franklinbreen. – Symbols*: *a – dolomite, limestone*; *b -- sandstone, quartzite*; *c – claystone*; *d – mudstone, siltstone*; *d – dolomite with chert*; *f – tillite*; *g – geodes of dolomite*; h - *oolitic limestone*; i – *dolomitic claystone, calcareous mudstone.*

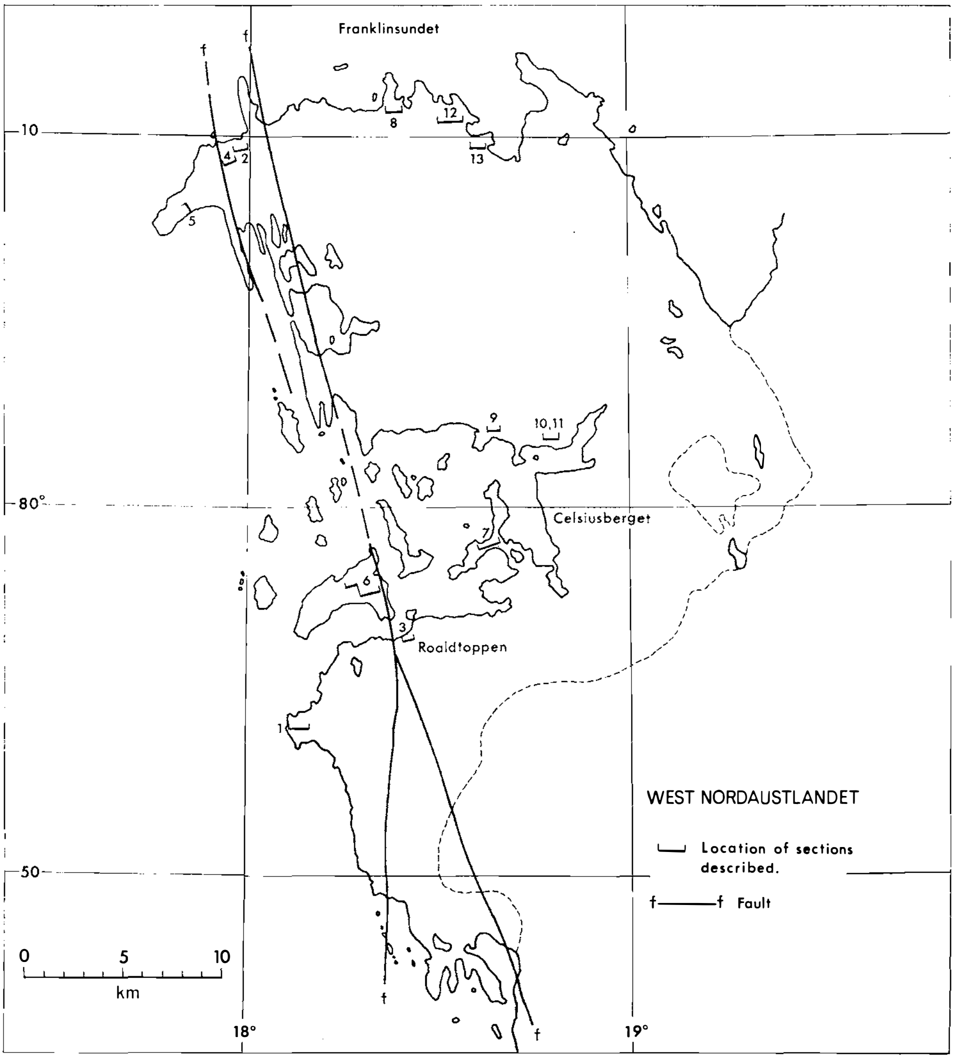


Fig. 8. *Location of the profiles described in the text and shown in Fig. 7.*

WEST NORDAUSTLANDET

KULLING's scheme is as follows:

The Cape Sparre Formation
» Sveanor Formation
» Murchison Bay Formation

The Murchison Bay Formation was divided into the following units:

The Ryssö Series
» Hunnberg Series
» Sälodd Series
» Raudstup Series
» Norvik Series
» Flora Series

The stratigraphic scheme proposed by the present authors is:

Formations	Groups	Supergroups
Kapp Sparre		
Sveanor		
Ryssö	Roaldtoppen	Murchisonfjorden
Hunnberg		
Raudstup–Sälodd	Celsiusberget	
Norvik		
Flora		
Kapp Lord	Franklinsundet	
Westmanbukta		
Persberget		

As the reader will see, we have raised Kulling's Series within the former Murchison Bay Formation to formations, but let the Raudstup and Sälodd Series form one formation. In the lower part are added three new formations found below the Flora Formation, namely the Kapp Lord Formation, the Westmanbukta Formation and the Persberget Formation. The names are from localities where the units are well exposed. The Ryssö and Hunnberg Formations form the Roaldtoppen Group; the Raudstup–Sälodd, Norvik and Flora Formations form the Celsiusberget Group; and the Kapp Lord, Westmanbukta and Persberget Formations form the Franklinsundet Group.

These three groups form the Murchisonfjorden Supergroup, which is the Murchison Bay Formation of Kulling and the new Franklinsundet Group added together.

The following is a description of the formations in the area of Franklinsundet and Murchisonfjorden; it starts with the youngest one.

The Kapp Sparre Formation

The Kapp Sparre Formation is found at Sparreneset, on two islands north of this, and north of Bråvika. It is also probably present in the middle part of Søre Russøya and in the easternmost part of the island. Also south of Søre Russøya some dark shaly claystones might belong to the Kapp Sparre Formation.

Further south in the eastern and western limb of a wide anticlinal structure the presence of Kapp Sparre Formation is found east and west of Gimleodden, stretching towards the north and bounded on both sides by faults. No detailed investigations have been undertaken here, but the area was visited briefly by T. Siggerud.

Kulling (1934) has measured the formation at Sparreneset and arrived at a thickness of between 700–800 m with the following sequence (Fig. 7, No. 1):

40	m	black-grey, dolomitic mudstone with trail marks and brachiopods
70–100	»	grey dolomite
3	»	black-grey, laminated dolomite
4	»	red-grey, laminated slaty sandstone
3	»	dark brick-red quartzose sandstone
10	»	grey-white, hard quartzose sandstone
18	»	grey-green to grey, slaty sandstone
9	»	white, hard, thick-bedded quartzose sandstone
46	»	grey-green to red-grey quartzose slate, with cracks and ripple marks on the bedding planes
20	»	light-grey quartzite slates, merging into grey dolomite with chert streaks
130–140	»	exposures and *in situ* surface-shale of shales and laminated dolomitic slates with chert streaks
120	»	dark grey to black-grey dolomite, in the north shore, where a zone of tectonic disturbance makes the thickness uncertain
30– 40	»	white, quartzose sandstone
250	»	without outcrops, but with *in situ* surface shale of grey-green and red-brown shales and also calcareous mudstone

Lower down follows 100—150 m tillite of the Sveanor Formation. The trail marks from the top layers were first found by De Geer in 1901, but in 1931 Kulling also found brachiopods of *Lingulella* and *Obolus* types, being the first fossils found within the Hecla Hoek rocks and indicating a Cambrian age of the strata. In 1965 the site where the fossils were found was covered by ice, and no new material was obtained.

The Kapp Sparre Formation is in part well exposed north of Bråvika where it stands steeply inclined towards west. The following sequence was measured in 1957, east of a tectonic break (Fig. 7, No. 2, and Fig. 8):

55	m	dark limestone, with the upper 15–20 m containing oolites
2	»	light limestone in gravel, upper part light pink
40	»	dark limestone, oolitic 5 m from top
2	»	grey-black quartzite, massive
28	»	blue-grey, massive limestone, with intraformational conglomerate and layers of chert
2–3	»	covered, but containing red clay in the surface gravel
60	»	light limestone, partly covered
4	»	dark limestone, shaly
98	»	light dolomite-limestone, yellow weathering
40	»	grey dolomite, with some yellow chert
70	»	dark limestone, hard, with some intercalations of shaly claystone
40	»	dark claystone, shaly and soft
80	»	dark grey claystone, shaly, with some rusty surfaces
40	»	dark claystone, shaly, with dolomitic geodes up to 0.5 m across
2	»	sand-claystone, shaly
1	»	red sandstone, shaly, fine-grained

4 » yellow-red sandy limestone
2 » yellow-grey limy sandstone, fine-grained
2 » reddish sandstone, fine-grained
11 » yellow weathered limestone
7 » grey sandstone, fine-grained
2 » green sandstone, fine-grained
5 » red sandstone, fine-grained
2 » limestone, sandy
15 » limestone, sandy
10 » light sandstone, fine-grained
15 » light-grey quartzitic sandstone
45 » yellow-brown sandstone, soft
21 » sandstone, shaly
13 » sandstone, fine-grained
130 » grey quartzitic sandstone, partly flaggy, partly calcareous
36 » covered, in scree fine sand and marls
12 » yellowish sand limestone
25 » light-grey lime-sandstone, shaly
28 » limy (calcareous) sandstone, fine-grained, slaty
20 » black claystone, shaly
125 » light calcareous claystone, containing 3 layers of limestone, 2 m apart in upper part
30 » dark claystone, shaly, some lighter in upper part

Below follows tillite of the Sveanor Formation.

The Sveanor Formation

The Sveanor Formation is found in several places north and south of Murchisonfjorden. East of Langgrunneset it is found in the core of a syncline. Further east it occupies the stratigraphical position east of the Kapp Sparre Formation which is seen north of Bråvika. The tillite is also present north and south of Claravågen in a fault-bounded syncline. The fold pattern can be followed to the south of the fjord, and here the Sveanor Formation is found east of Sparreneset and running across Søre Russøya and on to the mainland. Further east and south the formation has been observed in both limbs of the anticline of Gimleodden and also a little further east where a fault gives a repetition of the layers.

Very few exposures give any possibility of detailed stratigraphic measurements. According to Kulling, the formation is 120—150 m on the south shore of the fjord and following measurements are given, starting from below black and red-brown shales and 8 m of yellow-weathering grey dolomites of the Kapp Sparre Formation (Fig. 7, No. 3, and Fig. 8):

15 m grey tillite, grey laminated shales, with numerous striated boulders.
9 » red-brown to grey tillite, sandstone with small boulders and fragments
20 » grey tillite, laminated shales with numerous striated boulders
9 » red-brown tillite, slightly phyllitic shale, in some horizons plenty of boulders occur

40 »	green-grey tillite and sandstone with numerous boulders
60 »	light-grey sandstone, which is similar to the matrix of the sandy types of tillite
10–20 »	a narrow dolomite horizon
c. 130 »	surface material of shale and marly mudstones follows to the east with a thickness of about 130 m

In 1957 the formation was measured north of Bråvika. Below shales of the Kapp Sparre Formation follow (Fig. 7, No. 4, and Fig. 8):

14 m	tillite with a yellow-weathered sandy matrix and small dolomite boulders
14 »	light marls
2 »	dark-brown lime-sandstone
3 »	dark limestone, massive, yellow-weathered
8 »	marls.
1 »	fine sand
10 »	light-yellow sandy dolomite
2 »	soft marls
1 »	dark limestone, with sandy lamina
9 »	dark limestone
13 »	light sand limestone
4 »	dark and light sand limestone
26 »	dark-brown fine sand, massive
10 »	lime sandstone, flaggy, yellow-weathered
3 »	green and red fine sandstone, massive
2 »	very light limestone
1 »	covered
5 »	light sand-limestone, more sandy laminas
4 »	covered
8 »	light lime-sandstone, undulating surface
c. 100 »	covered, but surface consists of fine sandstones, marly

Below follows Ryssö dolomite.

At Langgrunneset, the Sveanor Formation has quite another form. Below dark shales follow (Fig. 7, No. 5, and Fig. 8):

10 m	tillite
10 »	dark, shaly limestone with layers of chert
30–50 »	dark marls, laminated, varved
30–50 »	dark, sandy marls, laminated, varved
5 »	yellow-weathered sand-limestone
5 »	red sandstone, fine sand
8 »	light lime-sandstone
75 »	sandstone, partly red, flaggy, cherty
5 »	red and green fine sandstone

Conformably below follows Ryssö dolomite.

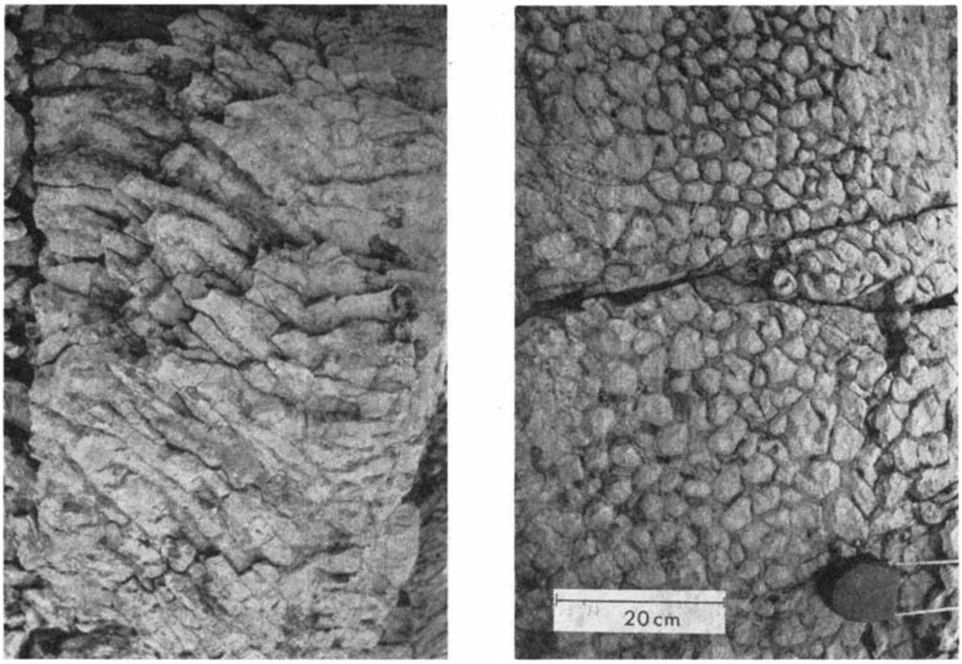


Fig. 9. *Columnar stromatolites at the top of the Ryssø Formation.*

On Søre Russøya a profile through the Sveanor Formation was measured in the eastern part of the syncline. Below 200 m of clay-sandstone (of silt-grade), containing some geodes of hard dolomite and 8 m of light dolomite, standing as a ridge, there follow (Fig. 7, No. 6, and Fig. 8):

1.6 m	tillite, sandy, fine-grained and containing mostly small pebbles of dolomite. A few bigger boulders of a dark intrusive rock were also found
1 »	yellow-brown lime-sandstone, shaly
42 »	light-yellow quartzitic sandstone, blocky and flaggy
38 »	dark sandstone, partly covered, shaly
7 »	light blue-grey dolomite
240 »	limy claystone and siltstone, dark, partly covered
5 »	conglomerate, in upper part with limestone pebbles, in lower part with quartzite pebbles. Here also a cross-bedded sandstone

Lower down follows a light dolomite of which the upper 2 m consist of columnar stromatolites (Fig. 9).

The Roaldtoppen Group

The Roaldtoppen Group has its name from the locality Roaldtoppen on the south side of Murchisonfjorden where the sequence is well exposed (Fig. 7). It consists of two formations, the Ryssö Formation and the Hunnberg Formation.

The Ryssö Formation. – The Ryssö Formation is characterized by conspicuous light-grey dolomites with very poor stratification. They are in part sandy and containing oolites and beautiful stromatolite structures, which often are the only means to decide the orientation of the strata. The formation is situated along the coast of Hinlopenstretet from Gimleodden in the south to Franklinsundet in the north, crossing Murchisonfjorden in the outer part.

Apart from the light dolomite, the formation also contains dark oolitic limestone, light dolomitic limestone with chert and some clay-shales.

The stratigraphy of the formation was investigated in 1965 in the eastern part of Søre Russøya and in a section on the south shore of Murchisonfjorden, at Roaldtoppen (Fig. 8). At Søre Russøya the following section was measured in the eastern part, from west towards east (Fig. 7, No. 6, lower part, and Fig. 8):

30 m	light dolomite with a 2 m bench of columnar stromatolites at the top (Fig. 9)
40 »	dark-grey limestone, shaly
36 »	black limestone, shaly
35 »	light dolomite, sandy and massive
18 »	covered
1 »	light-yellow-red dolomite
1.5 »	light-violet clay-limestone, shaly
1.5 »	light limestone, massive
6 »	light dolomite, sandy, shaly in parts
c. 270 »	light-grey dolomite, massive, containing stromatolites and, in part, oolites.
8 »	dark-grey dolomite
35 »	black and grey limestone, shaly and partly covered
53 »	dark-grey to black limestone, shaly with more massive benches with oolites
32 »	black limestone, shaly
170 »	light dolomite, the lower part contains numerous layers of a yellow-weathered chert

In the southern part the chert-bearing dolomite is approximately 80 m thick, but in the northern part of the island, the chert layers occupy 33 m, and are underlain by 78 m of light dolomite with stromatolites. East of this is found 40 m of a very dark quartzite, but due to tectonic disturbances here, its stratigraphic position is uncertain. The thickness of the light dolomite is believed to vary considerably as indicated by the uneven distribution, but difficulty in obtain-reliable measurements due to tectonic disturbances and absence of stratification makes it impossible to show this. Kulling indicates a maximum thickness of 1 070 m for "The Ryssö Series".

In a recent paper Krasil'ščicov, Golovanov and Mil'štejn (1965) describe the sequences from Murchisonfjorden and give a description of the Stromatolites and other structures. Based on the structures of the algae, a correlation with the U.S.S.R. is given. The Ryssö Formation contains *Vermiculites irregularis* characteristic for Venda, Lower Cambrian in Siberia.

The Hunnberg Formation. – Below the Ryssö Formation follows a sequence of mostly dark limestones. The border between the two formations is put somewhat lower than that of Kulling, as the conspicuous light dolomite with chert more naturally belongs to the Ryssö Formation and is a good lower boundary for the latter.

The Hunnberg Formation was estimated by Kulling to be 400–600 m thick, consisting of grey-black and grey dolomitic limestone and limestone as the typical rocks, with lighter limestone and subordinately red-brown limestone and brown shale in the middle part. Occurrence of chert concretions, chert conglomerates and phosphoritic concretions were also mentioned, but no detailed measurement was undertaken.

Gee and Winsnes went through the sequence on the north and south coasts of Murchisonfjorden, but due to incomplete sections (exposures) in the north no detailed measurements were undertaken here. Typical rocks of the formations are dark limestone in the middle and grey, dark mottled limestone in the lower part.

In a section west of Snaddvika, the contact to the younger formations was covered, but eastwards the following rocks were seen (Fig. 7, No. 7, and Fig. 8, No. 7):

c. 150 m	dark to black limestone, partly massive and containing some oolites.
5 »	light-grey limestone
1.5 »	light-violet clay-limestone, shaly, with an intraformational conglomerate
10 »	yellow-brown limestone, shaly, and lime-sandstone
136 »	mottled limestone, with a 10 m zone of yellow-green claystone, fine-shaly
32 »	dark-grey limestone, partly shaly, yellow-weathered

Lower down follows shaly, clayey and limy mudstones of the Raudstup-Sälodd Formation. The total thickness thus is at least 335 m, but less than 500 m.

A section through the Hunnberg Formation was measured by Kulling on the south side of Franklinsundet. He mentions a thickness of possibly 700–800 m for the formation (his series) with the beds dipping vertically. The same part of the section was visited by Gee, and he found that the strata are not near vertical, but dip with moderate to high angles eastwards, the estimation of thickness is therefore probably excessive.

Celsiusberget Group

The Celsiusberget Group has its name from Celsiusberget east of Snaddvika, where the quartzitic sandstones of the group form the highest mountain in the area.

The three formations of this group are exposed from Lågøya in the north, where they form the limbs of a syncline, to Vestfonna in the south, crossing the inner part of Murchisonfjorden. In a syncline at De Geerfonna further east the two lower formations reappear. Also in a small nunatak in Søre Franklinbreen pink sandstones occur, being similar to rocks of the Flora Formation.

The Raudstup-Sälodd Formation. — This formation is a combination of the Sälodd Series and the Raudstup Series of Kulling. The formation is beautifully exposed on the north coast of Murchisonfjorden. South of the fjord it can be followed until it disappears below Vestfonna. It is also seen along Franklinsundet, both on Lågøya and on the south side. In the latter area measurements by Kulling give excessive thicknesses, as the strata also in this case often are dipping less steeply than he thought, i.e. at moderate to high angles towards east (Gee). Kulling's section is (Fig. 7, No. 8, and Fig. 8):

30 m	wanted (Gee recorded 20 m red and green mudstone with thin (5 cm) limestone bands
150 »	light-grey, laminated shaly dolomite with subordinate dolomitic siltstone types
250 »	alternating strata of mostly red-brown and grey shales with some intercalations of slaty quartzite rocks
60 »	white quartzose sandstone
50 »	grey shale, interstratified with dolomitic slates, rich in quartz
80 »	frequently interstratified red-brown and green-grey shales as well as quartzose sandstones

In Murchisonfjorden the thickness of the two series making up the formation was estimated by Kulling to be some 560 m. The upper 260 m consist of greenish-grey dolomitic siltstones, and the lower 300 m of reddish-brown, partly rather calcareous slates. Grey-green slates also occur, though more subordinately.

The border between the upper and lower part is difficult to place, and the lithologies in the two parts are so intermingled that we have decided to make one formation of this sequence. The Raudstup-Sälodd Formation probably does not exceed 500 m in thickness.

West of Snaddvika the upper part of the formation is well exposed. Below the Hunnberg Formation follow c. 100 m of grey-green calcareous and clayey shaly fine-sandstones, the uppermost containing 2–3 thin (0.5 m) quartzites. Then follows red-brown shaly siltstone with green zones in the western part. Some sandy layers are current-bedded. The red-brown colour of the formation makes it easily distinguishable in the landscape from the lower dark Norvik Formation.

The Norvik Formation. – On the north side of Murchisonfjorden this formation is well exposed east of Raudstupet and the following detailed section was presented by Kulling (Fig. 7, No. 9, and Fig. 8):

30 m	grey sandstone and slaty sandstone
3 »	white quartzose sandstone
30 »	grey sandstone and slaty sandstone
4 »	white quartzose sandstone
20 »	grey sandstone and slaty sandstone
2 »	green-grey dense quartzite
25 »	grey sandstone and slaty sandstone, with two 1 m intercalations of light-grey, hard quartzose sandstone
3 »	grey-brown shale
15 »	green-grey shale
10 »	red-brown to grey shale
1 »	white quartzose sandstone

8	»	green-grey shale
3	»	white quartzose sandstone
3	»	grey slaty sandstone
2	»	white quartzose sandstone
4	»	grey slaty sandstone
2	»	white quartzose sandstone
15	»	green-grey quartzose shale
5	»	red-brown-grey shale
10	»	white quartzose sandstone
150	»	light greenish-grey sandstone, beautifully bedded with slaty sandstone between the harder sandstone beds. Frequently grey-black shale films occur on the bedding planes

The impression after walking through the formation is that the lower half consists of shaly dark siltstones intercalated every 1—2 m with thin more massive beds of dark sandstones. These are often current-bedded and weather to a light yellow-brown.

In the upper half, shaly, dark grey-green siltstone is still dominant, but contains thicker beds of quartzitic sandstone. In the uppermost part a few thin beds of dolomite are seen. South of the fjord, east of Snaddvika, the formation gave the same impression. On the south side of Franklinsundet the formation is rather poorly exposed.

The Flora Formation. — During the field work in 1965 it soon became evident that the Flora Series of Kulling in Floraberget was not repeated in an isoclinal fold, but was one continuous series. Kulling gives the following measurements (Fig. 7, No. 10, and Fig. 8):

85	m	white quartzose sandstone, in western part shaded to grey and green
65	»	pink quartzose sandstone
40	»	whitish-grey quartzose sandstone, dark films on the bedding planes
50	»	greyish-white quartzose sandstone, finebedded
300	»	pink quartzose sandstone dominates, subordinate white and grey sandstones
200	»	pink to reddish-white quartzose sandstone
80	»	grey quartzose sandstone dominates, subordinate white ditto
100	»	grey-green quartzose sandstone
60	»	grey-white quartzose sandstone
120	»	reddish-white quartzose sandstone
10	»	grey-black muddy sandstone
50	»	pink, red-brown and green sandstone
50	»	green-grey to green sandstone
50	»	pink, red-brown, pale green, and green-grey quartzose sandstone

The formation as measured here totals 1260 m.

Walking through the section, I gave the following description and thicknesses in my notebook (Fig. 7, No. 11, and Fig. 8,). Below sandstones of the Norvik Formation follow:

10 » yellow-green quartzitic sandstone
50 » reddish, flaggy quartzitic sandstone
45 » light yellow-brown, flaggy quartzitic sandstone.
In this there was a minor discontinuity, the underlying rocks having a slightly lower dip and a 5^g difference in strike
20 » grey-brown thin-bedded sandstone, which seems to taper out upwards
30 » dark-brown thin-bedded sandstone
10 » dark siltstone, containing a sharp fold and possibly a small break
40 » yellow, thin-bedded quartzitic sandstone
140 » reddish, thin-bedded quartzitic sandstone
350 » pink and yellow-brown bedded quartzitic sandstone
100 » dark-green siltstone and quartzitic fine-sandstone. 5 m and 15 m from the top are 2 m light quartzite beds
70 » light quartzitic sandstone
50 » light and red quartzitic sandstone, thinbedded and containing ripple-marks and some red shale between the beds
7 » light quartzitic sandstone
3 » green and red shaly siltstone
10 » light quartzitic sandstone
10 » dark-green quartzitic sandstone, shaly
250 » red-brown shaly siltstone and claystone, partly cross-bedded; the lower 5 m are green. In the middle part a thin light quartzitic sandstone bed
10 » light quartzite, massive
35 » covered, but presumed to be siltstone
5 » white quartzitic sandstone, massive. Lower follow dark mudstones and siltstones

This gives a total thickness of 12—1300 m.

The Flora Formation is easily seen south of the fjord, where, passing through Celsiusberget, it runs southwards and disappears under the Vestfonna ice. Towards the north it extends to Franklinsundet and Lågøya, where it turns round towards west and south, and therefore also is seen on the west coast of the island.

The Franklinsundet Group

Below the N-S outcrop of the Flora Formation of the Celsiusberget Group there follows a thick sequence of mostly fine-grained, sedimentary rocks occupying the area eastwards to Lady Franklinfjorden. This sequence was thought by KULLING to consist of the Raudstup—Sälodd and Norvik Formations, but our field work in 1965 proved it to be a sequence below the Flora Formation and not a repetition of the rocks in the west, caused by an isoclinal folding with a core in the Flora Formation.

The area was investigated by GEE and WINSNES. With reference to the sections measured and given below, we make the same reservations that KULLING did about his own work in 1931, when he remarked (p. 220) "every section of soldi rock examined was only crossed once, and at fairly great speed". The thicknesses are mostly estimations after counting paces and observing dips.

The sedimentary rocks were divided into three formations: 1) The Kapp Lord Formation, 2) The Westmanbukta Formation, and 3) The Persberget Formation. The upper consists of about 1000 m of mudstones with subordinate quartzite beds and limestone beds. Many of the rocks are calcareous.

In the middle follows a sequence of about 650 m of shaly mudstone and fine sandstone. The two upper formations are characterized by numerous beds of red-brown mudstone and fine sandstone, often containing ripplemarks. Much of the mudstone has a fine interlayering of current-bedded thin sandstone beds, which often show irregular flow casts.

The lower formation consists of quartzite beds and some dark shale. The thickness of this formation is not ascertained, but in the north on Persberget at least 300 m has been seen.

The Kapp Lord Formation. – At the head of Murchisonfjorden, east of Floraberget, it is possible to continue eastwards from the Flora Formation down through the upper part of Kapp Lord Formation. The top of the latter consists of nearly 100 m dark mudstone with many thin quartzitic, partly calcareous beds followed by a brown lime-sandstone. Then follow more mudstone and lime-sandstone with some quartzite bands. A 10 m thick hard, dark mudstone is very conspicuous and forms a marked line which can easily be seen in the nearby hills. Below this are seen beds of sandy limestone and mudstone. Three beds of red siltstone with ripplemarks can also be traced for long distances. In the innermost part of the bay follows a nearly horizontal light grey-green mudstone.

In the north, at Franklinsundet, Gee has measured the following type section (Fig. 7, No. 12, and Fig. 8):

Below 2—300 m of quartzites of the Flora Formation with a basal 10 cm conglomerate follow:

5 m red mudstone
2 » quartzite
10 » red mudstone
10 » grey limestone
30 » grey-white quartzite
30 m grey shales with quartzite at the base
30 » red mudstone with subordinate quartzite
25 » quartzite
30 » scree
40 » dark limestone
5 » quartzite with 0.5 m grey shale on top
5 » grey mudstone
3 » grey limestone
2 » grey, shaly mudstone
2 » dark limestone
5 » grey shale
2 » dark limestone
5 » quartzite
15 » limestone

5 »	quartzite
c. 200 »	indeterminate scree (at head of Murchisonfjorden corresponding beds are light grey-green shaly mudstone), with small outcrops of limestone; towards the east this passes into a crossbedded calcareous sandstone
50 »	shaly mudstone in scree, with a 1 m limestone
20 »	scree
10 »	grey-green mudstone
5 »	red mudstone
30 »	muddy, well cleaved limestone(?)
70 »	scree of reddish, shaly mudstone
3 »	green, muddy limestone
70 »	scree of reddish, shaly mudstone
3 »	red, with green middle part, layered mudstone
40 »	scree of red shale
2 »	green mudstone
6 »	red mudstone
5 »	green muddy limestone
3 »	red mudstone
2 »	green mudstone
3 »	red mudstone
10 »	muddy limestone
30 »	scree of shales
50 »	red shales in scree
15 »	muddy limestone
5 »	limestone
50 »	red mudstone with subordinate quartzite and including some minor limestone units

The formation, c. 900–1000 m thick, can be followed from Lågøya in the north, southwards to Murchisonfjorden and Vestfonna. It also reappears in the eastern limb of the Fogberget syncline (Fig. 33, p. 72) along the western side of Lady Franklinfjorden and Søre Franklinbreen.

The Westmanbukta Formation. – The Westmanbukta Formation makes up a great part of the area between Lady Franklinfjorden and Nordvika, follows the same fold pattern from Lågøya, over Westmanbukta to Nordvika and east to Lady Franklinfjorden.

This formation looks very much the same as the Kapp Lord Formation, but contains much less limestone and is more silty, with fine sandstones.

A section by Gee on the south-west side of Westmanbukta gave (Fig. 7, No. 13):

150–200 m	scree, containing green and buff weathering mudstones and quartzites
30 »	green mudstone
40 »	mainly white quartzite
50 »	green mudstone
10 »	red mudstone

10 » red and green mudstone
15 » green mudstone
50 » green mudstone
10 » red mudstone
2 » hard brown dolomitic mudstone
30 » green mudstone
200 » scree of grey-green mudstone

Below this 600–650 m section follow the lower quartzites of the Persberget Formation.

North of Nordvika, above the quartzite, is seen dark-green siltstone with lighter thin layers of fine sandstone. Overlying these follow red sandstones, green mudstones, and red siltstones in thin beds and a wider bed of light mudstone. Higher up towards west follow more red beds with some quartzitic rocks in between.

The Persberget Formation. – No complete measurements were made in this formation, but it is easily recognized in the field, being characterized by massive white and grey quartzites and subordinate grey shales.

It is found in the eastern part of Lågøya, in the anticlines south and east of Westmanbukta, at Kapp Lady, and in the south, just west of Søre Franklinbreen.

In the last of these areas, Gee has measured:

50 m white-grey quartzite
10 » banded grey quartzite and grey shale
40 » quartzite containing a ½ m horizon of ironstained, brown spotted quartzite. Lower part covered by glacier

At Lågøya the quartzite formation attains a thickness of 3–400 m (Gee).

The quartzite at Persberget also consists of grey massive beds with some dark shales between the beds, sometimes represented only by dark films on the bedding planes. Ripplemarks are common. The brown spots of iron colouring are found to continue all over the area towards the north and seems to characterize these quartzites.

The uncovered part of the quartzite is about 70 m thick.

Further to the north, in the core of the anticline is seen a small hill of dark silt-claystone at least 50 m thick with some calcareous zones in the lowest part, mostly seen as scree. This formation must have a dark silt-claystone member about 100 m below the top in this area.

The Persberget Formation is distinguished from the Flora Formation by its grey colour, with dark shale-zones and absence of red colour.

WAHLENBERGFJORDEN

The eastern part of this area was examined during the 1924 Oxford Expedition and Sandford (1926) has given a good account of the rocks at the head of the fjord. Later (1963) he also gave an account of the geology of the north side of the fjord.

On the north coast of Wahlenbergfjorden several outcrops of Hecla Hoek rocks are seen, which were visited by SIGGERUD in 1965. At the mouth of the fjord, apart from the dolerites of Brageneset and Idunneset, some small outcrops of the Franklinsundet Group are seen in front of Bragebreen. This group is terminated towards the east by a fault, running N-S through Idunfjellet. This mountain is capped by a dolerite sill overlying Carboniferous-Permian rocks. Below these rocks, to the east of the fault, are rather flat-lying limestones of the Roaldtoppen Group. Further down, near the shore, are dark siltstones and light, quartzitic sandstones of the Celsiusberget Group, which disappear towards east. In a smaller outcrop further east only rocks of the Roaldtoppen Group are seen.

Near the head of the fjord a nearly complete repetition of the strata found in Murchisonfjorden is met with. In a small downfaulted area are seen shales and a tillite of the Sveanor Formation, dipping towards the east and lying above a light dolomitic limestone of the Ryssö Formation.

Towards the east follows a dark limestone of the Hunnberg Formation, red and green silty clay shales of the Raudstup-Sälodd Formation and dark siltstones and quartzite beds of the Norvik Formation. The layers dip at small angles towards the north and west.

A fault runs N-S across the head of the fjord. East of the fault are seen light quartzitic sandstones of the Flora Formation. On the north side of Bodleybukta an outcrop of a dolomite in the fault-zone indicates considerable displacement as the stratigraphically nearest limestone is in the Roaldtoppen Group far above. To the south of the bay, sandstone of the Flora Formation is found on both sides of the fault.

Further east of the head of the fjord, the strata dip with varying degree towards west and as we go east we go downwards in the sequence. Within the quartzite sandstone is a dark silt member, seen on the east side of the hill on the north side of the head of the fjord. Towards the glacier in the north, some kilometres east of Bodleybukta, the layers lie with small dip, and SIGGERUD suggests the presence of a disconformity below the upper light sandstones, here, forming the upper part of the Flora Formation. The same flat-lying strata are seen further south in the western part of the Oxfordhalvøya. Further to the east follow siltstones and mudstones of the Franklinsundet Group, calcareous in the upper part. The strata dip at a greater angle here, and furthest east are seen the steeply dipping quartzites of the Persberget Formation. At the base of this formation a conglomerate with rather angular quartz pebbles was seen at several places. In the southern part of the area a fault running SW-NE cuts the lower part of the Franklinsundet Group and brings a dolomitic limestone of the Austfonna Formation in contact with the middle part of the Franklinsundet Group.

In a few places in the area the strata are cut by dolerite dikes.

Along the eastern rim of Vestfonna, in Rijpdalen, quartzites of the Persberget Formation occur in two places. Another big area where these rocks occur is found west of Rijpfjorden, to be described below.

WESTERN RIJPFJORDEN

West of Rijpfjorden, Bengtssenbukta cuts an area of rocks largely composed of the Celsiusberget and Franklinsundet Groups in two parts. SANDFORD (1950) has described the area using field observations of A. R. GLEN, leader of the Oxford University Expedition of 1935–36 and by studying the air-photographs. GLEN made notes of many faults in the area, but SANDFORD disregarded these and indicated a wide syncline in the area. The investigations by FLOOD in 1965 reestablish most of these faults and show that the geology west and north of Bengtssenbukta is more complicated than was previously believed.

The area south of Bengtssenbukta is of fairly simple design. Discordantly overlying the Austfonna Formation, occur Persberget quartzites with a basal conglomerate, dipping 45—50^g towards west. They can be traced northwards from Thank God Bay. The formation is thicker in the north, where it attains a thickness of about 100 m of grey and dark quartzites with a dark fine sandstone to siltstone above, terminated with a 6 m light quartzite on top. Further west follow conspicuously red mudstones and siltstones. The upper part of this characteristic sequence contains much lime-sandstone of grey colour. These rocks make up the Westmanbukta and Kapp Lord Formations in the area. Further towards the west follows a quartzitic sandstone with a very marked red sandstone in the lower part. These sandstones of the Flora Formation can be followed in the N-S ridges throughout the south-western part of Rijpfjorden, and are terminated in the south by a fault running SW-NE. The quartzitic sandstones contain a dark shaly siltstone in the upper part. West of this, the dip of the sandstones gradually increases to the vertical, towards a fault. West of the fault, siltstones of the Westmanbukta Formation are cut by a dolerite dyke and show drag-folding. The western area consists of an anticline with the axis dipping south.

At the head of Bengtssenbukta are seen quartzites of the Persberget Formation. Some grey quartzites interlayer with beds of shale. The quartzites are also seen in the cliff at the glacier front. Towards south the strata of the Westmanbukta and Kapp Lord Formations occupy the Langen valley running S. Towards the south-west, the hill consists of quartzitic sandstones of the Flora Formation with a gentle dip towards SW.

On the north side of Bengtssenbukta the picture is more complicated. The area was investigated by FLOOD in a traverse across the middle part and by several helicopter landings. The fault mentioned in the area south of Bengtssenbukta continues in a more northerly direction. East of the fault rather flat-lying sandstones of the Flora Formation are found, and east and north of this the rocks of the Franklinsundet Group occupy most of the area. The northern tip of the area is made up of the dark phyllites of the Austfonna Formation, described by FLOOD below.

A formation also occurs west of the (main) fault in a horst wedged in between this and another fault further west. The area west of this horst is made up of the Celsiusberget Group. The rocks dip eastwards and in the east, against the horst, dark units of the Norvik Formation are found. Westwards, light quartzitic rocks of the Flora Formation underlie the Norvik Formation and make a row of hills from Planciusbukta to Ismåsetoppen. The border to the underlying Franklinsundet Group goes through the nunatak and runs in a NNE direction. The rocks of the Franklinsundet Group are terminated towards west by a fault, on the other side of which occur the Austfonna Formation and a quartz porphyry which are described by FLOOD below.

CORRELATION WITH SPITSBERGEN

Correlations between the sequences in Nordaustlandet and Spitsbergen have been given by several authors, but as the Nordaustlandet sequence now is more fully known, a correlation with the Hecla Hoek succession in north-eastern Spitsbergen is given below. It is demonstrated in Fig. 10.

HARLAND, WALLIS and GAYER (1966) have revised the names of the Hecla Hoek succession in Spitsbergen, and their terminology is used.

Looking at the two sets of formations, starting at the top, one will see that the Sveanor Formation with the tillite and shales corresponds with the Wilsonbreen and Elbobreen Formations. The Roaldtoppen Group with the Ryssö and Hunnberg Formations coincides with the Akademikerbreen Group, as both groups contain thick dolomites and limestones. It is possible that the upper 150 m of the Raudstup-Sälodd Formation with shaly dolomite and dolomitic siltstone also can be correlated with the lower part of the Grusdievbreen Formation.

The Celsiusberget Group, mostly consisting of sandstones, must then be correlated with the upper part of the Veteranen Group in which quartzites are dominant in the Glasgowbreen Formation and in the upper part of the Kingbreen Formation.

The Kapp Lord Formation with its content of calcareous rocks might corre-

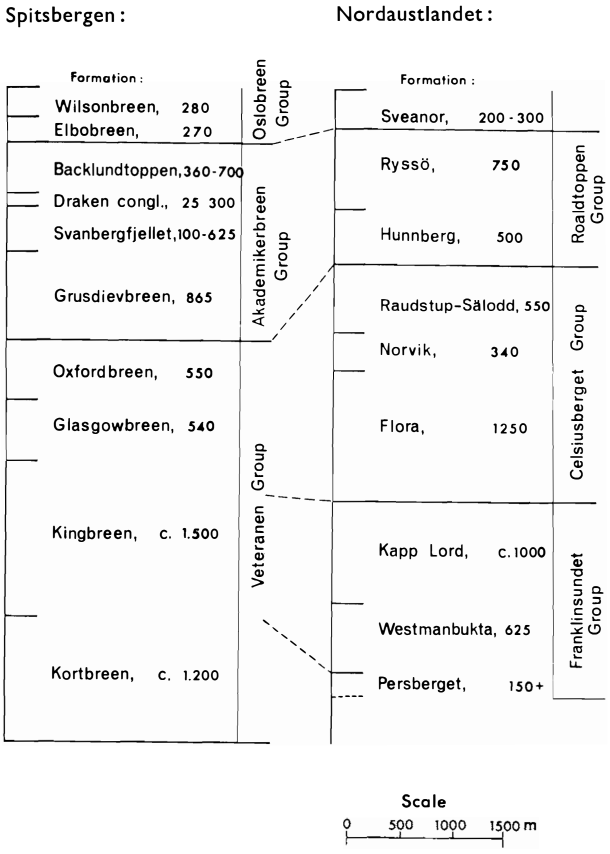


Fig. 10. *Correlation between the sequences in Nordaustlandet and Spitsbergen.*

spond with the limestones in the lower part of the Kingbreen Formation and the mudstones and quartzite of the Westmanbukta Formation seem to fit with the lowest part of the Kingbreen Formation. Red to brown colouring of some layers due to a weak iron content is also a resemblance to be noted.

The quartzite of the Persberget Formation must be correlated with the quartzite at the top of the Kortbreen Formation. As the lower boundary of the Persberget Formation is not known, and in the eastern regions there seems to be a break in the succession, it is difficult to continue the correlation further down, but the limestones found within the Austfonna Formation and also reported from Kapp Wrede (NORDENSKIÖLD 1866) could be the same as the limestone in the lower part of the Kortbreen Formation.

The Botniahalvøya Group

BY

B. FLOOD

Botniahalvøya is the peninsula extending northwards between Lady Franklinfjorden and Brennevinsfjorden. Kapp Hansteen is its extreme northern point and forms an escarpment towards the sea. During the Sveanor expedition of the summer 1931 (see SIGGERUD's general introduction), KULLING (1934) visited this locality and introduced the name Cape Hansteen Formation for the volcanic rocks he observed there. The peninsula (see the geological map) consists of volcanic as well as sedimentary rocks, with both sequences intruded by quartz porphyries. As KULLING's main work was done in the Murchisonfjorden region, he only had time to carry out a coastal reconnaissance of Botniahalvøya and the head of Lady Franklinfjorden. It was only at two localities, Gerardodden and Kontaktberget, that he observed sedimentary rocks, and he was in doubt whether those on Gerardodden should be placed in his Murchison Bay Formation or the Cape Hansteen Formation. The rocks in contact with the granite in Kontaktberget on the east side of Brennevinsfjorden are described as "fine-grained grey-green, slightly phyllitic representatives of the Cape Hansteen Formation". Thus we see that the original name Cape Hansteen Formation mainly referred to the volcanic sequence in the area. Later, thick sequences of overlying sedimentary rocks were placed in the same formation by SANDFORD (1950, 1956). As these and recent investigations have revealed still thicker units of Lower Hecla Hoek rocks with a great variation in lithology, the necessity of a new stratigraphical scheme in these regions has become obvious. All the rocks below the Murchisonfjorden Supergroup have been placed in the new Botniahalvøya Group. The Kapp Hansteen Formation is restricted only to the volcanics from Botniahalvøya and those from other localities which definitely can be related to these. As the old name Cape Hansteen Formation for so long also has included the sedimentary series, our change to Kapp Hansteen Formation, according to The Place-names of Svalbard (ORVIN 1942), should not be incorrect.

FORMATION NAMES AND LOCALITIES

Until the geological map of WINSNES (1965) was published, no differentiation of the rock units on Botniahalvøya had been made. Based on short trips to the peninsula by HJELLE and WINSNES during Norsk Polarinstitutt's expedition to Nordaustlandet in 1957 (in which the present writer took part as a field assistant), WINSNES distinguished between the Cape Hansteen Formation with "plugs" of quartz-feldspar porphyry to the west and a basal conglomerate and sandstones, probably belonging to KULLING's Lower Murchison Bay Formation, to the east. Lithologically this is similar to the division we have made on the present map, but as a result of the latest investigations the borders between the different units are somewhat modified. The conglomerate which is more thoroughly described below, is no longer regarded as basal for the Murchison Bay Formation (Murchisonfjorden Supergroup), but seems to separate distinctly the two lowermost formations within the Botniahalvøya Group (see p. 49). As mentioned, the name Kapp Hansteen Formation has been restricted to the volcanic unit to the west, and the sedimentary sequence along the east side and at the head of Brennevinsfjorden has been given the new name the Brennevinsfjorden Formation. Volcanic and sedimentary rocks which belong to these formations are also met with in the central part of Rijpdalen. The larger part of the latter area, however, is occupied by dark shales and phyllites with some marked horizons of calcareous rocks, amphibolites and quartzites. The contact between the latter units and the Brennevinsfjorden Formation seems partly to be gradational and at present in most cases cannot be fixed precisely. Nevertheless, the lithological variations (see Fig. 11) between the Brennevinsfjorden Formation and the overlying sediments are so marked that we have chosen to place the latter into a separate formation. It has been given the name the Austfonna Formation after the adjacent ice-cap. Related rocks are also met with along the west side of Rijpfjorden and Rijpdalen.

Thus we have found it suitable to divide the Botniahalvøya Group into three formations. They are tabulated in Fig. 11 which shows the most probable age relationships between them, based on the evidence available at present.

The position of the sedimentary rocks on Platenhalvøya is somewhat doubtful. As they lithologically compare most closely with the rocks in the Austfonna Formation, they have been given the same colour on the geological map. However, they are treated separately as the Kapp Platen Formation in the description below, written by WINSNES, who investigated the area.

BOTNIAHALVØYA

Before describing the two formations located here, it must be stated that one of the most conspicuous lithological units in the western part of Botniahalvøya, namely the quartz porphyries, are excluded from the Kapp Hansteen Formation. These porphyries (pink colour on the map) were observed by KULLING, but he was not aware of their great extension and describes them as: "Grey Quartz-porphyries usually in the form of thin sills or beds, . . .". The recent investigation revealed that the quartz porphyries also appear within the Brennevinsfjorden and Austfonna Formations and are therefore representative of the Botniahalvøya

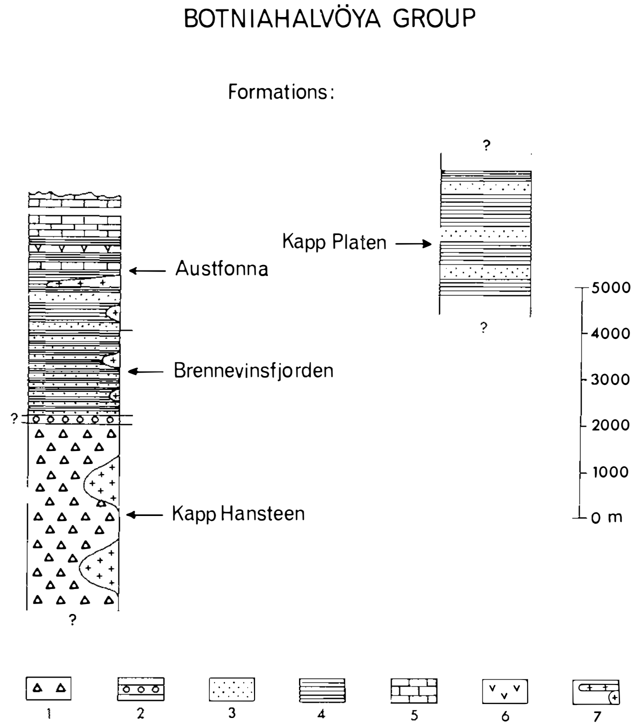


Fig. 11. *Schematic stratigraphical column of the Botniahalvøya Group.* 1 – *Intermediate volcanic rocks, mainly tuff and agglomerate.* 2 – *Quartzite and porphyry conglomerate.* 3 – *Quartzite.* 4 – *Shale and phyllite.* 5 – *Limestone.* 6 – *Amphibolite.* 7 – *Quartz porphyry.*

Group, whilst being absent in the overlying rocks. They are treated separately in this account after the description of the formations.

Generally the topography on Botniahalvøya rises gently from the coast of Brennevinsfjorden towards the west, and reaches its highest contours between 400 and 450 m along Lady Franklinfjorden. It contrasts conspicuously with the granitic, hilly area on the east side of Brennevinsfjorden. Outcrops are fairly frequent, but large areas are covered with blocks. Comparing the blocks with the outcrops present, the majority appear to be of local origin. This evidence has been used to infer the underlying lithologies in areas where outcrops are absent.

The Kapp Hansteen Formation

The base of the Kapp Hansteen Formation is not exposed and it is rather difficult to estimate the thickness precisely. No assumption concerning the thickness was given by Kulling, but Orvin (1940), on his geological map of Spitsbergen, suggested 4 000 m for the Cape Hansteen Formation. Sandford (1956) has calculated the thickness from maps and air-photographs for the eastern limb of the Lovén Peninsula Syncline, and obtained a figure of 750 m. This calculation was subsequently given a more general bearing for the whole Cape Hansteen Formation (in the sense of Sandford) by Winsnes (1965) and Krasil'ščikov (1965). It led to a rather erroneous impression regarding the regional development of the formation. When investigated in the field by Winsnes in 1965, this particular locality was found to consist of an entirely sedimentary sequence, probably belonging to the Austfonna Formation (this paper).

The estimation of thickness presented here is for the Kapp Hansteen Formation in the new sense, i.e. only for the volcanics. The selected locality for this purpose is Franklindalen, an area suffering least from disturbances due to the later intrusion of the quartz porphyries. The average dip across Botniahalvøya in this area is estimated at 60°, which suggests a thickness of the volcanites of a little less than 4 000 m (but possibly lower due to fold repetition), in good accord with ORVIN's figures.

The description of the volcanic rocks from the west part of Botniahalvøya is fairly extensive as this area is taken as type locality. The greatest variety of lithologies are found here. The more briefly examined volcanic rocks in Rijpdalen are described in less detail in a comparison with the rocks from Botniahalvøya.

The following description deals with the rocks west and north of the conglomerate and is based on fairly continuous sections in the area south and east of Norgekollen, and some helicopter landings by the present writer on Hansøya and Gerardodden. Regarding the more northern part of the peninsula, I have been able to use samples and diary notes from HJELLE and WINSNES's trips to both sides of Franklindalen in 1957, and from HJELLE's helicopter reconnaissance in 1965.

The formation consists to a large extent of fragmentary ejected material ranging from volcanic breccias and agglomerates to tuffs and tuffaceous rocks. Massive homogeneous and porphyritic rocks also frequently occur. In general, they comprise a most conspicuous lithological unit which may be useful for correlation with other units throughout Spitsbergen.

Despite numerous observations, we have still not enough information to draw any borders between continuous or discontinuous zones within the volcanics.

Nearly all the varieties have different shades of greyish-green colours on unweathered surfaces; exceptionally some show a more purplish tint. The weathered surfaces generally display marked contrasts between the fragments and the groundmass, grey to almost white colours are present, often with a dark rusty staining due to a high content of iron oxides. The general assumption that the lighter representatives belong to the more acid varieties is therefore not always valid. This is demonstrated through the chemical analyses shown in Table 1. No. I was sampled near the shore, about 3 km south-east of Norgekollen, and belongs to darker, slightly purple, fine-grained crystal tuffs. No. II was taken adjacent to the conglomerate due east of Norgekollen (see Fig. 12). It carries plagioclase phenocrysts, averaging around 0.5 mm across, and belongs to the light greyish-green varieties.

Chemical analyses seem to be the only way of providing a satisfactory classification. The much simpler and less expensive method of modal analysis cannot be used, due to the general fine-grained textures of the rocks, and their extensive alteration.

The chemical analyses with mol. norms and Niggli parameters are presented in Table 1. According to RITTMANN's (1952) classification, the analysed samples Nos. I and II would be a rhyodacite and a dark labradorite-rhyodacite respectively.

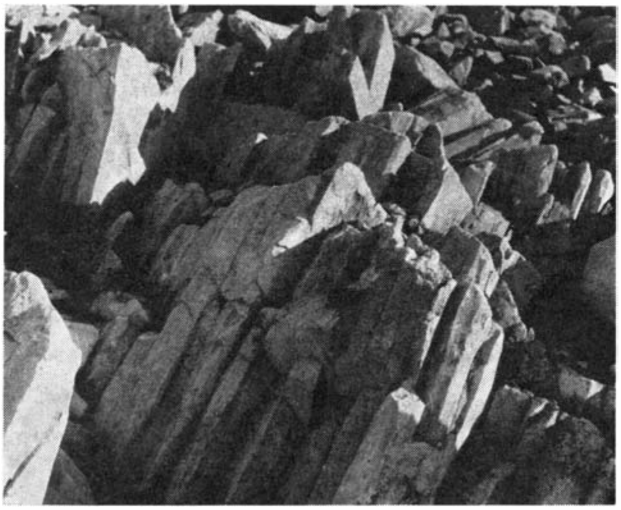


Fig. 12. *Columnar jointed micro porphyry of the Kapp Hansteen Formation, Botniahalvøya Width of fig. c. 1.6 m.*

In "A classification for quartz-rich igneous rocks based on feldspar ratios" O'CONNOR (1965) used a triangular diagram for classification of the lithologies. In Fig. 13 the two samples from Botniahalvøya are plotted on such a diagram together with four analyses of the quartz porphyries (see below, p. 59).

Elsewhere the descriptions of these rocks, based only on field observations and thin sections, follow the classification given by WILLIAMS (in WILLIAMS et al. 1955).

Fragmental volcanic rocks. – The best observation of a volcanic breccia was made just east of the lake south-east of Norgekollen. What distinguishes this rock from the much more abundant agglomerates is the generally large fragments, between 1 and ½ m, and the almost complete lack of matrix. When present, the latter is made up of black, irregular fillings, extending over less than 1 m, and apparently consisting mainly of hematite needles with some jasper, quartz and chlorite. Jasper is also met with as thin veins and of a more irregular appearance within the other rocks of this area.

The agglomerates are demonstrated in Figs. 14 and 15. These photographs show their most important variations, with light fragments in a darker matrix and *vice versa.* The sorting, both as far as composition and size are concerned, is generally not as good as is seen on the photographs. Fragments up to 40–50 cm across are not uncommon. The ratio fragments/matrix also varies considerably; the angular appearance of the fragments is typical. At some localities the larger porphyric fragments may show a zoning which macroscopically appears as a non-porphyritic rim, 2–3 cm wide. Thin section investigation, however, reveals the plagioclase phenocrysts still to be present in the rim, but strongly sericitized. An increased content of sericite also in the groundmass reduces the contrast between the phenocrysts and groundmass. This is similar to what is observed in many of the porphyry boulders in the conglomerate and must necessarily influence the interpretation of this (see p. 50).

Table 1.

Chemical analyses with calculated molecular norms and Niggli values from the Kapp Hansteen Formation volcanics on Botaniahalvøya.

	Analysis No.	I	II
	Sample No.	65–BF–27	65–BF–58
Weight %	SiO_2	62.17	57.80
	TiO_2	0.89	0.75
	Al_2O_3	17.16	15.57
	Fe_2O_3	3.71	0.93
	FeO	1.16	5.40
	MnO	0.11	0.13
	MgO	1.91	5.11
	CaO	3.53	6.73
	Na_2O	3.41	1.54
	K_2O	2.36	1.92
	H_2O^-	0.09	0.14
	H_2O^+	2.22	3.86
	CO_2	1.08	0.03
	P_2O_5	0.07	0.08
		99.87	99.99
Molecular norms	Q	23.1	15.8
	Or	14.5	12.0
	Ab	32.0	14.5
	An	15.0	31.7
	C	4.5	–
	Σ sal	89.1	74.0
	Wo	–	0.4
	En	5.4	14.8
	Hy	–	8.4
	Mt	3.0	0.9
	Hm	0.7	–
	Tit	1.8	1.5
	Σ fem	10.9	26.0
Niggli values	al	40.2	28.8
	fm	26.3	40.4
	c	14.5	22.4
	alk	19.0	8.4
	si	246	181
	k	0.31	0.44
	mg	0.43	0.59
	qz	+70	+47

Analyst:
P. R. Graff,
Norges geologiske undersøkelse,
Trondheim.

Layered structures have not been observed in these agglomerates, the matrix being completely massive. By association, the matrix is regarding as having originated from ejected ashes. Most of the non-fragmental rocks in the field were interpreted as lava flows. They do, however, strongly resemble this matrix, suggesting that most of the Kapp Hansteen volcanics result from ejection rather than flows.

Tuffs and tuffaceous rocks. – All the fine-grained rocks with a more or less pronounced stratification are categorized under these terms. They have a wide distribution within the Kapp Hansteen Formation and consist of alternating

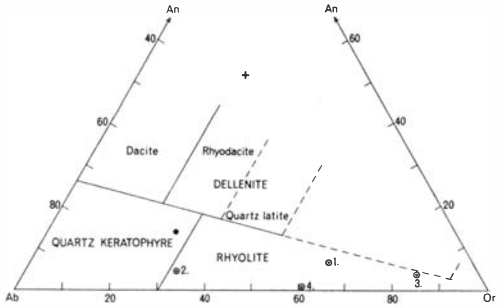


Fig. 13. *A normative classification for some of the Botniahalvøya Group igneous rocks, based on feldspar ratios.* ● *– Dark, fine-grained crystal tuff, analysis No. 1.* **+** *– Light, columnar jointed micro porphyry, analysis No. 2.* ⊙ *- 1-4. Quartz porphyries, see Table 2 and 3.*

dark and light bands from less than 1 cm up to 1 m thick, displaying well-preserved primary banding. A thin section description of a typical representative is given at the end of this chapter. The distinction between tuffs and tuffaceous rocks is made according to the content of calcareous material, this being greater in the latter. The amount of calcite can be considerable and varies distinctly from one band to another. Some boulder-bearing stratified rocks are also described here. They differ significantly from the agglomerates above, the fragments all showing rounded features and generally being widely scattered in the tuffaceous matrix. These fragments may exceed ½ m across and are difficult to distinguish from the matrix on unweathered surfaces. They are assumed to result from volcanic bombs ejected into shallow water and rounded either by wave action or during their ejection.

KULLING (1934) observed within the formation rocks "of a more or less distinct clastic structure, undoubtably some more or less rearranged pyroclastic material". Lithologies covered by this description are met with in a few places (see Fig. 16). Their extension is not known, but it is improbable that they comprise a large lithological unit. If they had not been found within a sequence of volcanics, a sedimentary origin could have been accepted. But as pyroclastic beds are observed within the clastic ones and signs of local erosion occur, KULLING's classification is thought to be the most probable. This rock consists mainly of a very

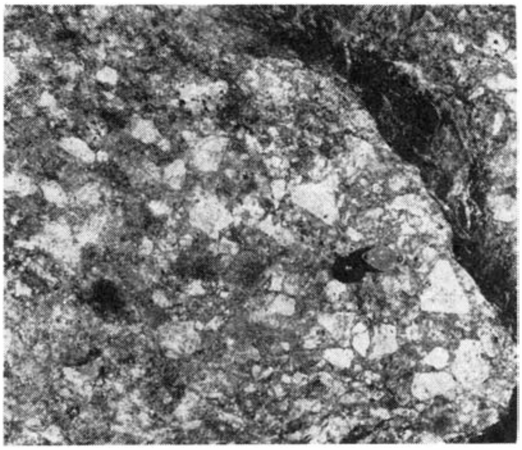


Fig. 14. *Agglomerate of the Kapp Hansteen Formation, Botniahalvøya.*

Fig. 15. *Agglomerate of the Kapp Hansteen Formation, Botniahalvøya.*

Fig. 16. *Rearranged pyroclastic material (lower half) with a pyroclastic bed (upper half). Note erosional contact. The Kapp Hansteen Formation, Botniahalvøya.*

Fig. 17. *Concretions in a banded tuffaceous rock. The Kapp Hansteen Formation, Hansøya.*

fine-grained matrix of sericite and some quartz, with varying amounts of anhedral grains of quartz and microcline, averaging around 0.1 mm. As microcline has not yet been observed within the volcanic rocks of the Kapp Hansteen Formation, it is likely that these rocks, in addition to the rearranged volcanic material, also contain clastic derivates from other geological units and possibly from a pre-Hecla Hoek basement no longer exposed.

A rather remarkable tuffaceous rock with a concretionary structure was observed on Hansøya. The rock itself consists of alternating dark and light, slightly purplish bands, not differing much from the tuffaceous rocks in the area. Scattered in this in varying amounts are small concretions with a fairly constant diameter of 1 cm. They contrast with the groundmass by having a lighter colour, especially well seen on weathered surfaces (see Fig. 17). Under the microscope the main difference between the groundmass and the nodules is a concentration of calcite and epidote in the latter. The groundmass seems to consist almost entirely of a sub-microscopic aggregate, probably of quartz/feldspar, and strongly sericitized. Anhedral hematite occurs frequently, spread at random or forming part of square and rectangular pseudomorphs. The mode of occurrence of the hematite both outside and inside the nodules is the same (see Fig. 18). The concretionary structures of this rock are difficult to explain, but they may have originated as lime concretions in an ashy calcareous sediment which during subsequent metamorphism was epidotized.

Tuffaceous rock from the west side of Kapp Hansteen displaying cm thick bands of dark and lighter green colours, sample 57 – WS – 95. – Minerals identified: plagioclase, quartz, sericite, chlorite, calcite, opaques, and sphene.

Plagioclase occurs in strongly sericitized subhedral phenocrysts spread at random with a length around 0.5 mm. Some of them carry epidote in the central part, indicating previous zoning. Remnants of albite twins can be distinguished in some grains. Anhedral grains of quartz 0.1 mm with recrystallized rims occur together with the plagioclase. Patches of groundmass dominated by sericite together with the frequent occurrence of calcite grains 0.3 mm, or aggregates of grains up to 1.5 mm in extension, are important constituents of the lighter bands. The sericite is orientated at an angle around 80^g on the banding, and parallels the general cleavage of the rock.

The chlorite, pleocroic light green to colourless, with dark grey to dark brown interference colours, dominates the groundmass in the dark bands together with frequent opaque dust. The chlorite also appears in some semi-rectangular aggregates, up to 1.5 mm, with subordinate sericite and sphene, possibly forming pseudomorphs after hornblende. Small anhedral sphene grains are also frequent in the darker bands, often in an epidote, sericite assemblage.

Massive fine-grained and porphyric rocks. – As mentioned (p. 44), there is a notable similarity between the matrix in the agglomerates and some of these fine-grained rocks, regarding both composition and structure. The absence of fragments in the latter may simply be dependent on the distance from the erupting vent.

Among the porphyries, one in particular is outstanding both with regard to extension and appearance. This has been designated the Kapp Hansteen porphyry, and has been found to outcrop throughout the whole peninsula west of the conglomerate. It occurs frequently as fragments in the agglomerates and dominates among the boulders in the conglomerate (see p. 50). It consists of light plagioclase phenocrysts, mostly 1—3 mm across, in a dark grey groundmass (see Figs. 19 and 20). Weathered surfaces are typically brownish coloured. A thin section description is given below.

Under the microscope most of these rocks show a porphyric texture. This can

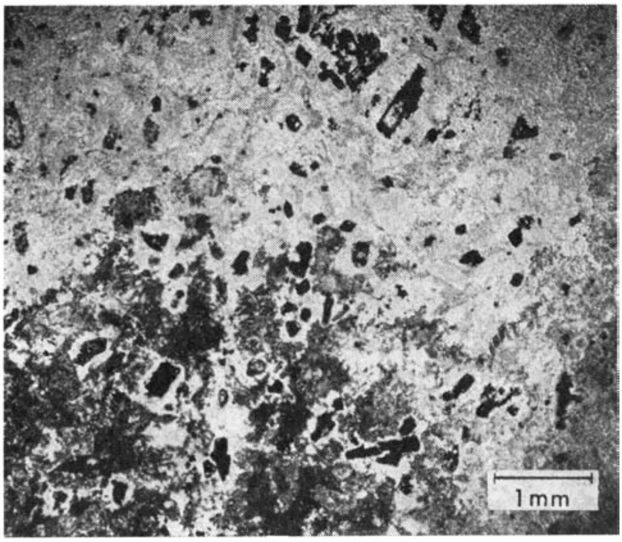


Fig. 18. *Concretions with dark calcite and epidote (lower left part) and light sericitized groundmass. Note possible pseudomorphs of zoned plagioclases in the groundmass. Black hematite.*

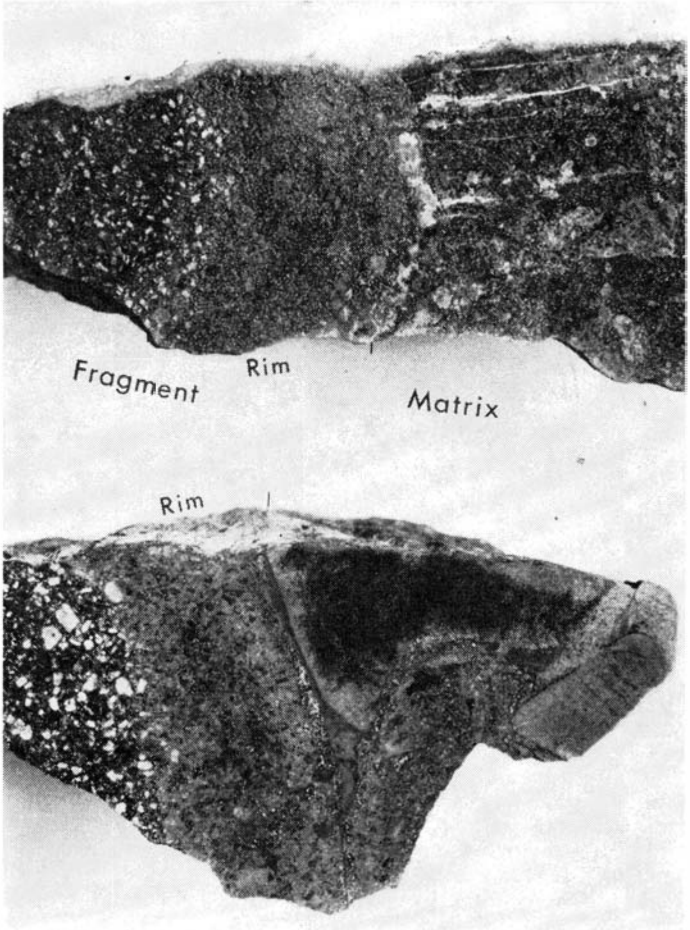


Fig. 19. *Wedges of porphyric agglomerate fragment on the top and porphyry conglomerate boulder at the bottom. Botniahalvøya. Etched by HF. Nat. size.*

hardly be distinguished in the field or in hand specimens, either because the ubiquitous plagioclase phenocrysts are too small, around ½ mm, or due to their alteration. A sericitization equivalent to that described for the rims in the agglomerate fragments (p. 43) is common, as well as epidotization. The light columnar rock (Fig. 12) is a typical representative of this category. Whether it has resulted from a flow, an ignembrite sheet, or occurs as a sill, is still an open question. Detailed field work establishing the contact relations between the latter rocks and the more certain ejecta is desirable before any further genetical interpretations are put forward. However, in Rijpdalen, rocks occur (p. 63) which in thin sections are comparable with the Kapp Hansteen porphyry, and which apparently are of intrusive origin.

Kapp Hansteen porphyry from a boulder in the volcanic conglomerate, 65–BF–80. – This sample was selected due to the best preservation of the plagioclase phenocrysts. A macrophoto of the specimen is shown in Fig. 19.

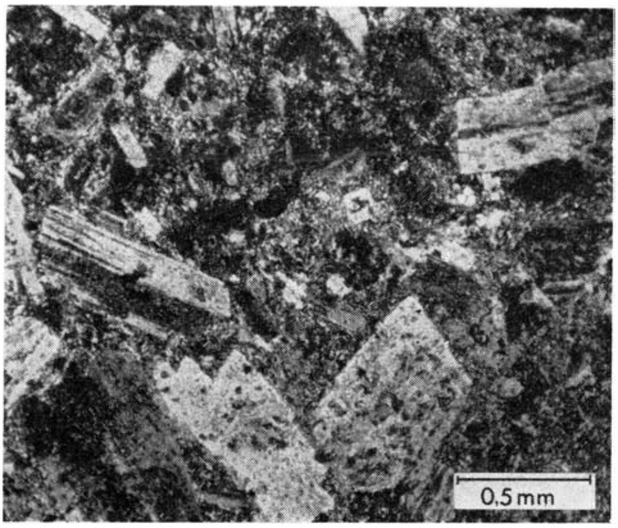


Fig. 20. *Kapp Hansteen porphyry showing plagioclase phenocrysts in a dark chlorite-rich groundmass.*

Minerals identified: plagioclase, quartz, chlorite, sphene, ilmenite, epidote, and sericite

The plagioclase occurs mainly in rectangular phenocrysts ranging from 0.05 to 3 mm long. They display both albite and, but more rare, pericline twin lamellae. The phenocrysts are sericitized and carry inclusions of chlorite and epidote. The An content is estimated as c. 5%.

Quartz is assumed to occur in significant amounts in the groundmass, but is only identifiable in recrystallized zones in the latter, and as vein-fillings in some of the plagioclase phenocrysts.

The chlorite is a major constituent of the groundmass, but also appears in separate aggregates as well as inclusions. It is pleocroic, light greyish-green to colourless with a marked bluish-violet interference colour; probably a pennine. This chlorite is dominant throughout the Kapp Hansteen volcanics.

Fine-grained aggregates of epidote mainly associated with sphene and ilmenite constitute dark semi-opaque patches in the thin section. The sphene often occurs as rims and lamellae intergrown with the ilmenite.

A modal analysis from counting 500 points is given below. The very fine-grained quartz and sericite together with the sub-microscopic constituents are presented as groundmass. A microphoto of the thin section is presented in Fig. 20.

Plagioclase	Groundmass	Chlorite	Epidote	Sphene/Ilmenite
40.8 %	29.8%	17.6%	5.8%	6%

The conglomerate

The occurrence of a conglomerate on Botniahalvøya was mentioned by KULLING (1934). One locality from the north-easternmost part of Franklindalen was described: "The conglomerate carries boulders of porphyry and quartzite, and its colour and general habitus indicate that it is closely related to the surrounding fine-grained members of the Cape Hansteen Formation". He did not try to place the conglomerate stratigraphically. From Norsk Polarinstitutt's additional observations during the summers of 1957 and 1965, it can be stated that in general the conglomerate separates the volcanic Kapp Hansteen Formation and the clastic Brennevinsfjorden Formation. Conclusive evidence regarding the mutual relationships between these formations was not found.

Occurrence and composition. – The conglomerate was investigated at four localities (A–D, Figs. 21 and 22), and a variation both in thickness and composition was observed. The boulders consist mainly of quartzite and the typical Kapp Hansteen porphyry. These two components usually occur separated in distinct units, (see Figs. 23 and 24). At the locality due east of Norgekollen the quartzite conglomerate was found to occur alone.

The quartzite conglomerate varies in thickness from 5–15 m. It is poorly sorted with the larger fragments up to 70 cm across. These are rounded or tabular with smooth surfaces, in contrast to the small ones of less than 2 cm diameter, which usually have a more irregular shape. The latter fragments constitute the matrix which is notable for the absence of fine-grained material. With the exception of a very few small silt and shale fragments the conglomerate appears monomict.

An increasing number of volcanic fragments appears in the conglomerate, crossing the strike from east to west. The porphyry conglomerate has a more polymict character, some quartzite boulders always being present. Its maximum thickness exceeds 100 m, but it is difficult to decide accurately due to poor exposure and observed gradation into an agglomerate of unknown extension. The porphyry boulders may exceed 1 m in diameter, giving the unit a typically unsorted character. The zoning, as described on p. 43, is demonstrated in Fig. 19. Smaller unzoned fragments of a micro-porphyry also occur, made up of fine-grained chlorite, quartz assemblages with c. 0.1 mm phenocrysts of zoned plagioclase.

Hjelle reported in one locality that the change from quartzite to volcanic fragments within the conglomerate was accompanied by a corresponding gradational change in the matrix. The colour in the latter changed from grey to green. Observations from other localities confirm that the matrix within the porphyry conglomerate consists dominantly of reworked volcanic material, most conveniently classified as tuffaceous. Weathered surfaces reveal the structure of small fragments, 1–2 mm across, with a marked relief against a calcareous groundmass. A typical quartzitic matrix has also been observed between the large porphyry boulders, consisting mainly of clastic, partly recrystallized quartz grains with a diameter 0.1–0.2 mm in a groundmass of recrystallized quartz and chlorite. A few microcline and plagioclase grains are also present.

Relation to the adjacent formations. – In Fig. 21 simplified profiles are presented from the localities A–D. The various observations to some extent contradict each other. A, B and D indicate the clastic formation to the east to be overlying the volcanics, while B_1 and C place the conglomerate beneath them.

C is the best exposed locality and has influenced the interpretation B_1. If the conglomerate underlies the volcanic Kapp Hansteen Formation, the occurrence of the porphyry boulders may be explained through a rapid increase in relief at the birth of the Kapp Hansteen volcanism. This caused a short and violent transportation of eroded and ejected material. The unsorted character of the conglomerate, the similarity between the zoned porphyry boulders and the fragments within some of the agglomerates, as described on p. 43, and the fact that

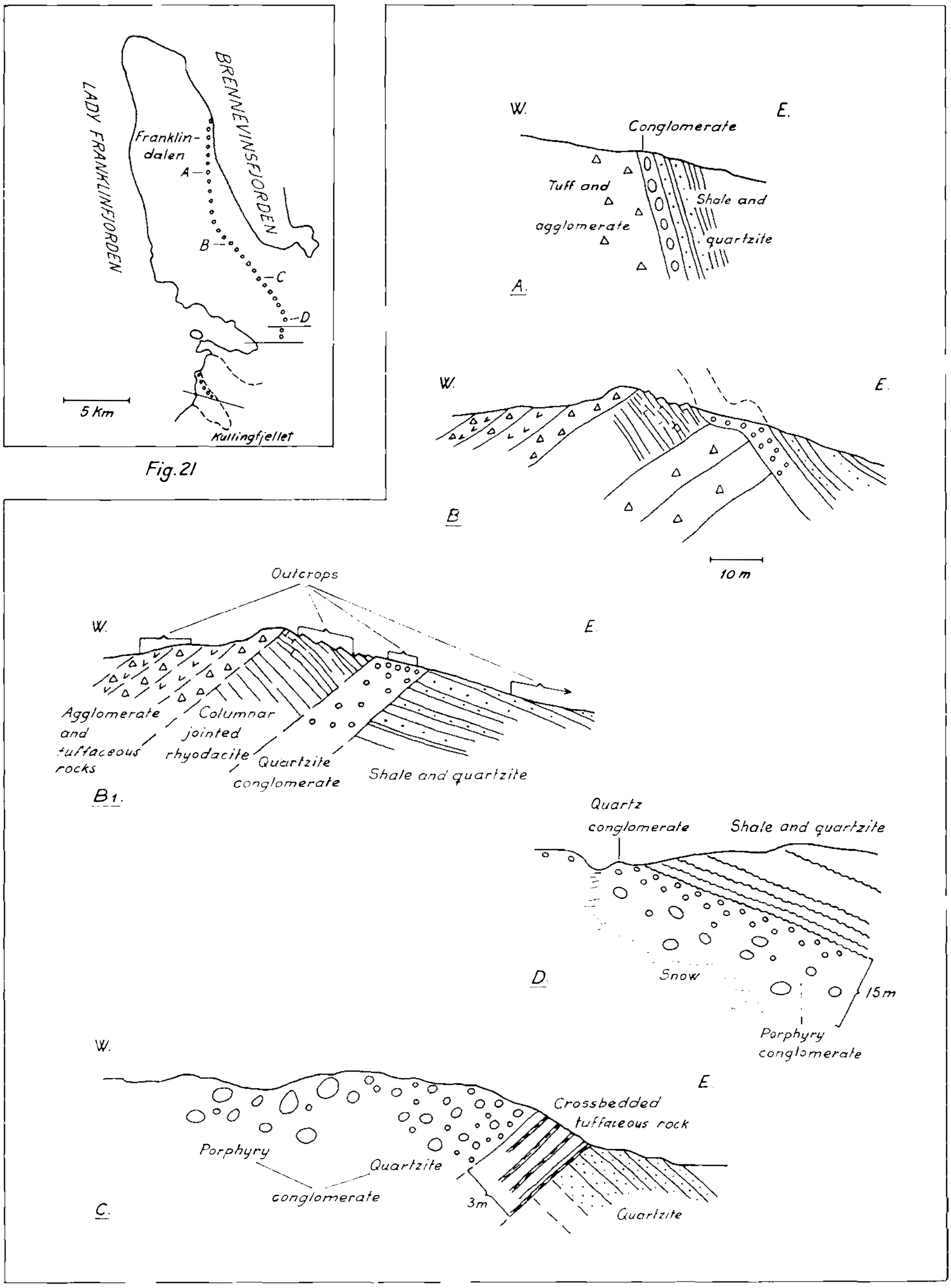


Fig. 21. *Key map showing the occurrence and investigated localities of the conglomerate on Botniahalvøya.*

Fig. 22. *Simplified profiles and interpretations from the investigated localities.*

Fig. 23. *The quartzite conglomerate from Botniahalvøya.*

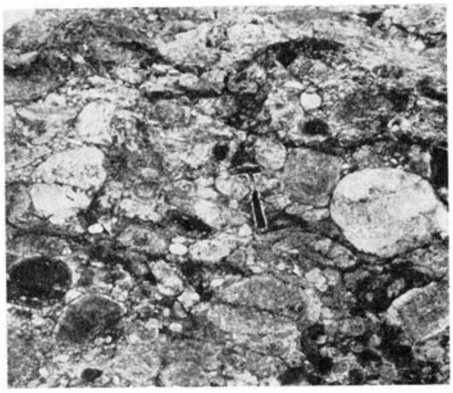


Fig. 24. *The porphyry conglomerate from Botniahalvøya.*

there is a gradational relationship between the two lithologies supports this hypothesis.

At this stage of the investigations, however, the Brennevinsfjorden Formation is thought to stratigraphically overlie the Kapp Hansteen Formation. This is based on the regional relationships as well as the observations from A and D. The latter have influenced the interpretation B. The dip of the bedding is mainly towards the east and the occurrence of the volcanic rocks as boulders in the conglomerate favours this to be younger than the Kapp Hansteen Formation. This argument cannot be used without also reflecting upon the presence of the quartzite boulders. However, these are by far not as characteristic as the volcanic material and could very well have originated from sources unknown today. The discordance indicated at B does not necessarily indicate any major tectonic break, but could be a result of tilting of the Kapp Hansteen Formation during the volcanic activity, and later erosion before conglomerate deposition.

Gerardodden. – Conglomerates closely resembling the one on Botniahalvøya were observed here by GEE and WINSNES. The presence of both volcanic and sedimentary rocks on this promontory was recorded by KULLING (1934), who wrote: "There does not seem to be any well-defined line of junction in the central part of Gerardodden between the fine-grained tuffs and the quartzose sandstone...".

A fault line, striking west-north-west divides Gerardodden into two parts. To the north of the fault there occurs a conglomerate c. 100 m wide, carrying volcanic boulders up to 1½ m in diameter, in general appearance very similar to the porphyry conglomerate on Botniahalvøya. To the west it is bordered by east dipping volcanics of the Kapp Hansteen Formation type. The overlying lithology towards the glacier is of more uncertain character. In a thin section it appears very similar to the volcanic rocks, but an intrusive origin is possible (GEE).

The area south of the fault is dominated by sedimentary rocks of the Brennevinsfjorden Formation type. Two conglomerates, both c. 2 m thick, carrying clastic and volcanic fragments in a mixed matrix, occur within this sequence.

Only the extension of the westernmost is marked on the map. Limited units of volcanics comparable with those of the Kapp Hansteen Formation were observed within the sediments on both sides of the conglomerates. If any of these thinner conglomerate units are contemporary with the one on Botniahalvøya, there either has to be a lateral variation in the depositional facies, or an interfolding of the Kapp Hansteen and Brennevinsfjorden Formations. According to GEE there is no evidence for the latter. Therefore, the observations seem to exclude the possibility for any break of importance between the two formations.

The Brennevinsfjorden Formation

The extension of this formation is dealt with earlier in this paper (p. 40). The relation to the adjacent Kapp Hansteen Formation has been discussed above (p. 49). Towards the east the formation is bordered by the Brennevinsfjorden granite (HJELLE part IV). Sharp, intrusive contacts have been observed (KULLING 1934).

Generally speaking the Brennevinsfjorden Formation comprises a monotonous sequence of quartzites, siltstones and shales. The different lithologies usually occur as thin interbedded layers, a typical appearance being shown in Fig. 25. The quartzites are grey with a whitish or yellowish weathering surface, while the siltstones and shales yield various shades of dark grey. More persistent beds of quartzite, 5—20 cm thick are common, and in a few places – for instance at the head of the fjord inside Hansøya – quartzites a few m thick were observed.

With a few exceptions, the bedding of the formation dips at medium to high angles to the east. This bedding is pronounced and mainly coincides with the cleavage. In some areas with more tight folding a marked fracture cleavage of the less competent shales appears. This generally results in strong weathering and poor exposures. Ripple-marks and cross-bedding occasionally indicating inversion were noticed. Some outcrops, however, show isoclinal folding with the axial plane dipping to the east. Thus some repetition of the unit occurs and the thickness of the formation indicated on p. 41 must be regarded as a rough estimate.

The quartzites consist mainly of detrital quartz grains with abundant plagioclase and some microcline. Both the latter show twinning. The quartz has slight undulatory extinction. The sorting of the grains is good with an average size around 0.1 mm. The rock varies in texture from typical clastic to locally completely recrystallized with sutured quartz grains. Not even in the former texture, however, is the rounding of the grains very pronounced.

The groundmass and main constituents of the shales consist of sericite and chlorite in about equal amounts, as well as quartz. The chlorite is light green, slightly pleocroic, with a dark bluish interference colour. Both the phyllosilicates appear irregular and very fine-grained. Thin laths of muscovite up to 0.1 mm long are spread at random throughout the rock, and concentrations of chlorite flakes up to 0.2 mm long are found in the recrystallized parts. Irregular patches of opaque minerals are frequent within the more shaly layers; also a few grains of sphene, epidote and zircon have been observed, the latter two presumably being detrital.

Fig. 25. *Laminated shale and siltstone of the Brennevinsfjorden Formation, Botniahalvøya.*

Fig. 26. *Quartzite boulder in the conglomerate from south-east Rijpdalen.*

On Gerardodden a somewhat larger variation in the lithology is found (p. 52). Also, some more calcareous beds were observed there. Apart from this, the lithologies within the Brennevinsfjorden Formation indicate deposition under stable conditions. The rather widespread presence of ripple-marks and cross-bedding indicate that the sediments have been laid down in shallow water. A similarity between the darker bands of the Brennevinsfjorden Formation and some of the presumed partly rearranged pyroclastic beds of the Kapp Hansteen Formation (p. 45) is interesting. A further investigation should give evidence of the extent to which material in the Brennevinsfjorden Formation may have been developed from the Kapp Hansteen Formation.

RIJPFJORDEN-WAHLENBERGFJORDEN

The Kapp Hansteen and Brennevinsfjorden Formations

Previous work (SANDFORD 1956) suggested that the volcanic rocks did not extend east of the western limb of the Lovén syncline. Further east the Cape Hansteen Formation was thought to consist of shales and carbonates. Our recent investigations have shown that the volcanics on the west side of the Lovén syncline are in fact intrusive quartz porphyries. On the other hand, the volcanics from Botniahalvøya reappear along the east side of central Rijpdalen. Numerous exposures are found of these rocks west of the migmatite area in the south-east part of the valley and also along two profiles towards the north-west from the two outcrops of the Franklinsundet Group near Austfonna. The sections investigated are all about 1 km wide, but only the southernmost of the areas is marked on the map. The two others fall within the Botniahalvøya Group "undifferentiated" as the extension of the volcanic lithologies is not yet known. Within the sections where the Kapp Hansteen volcanic rocks are exposed, also minor occurrences of shales, slightly phyllitic, and quartzites are found. This is reminiscent of a similar relationship between the volcanic rocks and the sediments on Gerardodden, south of the fault line (p. 53). This may be due to a facies difference from Botniahalvøya as suggested for the latter locality. The rocks show signs of intense folding with both schistosity and bedding dipping at moderate angles to the east and south-east. Thus, proceeding west of where the Kapp Hansteen Formation rocks are located, north of Winsnesbreen, sedimentary rocks of the Brennevinsfjorden Formation type are found. Between the sediments and the volcanic rocks a conglomerate, some 50 to 100 m thick, was observed by GEE. The conglomerate carries occasional quartzite boulders and also some volcanic material, possibly derived from the Kapp Hansteen Formation. Although the character of the conglomerate (Fig. 26) differs from that west of Vestfonna, its location separating the sediments from the volcanics is noteworthy, and implies a possible correlation with the sequence on Botniahalvøya. However, the volcanics in Rijpdalen overlie the sediments, which is the inverse of the regional pattern on Botniahalvøya. There is some structural evidence for inversion and it is therefore suggested that the region in Rijpdalen occupied by the Kapp Hansteen Formation more or less comprises the core of an anticline overfolded to the west, GEE, Part II.

In central Rijpdalen, some meta-gabbros are marked on the map. These have in the field been considered as younger, but pre-metamorphic, intrusives. There is evidence that also these are related to the volcanics of the Kapp Hansteen Formation (p. 63).

The Brennevinsfjorden Formation in the central part of Rijpdalen probably amounts to c. 1 000 m of east dipping grey shales and phyllites. Fold repetition might substantially reduce this figure (GEE). Approaching the Vestfonna ice-cap across a NNW-striking fault, the dip swings to the W and a series of dark shales, quartzites and limestones probably of the Austfonna Formation dip underneath the glacier. The displacement, if any, along the fault mentioned is not known in this part of the valley, but further to the north-west an increasing upthrow of the western side has been recorded. If this fault in central Rijpdalen is a continuation of the one cutting Bengtssenbukta, a similar pattern can be expected. According to GEE it is probably a strike-slip fault.

The Austfonna Formation

Between the migmatites at the head of Innvika and Djupkilen and extending southwards towards Austfonna appear the supracrustal rocks referred to as the Austfonna Formation. Due to marked lithological differences from the Brennevinsfjorden Formation, these extensive beds of quartzites and calcareous rocks, intercalated in a monotonous thick series of dark phyllites, had to be distinguished from the latter formation. The base of the Austfonna Formation towards the undifferentiated Botniahalvøya Group is placed along the first ridge of quartzite proceeding eastwards from Rijpfjorden. Further east, between the big lake extending N—S and the ice-cap, a new thick bed of quartzite, which was located by SANDFORD on the oblique air photos and referred to as part of the Murchison Bay Formation, was found during a traverse in the field. Both these quartzites disappear into the migmatites, and it is uncertain whether they belong to the same unit or are separate members of the formation. Between the easternmost quartzite and the glacier few observations were made, but at least one zone with concordant amphibolites was recorded. South of the head of Innvika and Djupkilen, near the migmatite, massive, fairly extensive beds of quartzites and calcareous schists grading into impure limestones were found dipping to the S and further east to the SW. The same variety of lithologies also appears as meta-sedimentary inclusions throughout the whole north-east migmatite area as well as within the migmatites adjacent to the Kapp Platen Formation on Mefjordheia. A description of the metasediments which occur adjacent to, and enveloped in the migmatites is given in Part III.

Lithologies comparable with those of the Austfonna Formation were also located in south-west Rijpdalen. They appear from under Etonbreen with the Rijpfjorden granite to the east and rocks belonging to the Franklinsundet Group to the west. Any estimation of the thickness of the actual formation is not yet obtained as the degree of fold repetition is not known.

Northwards along the west coast of Rijpfjorden, three localities of the Austfonna Formation were investigated.

Around Galten—Thank God Bay, WINSNES carried out the investigations, and found dark carbonates and shales with a more northerly strike than that in the discordantly overlying Franklinsundet Group (see WINSNES, p. 37). Along the whole section here from the fjord towards the glacier, a dip to the W occurs, the unit comprising the eastern limb of the S-plunging Lovén syncline.

The peninsula between Bengtssenbukta and Carolusbukta has been dealt with fairly thoroughly earlier in the literature (NORDENSKIÖLD 1863, 1866; KULLING 1934; SANDFORD 1950). On the present map a wedge-shaped "horst" of black shale, strongly crumpled and eroded, appears in the midst of the syncline. The shales are bordered to the east by a well-defined fault line extending across Bengtssenbukta. To the west another fault is drawn to explain the occurrence of the black shales adjacent to the grey, partly calcareous sandstones of the Norvik Formation. This fault pattern agrees rather well with the one occurring in GLEN's manuscript (SANDFORD 1950). The assumption that the rocks on Kapp Lovén belong to the Austfonna Formation is based on the following observations. A steep to almost vertical dip of black shales (SANDFORD 1950) does not conform with the general structure of the syncline. The occurrence of a thick bed of dark limestone, resembling the beds found in the Galten area by WINSNES. Lastly, the southernly plunge of the syncline, and the fact that the fault extending E-W to the south of Kapp Lovén has an upthrow on its northern side, makes it probable that the base of the overlying group is exposed there.

Along the west side of the peninsula a thin strip of intensely sheared dark shales and limestones appears between the quartz porphyry and a NNE-striking fault. Their relationship to the younger sedimentary formations is not known due to the fault, whilst they are definitely intruded by the quartz porphyries which nowhere appear east of the fault-line.

The last locality, Scoresbyøya, is built up of grey, slightly purplish shales and sandstones, in part calcareous. The southern part of the island consists of a strongly sheared, grey granite(?), perhaps a variety of the Brennevinsfjorden granite (observations by GJELSVIK in 1966). The stratigraphical position of these meta-sediments is uncertain, their geographical position has been considered when placed in the Austfonna Formation.

THE QUARTZ PORPHYRIES

The occurrence of the quarts porphyry was first observed by KULLING from Botniahalvøya and Gerardodden. SANDFORD (1950) assumed that the land at the head of Sabinebukta consisted of black shales of the Cape Hansteen Formation, but mentioned the presence of quartz-feldspar- or granite-porphyry from the land further eastwards as far as Irmingerneset.

The main extension of the quartz porphyries is found along the west coast of Botniahalvøya (within the Kapp Hansteen Formation) and along the east shore of Sabinebukta. The latter probably extends south-west and west where Sabineberget and some nunataks within Vestfonna are made up of quartz porphyries. A number of less conspicuous but definitely related outcrops have also been found within the Brennevinsfjorden Formation on Botniahalvøya. Generally the quartz porphyry appears in the form of plugs and dykes, the larger having a marked influence on the geomorphology (see map). Quartz porphyries of possibly similar origin were located in the central part of Rijpdalen during Norsk Polarinstitutt's expeditions in 1957 and 1965. These rocks (not marked on the map) were found outcropping mainly within the Botniahalvøya Group undifferentiated; a few occur in the Austfonna Formation along the west side of the valley. They are apparently of limited extension, and their relationship to the neighbouring rocks is not clear.

Characteristic of the quartz porphyries is the presence of quartz phenocrysts, usually c. 3-7 per cm^2, displaying sharp contacts to the groundmass. The quartz phenocrysts seen in hand specimen are generally 1–3 mm in diameter and show a smoky colour which contrasts well with the generally greenish-grey groundmass. Feldspar phenocrysts with a grainsize slightly exceeding that of quartz are normally present. These displaying greyish, white and pink colours may appear with distinct borders towards the groundmass, but are sometimes hardly distinguishable. The feldspars tend to disappear towards contacts and in sheared zones. Thus the quartz porphyries can be considered according to three main modes of occurrence; as massive undisturbed units, as sheared altered units, and as folded and foliated units (typical of Rijpdalen). The variations noted both with regard to structure and macroscopic mineral content are considerable, even within a single intrusion. Thus similar variations between more remote areas should not reject a comagmatic origin.

The microscopically identifiable minerals are listed in Table 2. This table presents seven modal analyses, giving some idea of the total mineral content and a good impression of the variations in the phenocrysts and their quantity in relation to the groundmass. A thin section description is given below.

Table 3 presents chemical analyses of the point-counted samples of Table 2. The analyses are made on ordinary hand specimens not particularly sampled for analysis. In Fig. 13 the four analysed quartz porphyries are plotted on a triangular diagram (see p. 45).

Table 2.

Modal analyses of the quartz porphyries. The samples representing analysis No. 1 are from Norgekollen, and No. 2 is from the quartz porphyry body due east of Hansøya, both on Botniahalvøya. No. 3 comes from Rijpdalen and No. 4 from Sabinebukta. 700–1 000 points were counted for each sample.

Analysis No. See Table 3	1.			2.	3.	4.	
Sample No.	65–BF–18	65–BF–29	65–BF–30	65–BF–35	65–G–360	65–BF–196	65–TS–88
Groundmass	70.8	74.8	71.5	71.4	89.1	63.6	67.1
Orthoclase	11.1	4.7	7.5	–	–	10.3	15.3
Plagioclase	4.6	9.2	7.8	20.7	–	13.6	4.4
Quartz	12.6	9.3	8.9	3.6	6.0	10.4	13.2
Carbonates	x	–	x	–	4.6	x	x
Opaque minerals	x	2.0	0.8	1.2	0.3	2.3	x
Apatite	x	x	x	0.2	–	x	x
Epidote	x	–	–	0.4	x	x	–
Tourmaline	–	–	–	–	–	–	x
Biotite/chlorite	0.9	–	1.8	2.5	–	–	–
Sphene	–	x	–	x	–	–	–
Zircon	–	–	–	x	–	–	–
Sericite	Abundant in all the thin sections						

The quartz porphyries from Botniahalvøya and Sabinebukta appear very similar under the microscope. 65-G-360 from Rijpdalen differs notably due to absence of the feldspar minerals and abundance of carbonates. Another comparable sample from a nearby locality shows both the feldspars under the microscope, although as very faint relics. It might be that the porphyries from this area represent pyroclastic equivalents to the more characteristic quartz porphyry further west.

Summary from thin section descriptions of the quartz porphyries. – Quartz: The size of the quartz and the feldspar phenocrysts varies mainly within the limits given for the macroscopically detectable quartz. In addition, the microscope reveals numerous smaller grains, relics and fragments, dependent on the geological environments (Fig. 27).

Sandford (1950) described – "beautiful examples of corroded large crystals in a fine-grained groundmass which has flowed round them...". Winsnes (1965) mentioned that the quartz displays reaction rims and claims that the groundmass is deficient in SiO_2. The latter is not necessarily the case, the analyses showing a general high content of SiO_2, and in a sample from the east side of Carolusbukta where the groundmass is recrystallized and microscopically detectable this reveals an abundance of quartz grains.

The quartz phenocrysts display all transitions from euhedral to anhedral grains. The extinction

	Analysis No.	1.	2.	3.	4.
Weight %	SiO_2	73.79	70.72	71.76	72.38
	TiO_2	0.23	0.28	0.20	0.20
	Al_2O_3	13.98	16.11	14.30	14.43
	Fe_2O_3	0.52	0.28	0.53	0.40
	FeO	0.99	1.36	2.22	0.96
	MnO	0.02	–	–	0.01
	MgO	0.29	0.50	0.86	0.86
	CaO	1.21	1.21	2.20	0.95
	Na_2O	1.85	4.51	0.36	2.50
	K_2O	5.80	3.30	3.57	5.72
	H_2O^-	0.02	0.06	0.04	0.01
	H_2O^+	1.08	1.03	2.13	0.94
	CO_2	0.20	0.30	1.41	0.62
	P_2O_5	0.11	0.09	0.12	0.10
		100.09	99.75	99.70	100.08
Molecular norms	Q	36.0	26.0	49.0	30.7
	Or	35.5	20.0	22.5	34.4
	Ab	17.0	41.0	3.5	23.0
	An	5.0	5.0	10.5	4.0
	C	3.3	3.7	7.5	3.1
	Σ sal	96.8	95.7	93.0	95.2
	En	0.8	1.4	2.6	2.4
	Hy	1.4	2.0	3.2	1.4
	Mt	0.4	0.3	0.6	0.4
	Tit	0.6	0.6	0.6	0.6
	Σ fem	3.2	4.3	7.0	4.8
Niggli values	al	49.5	49.0	49.9	47.0
	fm	9.7	10.8	20.6	13.6
	c	7.6	6.5	13.8	5.7
	alk	33.2	33.7	15.7	33.7
	si	443	365	426	402
	k	0.67	0.32	0.86	0.60
	mg	0.26	0.34	0.36	0.51
	qz	+205	+130	+263	+167

Table 3.

Chemical analyses with calculated molecular norms and Niggli values of the quartz porphyries from the same localities as represented in Table 2.

Analyst:

P. R. Graff,
Norges geologiske undersøkelse,
Trondheim.

is sharp, undulatory and sometimes, in the marked sheared zones and near to faults, the grains appear almost cataclastic. However, marked reactions between the groundmass and the phenocrysts have taken place, and it seems to exist in two generations.

1. Typical embayed and rounded phenocrysts, as demonstrated in Fig. 28, are frequent. This texture, present also in recent volcanics, appears during crystallization of the magma when already formed phenocrysts "react with or become partially redissolved in the magma" (Turner and Verhoogen 1960).

2. The texture mentioned above shows no relation to secondary structures. Frequent quartz grains, however, display corrosion only on two sides diameterically opposite. These diameters lie in the direction of the least stress as determined from the equal orientation of the sericite. The parts of the grains dissolved are now occupied by fine-grained recrystallized quartz and, if present in the groundmass, also calcite appears. This is best demonstrated in the samples from Rijpdalen

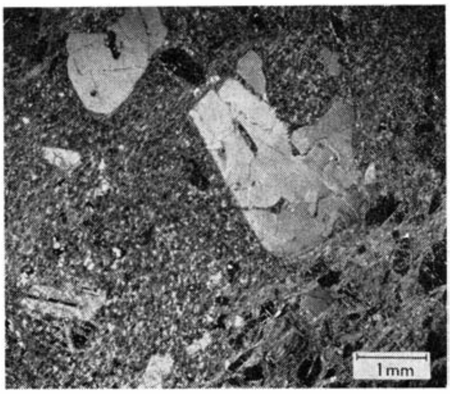


Fig. 27. *Quartz porphyry showing quartz and plagioclase phenocrysts in a varying groundmass.*

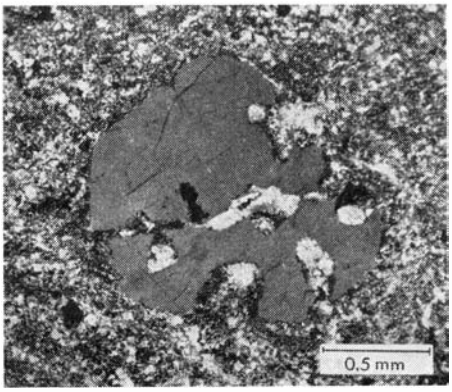


Fig. 28. *Quartz porphyry showing typically embayed quartz phenocrysts.*

where the rock probably due to smaller thickness has been folded together with the adjacent sediments.

Thus there has been: 1. Reaction between magma and early phenocrysts during emplacement and crystallization of the porphyry magma, and 2. Reaction due to stress during the general metamorphism of the area.

Feldspars: According to SANDFORD (1950), the feldspars are mainly orthoclase, with some microcline. Microcline is very rare while orthoclase and plagioclase occur in most of the thin sections. The latter mineral, however, is often hardly distinguishable due to a thorough sericitization (Fig. 27). The orthoclase usually appears distinct from the groundmass, in euhedral to anhedral crystals. Without the analyser the grains are typically cloudy, showing a brownish tint. Perthite lamellae are frequently observed. Corrosion phenomena, as described for the quartz, are also observed in the orthoclase. The grains are generally considerably less altered by sericite and carbonate than the plagioclase. Regarding the latter mineral, the degree of alteration varies greatly. In some samples the grains cannot be distinguished from the groundmass without using the analyser, in others the albite twin-lamellae appear sufficiently clearly for estimating the An content. This lies within the oligoclase range. The grains are mainly subhedral to anhedral.

Chlorite-biotite: These occur in close association with each other. Chlorite is the most frequent as it also may appear separately in the groundmass. In both cases it is pleochroic, grass-green to almost colourless. The biotite has Z=brownish-green, X=light yellowish-green. Where well-preserved, it is observed as inclusions and intergrowths in the quartz phenocrysts and has most probably crystallized as a primary mineral more or less simultaneously with the other phenocrysts. It is often extensively altered. Epidote, opaque minerals and sometimes carbonate occur usually on the cleavages, especially in some of the highly chloritized grains. All transitions from biotite to some linear arrangements of the three former minerals exist. These probable pseudomorphs from biotite are observed in samples from Rijpdalen and Sabinebukta.

Groundmass: The other minerals listed in Table 2 are accessories, except carbonates which in the samples from Rijpdalen constitute a considerable part of the groundmass. Generally the felsitic groundmass contains apparently the same mineral components as the phenocrysts. A thin section stained with sodium-cobaltinitrite reveals abundant potash feldspar, and where the groundmass has recrystallized, quartz appears. Sericite is a very important constituent, unorientated in the massive parts, and orientated with simultaneous extinction in the stressed parts. Distinct boundaries between fields of different grain-size within the felsitic groundmass are observed even in one and the same thin section. In 65–BF–35 spherulites up to 0.1 mm across were found in the coarse part.

Summarizing the present field and microscopical observations from the quartz porphyries the following can be stated:

1. Quarts porphyries appear within all the formations belonging to the Botniahalvøya Group, but are not observed in any of the younger rocks.
2. Quartz porphyries are intruded by the Brennevinsfjorden granite and occur as inclusions in this at the head of Sabinebukta (SIGGERUD).
3. Boulders of the quartz porphyry are not found in the conglomerate between the Kapp Hansteen Formation and the Brennevinsfjorden Formation.

Boulders of a quartz porphyry are found in a conglomerate between the small lake and the quartz porphyry body across the fjord due east of Hansøya. This conglomerate, which also carries boulders of the Kapp Hansteen volcanics, rests discordantly on fine-grained Kapp Hansteen tuffs. A later schistosity penetrates both lithologies.

The intrusive character towards the lower formations and the occurrence of biotite as a typical stable mineral of sub-volcanic facies suggest that most of the quartz porphyries represent sub-volcanic rocks. However, the pyroclastic appearance of the outcrops in Rijpdalen and the occurrence of spherulites mentioned above, probably representing devitrified glass, also indicate that extrusion has taken place. The main extension of the quartz porphyry in the region of the older Kapp Hansteen Formation volcanics suggests that this younger magma during the emplacement has mainly been dependent on the old feeder channels.

From what is said above, I find it as a possible explanation that the emplacement of the quartz porphyries took place during the later part of the deposition of the Botniahalvøya Group and contemporary with a slight movement prior to the general metamorphism of the Hecla Hoek in Nordaustlandet.

CONCLUDING REMARKS

The Botniahalvøya Group comprises the lowermost stratigraphic unit in Nordaustlandet and falls within the Lower Hecla Hoek complex. The base is not known, and no evidence of an underlying old Pre-Cambrian basement has been found. Towards the younger Franklinsundet Group an angular unconformity occurs under a basal quartzite conglomerate. The actual contact between these two groups has not been seen, but the conglomerate is present along the west side of Rijpfjorden and the south-west side of Rijpdalen. The folding of the axial plane schistosity in the Botniahalvøya Group, contemporary with the main folding of the overlying lithologies, as well as the interpretation of the isotopic age determinations (GEE, parts III and V) indicate probable diastrophism prior to the deposition of the younger groups. The metamorphism of the Botniahalvøya Group is very monotonous; biotite only appears close to the migmatite front. A difference between Botniahalvøya and the Wahlenbergfjorden-Rijpfjorden areas in this respect appears through a more tight folding and "phyllitization" in the latter area.

The group in question is the only one recorded to be intruded by the post orogenic Brennevinsfjorden and Rijpfjorden granites. This throws some doubt upon the isotope ages of these granites. However, the Kapp Platen Formation is intruded by the Rijpfjorden granite, and although in this paper it is related to the Austfonna Formation, it might be of a younger age (WINSNES, part II). For instance amphibolites observed from the Austfonna Formation have not been recorded from Kapp Platen, neither have the quartz porphyries been found in this area. The migmatization and intrusion of the synorogenic granites are also limited to this group, including the Kapp Platen Formation.

Earlier correlations between the Lower Hecla Hoek lithologies in Ny Friesland, Vestspitsbergen, and Nordaustlandet have for the latter region been based upon the Cape Hansteen Formation in the sense of SANDFORD (p. 39). HARLAND (1959) and WINSNES (1965) correlate the Cape Hansteen Formation with the Planetfjella series in Ny Friesland. In HARLAND et al. (1966) the name Stubendorffbreen Super-Group is introduced for the Lower Hecla Hoek lithologies west of Hinlopenstretet. These units, between 11 and 12 thousand m thick, are subdivided into the successively older Planetfjella, Harkerbreen and Finnlandveggen Groups. No apparent break between the Stubendorffbreen Super-Group and the overlying Lomfjorden Super-Group is recorded. Nevertheless, a correlation between the Stubendorffbreen Super-Group and the Botniahalvøya Group in this paper seems reasonable. HARLAND et al. (1966) repeat the correlation between the Cape Hansteen Formation and the Planetfjella Group, and says: "... and this correlation is supported by the striking lithological similarities of the pelitic top and the acid pyroclastic base, together with the lack of basic rocks and the general order of thickness of the strata." Due to the new interpretation of the "Archaean basement" east of Duvefjorden (see Introduction to Part III) it was further said: "On the basis of the lithology the Harkerbreen group – "Archaean" correlation is not impossible." This correlation was partly based on the known occurrence of amphibolites from Isispynten (SANDFORD 1954).

The Harkerbreen Group which is described by HARLAND et al. (1966) and GAYER and WALLIS (1966) consists of pelites, psammites, feldspathites with some marbles, and ubiquitous bands of amphibolites (regarding this nomenclature see WALLIS et al. 1968).

Our observations have confirmed a general occurrence of amphibolites east of Duvefjorden (p. 116), as well as within the Austfonna Formation near the migmatite border. The "feldspathites", especially abundant in the middle part of the Harkerbreen Group, was interpreted as acid pyroclastics and may be the equivalent to the less metamorphic quartz porphyries in central Rijpdalen (p. 57). A correlation between the Harkerbreen Group and the Austfonna Formation is therefore found conceivable.

Due to this interpretation of the quartz porphyry in Rijpdalen also the acid pyroclastics at the base of the Planetfjella Group might give a better correlation with the Austfonna Formation than with the typical intrusive masses of quartz porphyry within the Kapp Hansteen Formation. In this context a correlation between the upper part of the Planetfjella Group and the Kapp Platen Formation is suggested. The former is by HARLAND et al. described as "a monotonous sequence of uniform, finely laminated psammite/semipelites and massive pure quartzites and marbles." Although marbles were not observed by WINSNES in 1965 (p. 64), grey limestones were recorded from Kapp Wrede by NORDENSKIÖLD (1866).

Regarding the lower part of the succession, a correlation between the Brennevinsfjorden Formation and the upper part of the Finnlandveggen Group is suggested but is admittedly uncertain due to the lack of calcareous matter in the former. The relation between the highly gneissose area of the Eskolabreen Formation, lower part of the Finnlandveggen Group, with the weakly metamorphosed Kapp Hansteen Formation intermediate volcanics will be left an open, but interesting problem until further petrographical and chemical information is obtained. A transference downwards, however, of the Lower Hecla Hoek lithologies in Nordaustlandet in relation to what was earlier assumed seems obvious.

THE META-GABBROS

In the central part of Rijpdalen meta-gabbros occur within the low grade metamorphic rocks of the Botniahalvøya Group. These rocks are referred to as gabbros on the basis of texture and the relic primary assemblages containing basic plagioclase and, in one case, clino-pyroxene. Neither their extension nor the relationship to the surrounding rocks are clear, although from some localities they are recorded as probable intrusives.

These rocks resemble the Kapp Hansteen porphyry in their high content of plagioclase phenocrysts and the chlorite-rich groundmass. Texturally they vary slightly due to a more pronounced elongation of the plagioclase, and a slight orientation of the same. The plagioclase content is also seemingly higher in these gabbros, the crystals display zoning and twinning and have an An content c. 30—35%. They are mainly eu- to subhedral, varying from the general 0.5 mm to 2 mm in size. Primary features are often lacking due to an extensive sericitization and carbonatization. Some undulatory quartz is present, and probably also constitutes part of the submicroscopic groundmass. The light green, slightly pleochroic chlorite usually occurs along sub-parallel zones; dark bluish interference colours are typical. Accessories are sphene, opaque minerals, apatite, epidote and zircon.

One related sample found in scree showed remnants of clino-pyroxene in a largely epidotized matrix.

These gabbros are located in a region consisting mainly of Kapp Hansteen lithologies alternating with sedimentary units. Occasionally some more fine-grained samples very similar to the gabbros have been classified as "pyroclastics". No obvious compositional difference seems to exist between the rocks in question and the assumed Kapp Hansteen volcanics in central Rijpdalen. Their location and the intrusive character noted suggest that the meta-gabbros represent feeder channels.

The northernmost and largest mass of gabbro was sampled both by GEE and HJELLE. The latter observed a flatlying amphibolitic sill ?, c. 2 m thick, assumed to be the rim of a tabular body. This rock, found close to the migmatites, was enclosed in pelitic schists containing a few feldspar augen. GEE's sample, taken from the eastern part, belongs to the gabbroic variety described above. No evidence for any connection between these samples occurs, but their possible relation makes the sill's metamorphic mineral assemblage worth mentioning.

The central part of the sill consists mainly of unorientated actinolitic hornblende, the grains mainly around 1–1.5 mm in size. The hornblende is associated with frequent sphene aggregates around 0.5 mm in diameter, often enclosing opaque minerals. The groundmass consists mainly of plagioclase, possibly some quartz, and biotite. Average grain size is 0.05–1 mm. The biotite which to some extent replaces the hornblende has a preferred orientation.

Apatite, sillimanite(?), and chlorite appear as accessories. Close to the schist contact, the rock appears equigranular, the grain size being similar to the groundmass described above. Both the hornblende and the biotite have a pronounced orientation and are partly replaced by chlorite, especially along secondary veins filled by chlorite and carbonate.

For the present an extrusive origin for this "sill" may also be considered.

The Kapp Platen Formation

BY

T. S. WINSNES

Platenhalvøya was reached by helicopter and was investigated by a short traverse in the south-eastern part and by helicopter flights with landings for the rest of the area (Fig. 5).

Previously the northern part of the area was visited by NORDENSKIÖLD (1863). Later, by study of air-photographs and material brought back by the GLEN Expedition in 1935–36, SANDFORD published a map of the area (SANDFORD, 1956).

The area is built up of thick quartzite and siltmudstone beds. There seems to be three of each, but the areas with mudstones could hide several faults. To get a complete picture more field work will be needed.

From the visit and study of oblique air-photographs a presumed picture of the geology is presented in Fig. 29.

The traverse in the south-east, from the migmatite area to the mountain north of the bay, crosses several quartzite beds from 100–200 m thick. They are dipping steeply towards W. Between the quartzites are phyllitic claystones and shaly siltstones, often laminated. The shales weather mostly grey-brown to grey-green, but near the mountain in north-east the phyllite is very dark. As a whole the shales are strongly folded, often corrugated, with a prominent secondary schistosity.

Along the coast northwards the mountains consist of massive quartzites with a steep dip towards W. No observations showed a fault as indicated by SANDFORD (1956).

In the area south of Minebukta the rocks eastwards from a dark phyllite are massive grey-green and red-brown quartzites, both nearly 200 m thick. East of this follow dark-green, shaly siltstones 50–100 m, and a light massive 20 m bed of quartzite. Then follow dark phyllites, containing several folds, and near the shore are seen two beds of light quartzite, each some 10 m thick.

West of thick phyllites to the west of the head of Minebukta, the hills consist of light quartzite with a low dip towards W. Further to the west come more dark, shaly claystones, and another quartzite member.

At Tumen the cliff consists of light-grey, phyllitic siltclaystone. Towards west an anticlinal structure is seen, with steep dipping light quartzites in the western limb. Then follows a flat area with shales east of the quartzites making up Kapp Platen. In the eastern part this consists of dark, massive, partly reddish quartzite. Kapp Platen itself consists of light, partly wave-marked, steep-dipping quartzites. Just west of the cape is a small area of laminated flat-lying claystones.

It seems that Kapp Platen has a western narrow anticline, broken by a fault in the north, and an eastern more open syncline. The syncline is also seen in the mountains towards the south.

The western part of Kapp Wrede is made up of steeply dipping calcareous sandstones and quartzites. NORDENSKIÖLD (1866) mentions a limestone from this area. A N–S running dolerite dyke occurs here. East of a fault the rocks are mostly flat-lying, dark phyllitic shales, forming the steep cliff. Towards the south the mountains are capped by light quartzites, but the lower part consists of dark shales.

No contact with the migmatites in the south was observed but there seems to be a sudden change in direction of the strike across the border. East of Vindbukta exists a wide contact zone between the Rijpfjorden granitic rocks and dark argillites of the Kapp Platen Formation.

It is not possible to give any sequence of the layers through this big rock complex. Sufficient likeness to the sedimentary rocks of the Murchisonfjorden Supergroup in the west to justify correlation with these was not found. The phyllite rocks and pronounced schistosity make it probable that it belongs to an older sequence than the Franklinsundet Formation, and until more detailed work is undertaken, the author finds it natural to place it in a formation in the same uncertain position as the rocks in Rijpdalen (the Austfonna Formation). However, in view of the geographical separation of these rocks from the type area of the Austfonna Formation, we have decided to use a separate formation name, the Kapp Platen Formation.

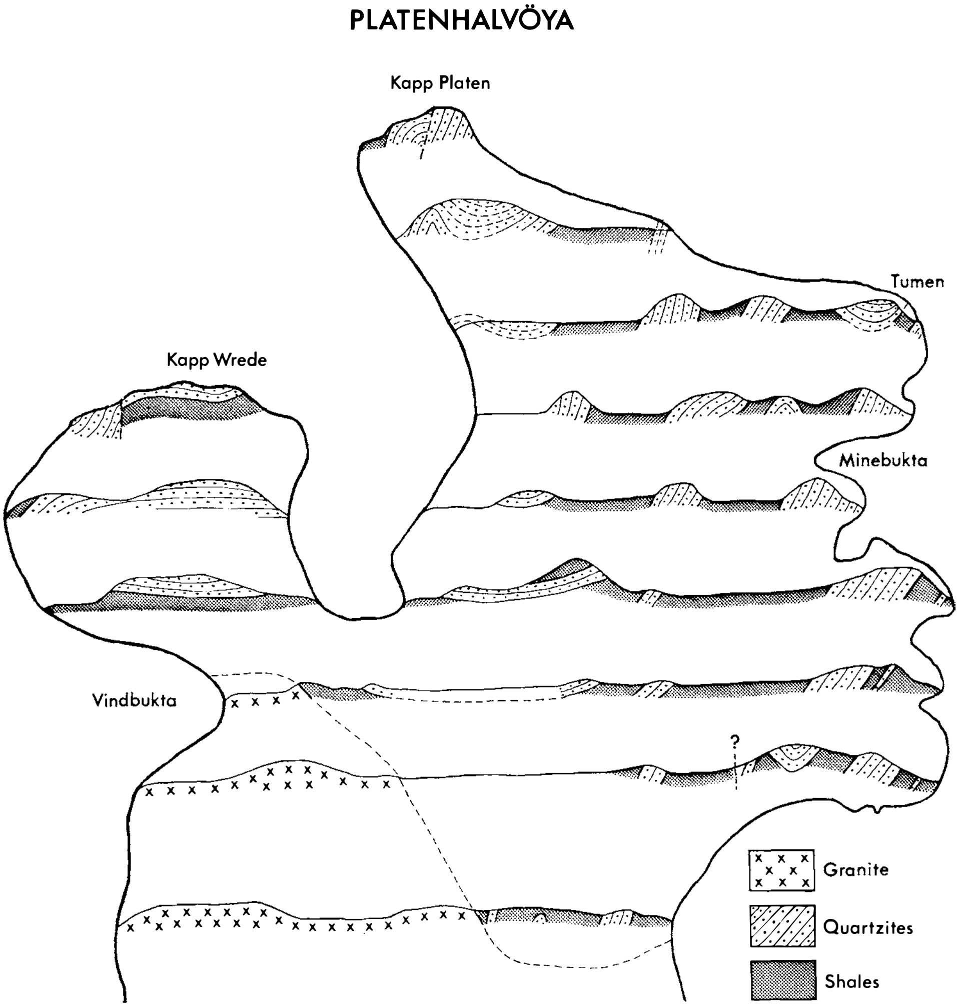


Fig. 29. *Platenhalvøya with profiles as observed by a few helicopter landings and a short travers (cf. Fig. 5). The north-south scale is reduced compared to the east-west scale.*

Part II.
Structure

BY

D. G. GEE

Introduction to Part II

Geological reconnaissance of Nordaustlandet in the middle and latter part of the last century established the presence of granites and granite gneisses in the eastern and northern parts, flanked to the south and west by sediments and low-grade meta-sediments (NORDENSKIÖLD 1863, DE GEER 1923). The former were considered part of the Archaean and the latter were thought to unconformably overlie this basement complex. A similar relationship was accepted for Ny Friesland, Vestspitsbergen, NORDENSKIÖLD considering that his sedimentary "Hecla Hooks Formation" overlay a previously metamorphosed basement. BLOMSTRAND, in 1864, described transitional relationships in north Ny Friesland between the Hecla Hooks Formation and the adjacent schists and gneisses, and his conclusion that a more or less continuous succession existed in the area along with a marked increase in metamorphic grade to the west, was given support by KULLING (1934). By analogy with Ny Friesland and also north-west Spitsbergen (HOLTEDAHL 1914), the hypothesis of major unconformity in Nordaustlandet appeared insecure.

During the last forty years the most significant contributions to the regional structure of Nordaustlandet have been made by SANDFORD. In 1926, he considered the Archaean basement hypothesis to be doubtful, emphasizing that at least a part of the granite complex was composed of discordant intrusive rocks. Subsequent information, however, led him to extensively explore the basement concept and eventually to favour it (SANDFORD 1950, 1956, 1963). Isotopic age-determination evidence (HAMILTON and SANDFORD 1964) gave some support to this conclusion.

Nevertheless, prior to the Norsk Polarinstitutt 1957 Expedition no qualified geologist had investigated the critical areas separating the supposed basement complex of granites and granite gneisses from the sediments. In that year, WINSNES (1965) recorded the relationship between gneissose granite and sediments as "intrusive" in central Rijpdalen. This evidence, taken in relation to the older (c. 600 m.y.) Nordaustlandet age-determinations, allowed the possibility of late Pre-Cambrian diastrophism effecting the lower part of the Hecla Hoek sequence, a hypothesis examined by GEE and HJELLE (1966) for north-west Spitsbergen.

Thus, before the 1965 Norsk Polarinstitutt Expedition, three possible models were considered for the regional structure of Nordaustlandet. The first favoured

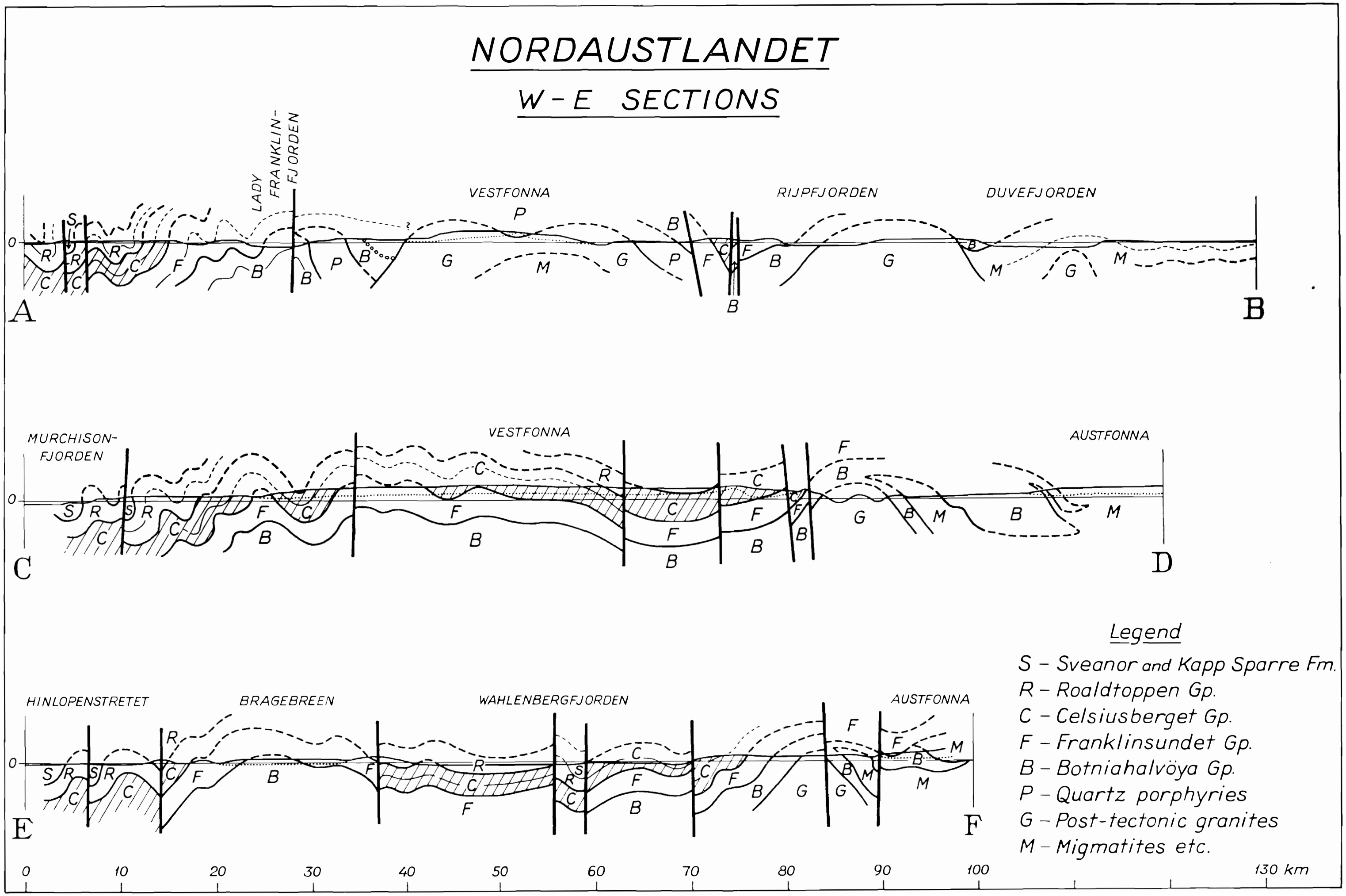


Fig. 30. *Diagrammatic sections across Nordaustlandet. The lines of the sections are shown in Fig. 31. The Carboniferous unconformity is not shown.*

an Archaean complex of mainly flat-lying granite gneisses unconformably overlain by the Hecla Hoek rocks. The second required formation of the gneisses during late Pre-Cambrian metamorphism affecting at least the lower part of the Hecla Hoek succession, followed by later Pre-Cambrian and early Palaeozoic deposition and Caledonian deformation. And the third accepted the whole sequence of the Hecla Hoek to be more or less conformable, the deformation, metamorphism and granite gneiss formation to be related only to Caledonian orogenesis, and the earlier age-determinations indicative of late Pre-Cambrian "thermal (volcanic) activity" (HARLAND et al. 1966).

Our knowledge of the structural detail of Nordaustlandet rested heavily on the careful reassessment of data from both geological and non-geological expeditions by SANDFORD. The general structure of the area he summarized in 1956 in a west-east sketch section from Murchisonfjorden to Duvefjorden, drawn approximately perpendicular to the regional strike of the Hecla Hoek. Intensity of deformation was illustrated to be greatest in the west with westerly asymmetric folding in west Murchisonfjorden and isoclinal folding overturned eastwards between Murchisonfjorden and Lady Franklinfjorden (the latter being based on a stratigraphic interpretation by KULLING, 1934). East of Lady Franklinfjorden, the structure was shown to be dominated by a major anticline, the N–S axis passing centrally through Vestfonna. This was flanked to the east by a symmetrical syncline (the Lovén syncline) followed eastwards by a symmetrical anticline in Rijpdalen, and another syncline along the western side of Austfonna. The structures in the sediments and low-grade meta-sediments were shown to simplify eastwards, and a pre-Hecla Hoek basement complex was illustrated to outcrop in the core of the Vestfonna and Rijpdalen anticlines, and to generally occupy the area of Duvefjorden and eastwards.

The new data is summarized on the accompanying geological map and in west–east sections (Fig. 30). Prior to further discussion of regional relationships, accounts are given of the structure in different parts of Nordaustlandet in the light of the data collected on the 1965 Norsk Polarinstitutt Expedition.

Eight separate areas are considered here (shown in Fig. 31). Some of these are described more fully elsewhere in this paper but a summary is included here in order to present a co-ordinated overall assessment of the regional structure. The data from the different areas was collected by those of us as indicated on Figs. 3–6, p. 15–16. Unless otherwise specified, they have been compiled by the writer.

Description of the areas

AREA 1. WEST NORDAUSTLANDET

KULLING (1934) established in this area the essential basis of the stratigraphy of Nordaustlandet. He demonstrated that the rocks were comparable with the Hecla Hoek Formation of northern Ny Friesland. His account of the structure of the area provided an invaluable foundation for the 1965 investigations. West Nordaustlandet was shown to be dominated by folding about N–S axes. KULLING

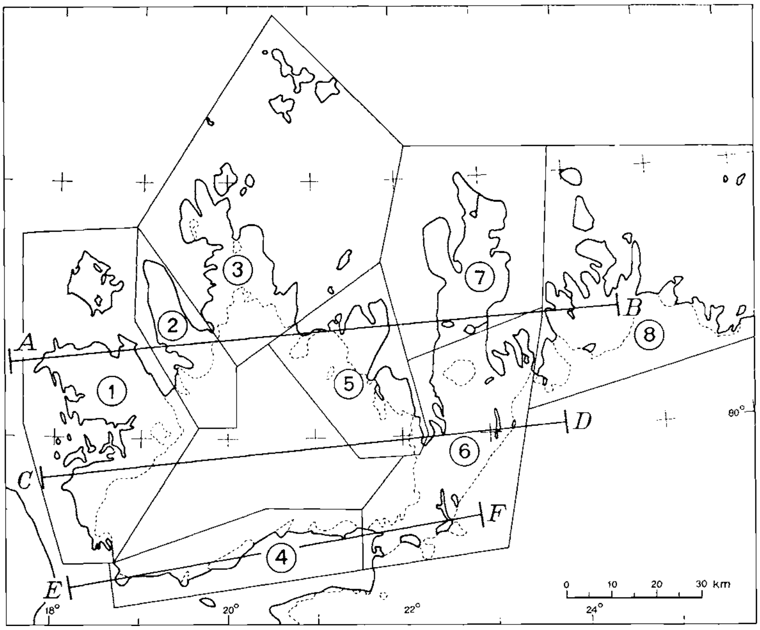
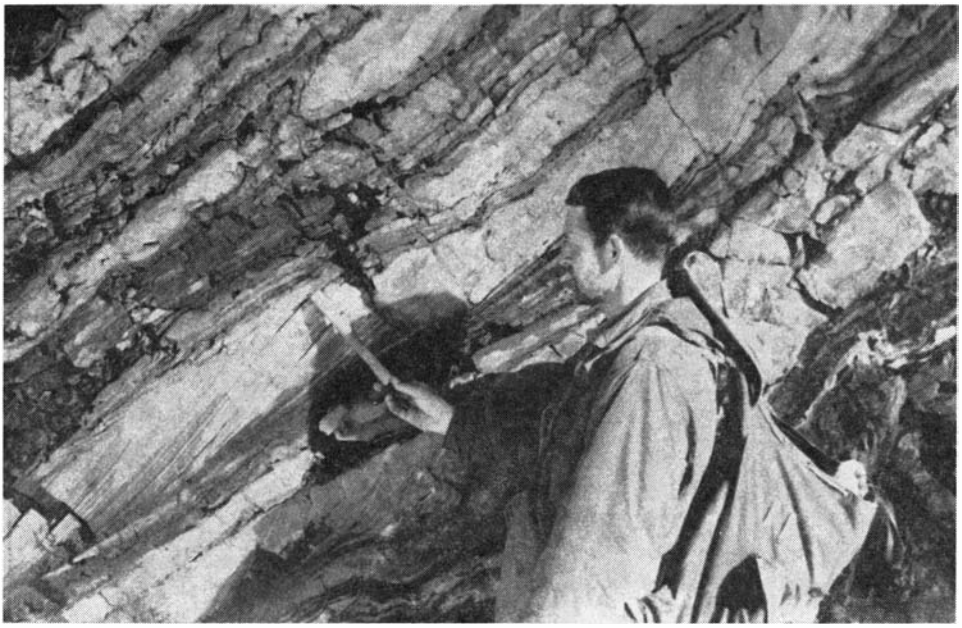


Fig. 31. *Location of the sections and the sub-areas described in the text.* 1 – *West Nordaustlandet* 2 – *Botniahalvøya–Gerardodden.* 3 – *Laponiahalvøya and Sjuøyane.* 4 – *The north coast of Wahlenbergfjorden.* 5 – *West Rijpfjorden.* 6 – *Rijpdalen–Innvika.* 7 – *Platenhalvøya.* 8 – *Duvefjorden–Leighbreen.*

differentiated between the westerly asymmetric folding of Murchisonfjorden, and a major isoclinal recumbent fold further east (KULLING 1934, p. 172—3). His description of the former we have been able to improve very little on; the latter we were unable to establish; a result premeditated by WILSON (1958) and SANDFORD (1963) and assumed by HARLAND et al. (1966).

The establishment of the fold pattern illustrated in Fig. 30 has been supported by the frequent observation of way-up structures (Fig. 32). The axial traces of the major, cylindrical, westerly asymmetric, cleavage folds are shown on Fig. 33. Stereographic projection of the data on these folds is given in Fig. 34 which illustrates the homogeneity of the structures. Except in the south-west and in the Oddneset area on the north side of Murchisonfjorden, all the major and parasitic minor folds plunge 180—190^{g}/10—15^{g}S. All these folds lie in the western limb of the Vestfonna anticline, and the rocks generally young westwards. A major syncline is inferred to exist in Hinlopenstretet, with the rocks on the west side of the strait younging from west to east away from the Heclahuken anticline.

Folds in the Celsiusberget Group are illustrated in Fig. 35. In the more homogeneous shale units a true cleavage is developed parallel to the axial surfaces of the folds. This secondary structure is developed only in the argillaceous rocks and shows a regionally constant orientation throughout West Nordaustlandet. In the calcareous siltstones and sandstones the axial surface structure is usually present as a false cleavage which does not generally penetrate the massive quartzites, dolomites and limestones. Folding of these competent units occurs with very



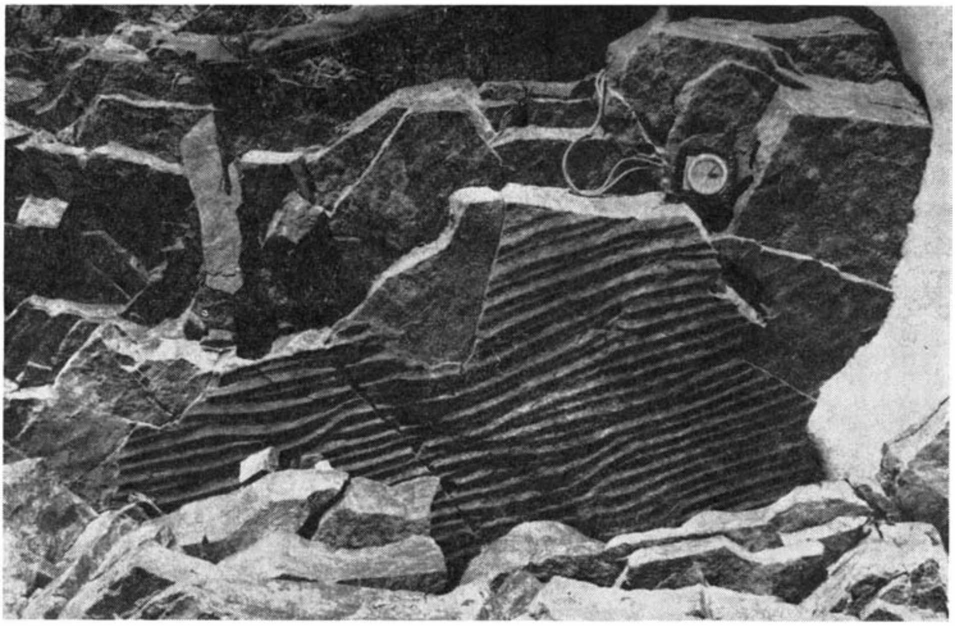


Fig. 32. *Cross-bedding and ripple-marks in the Celsiusberget Formation.*

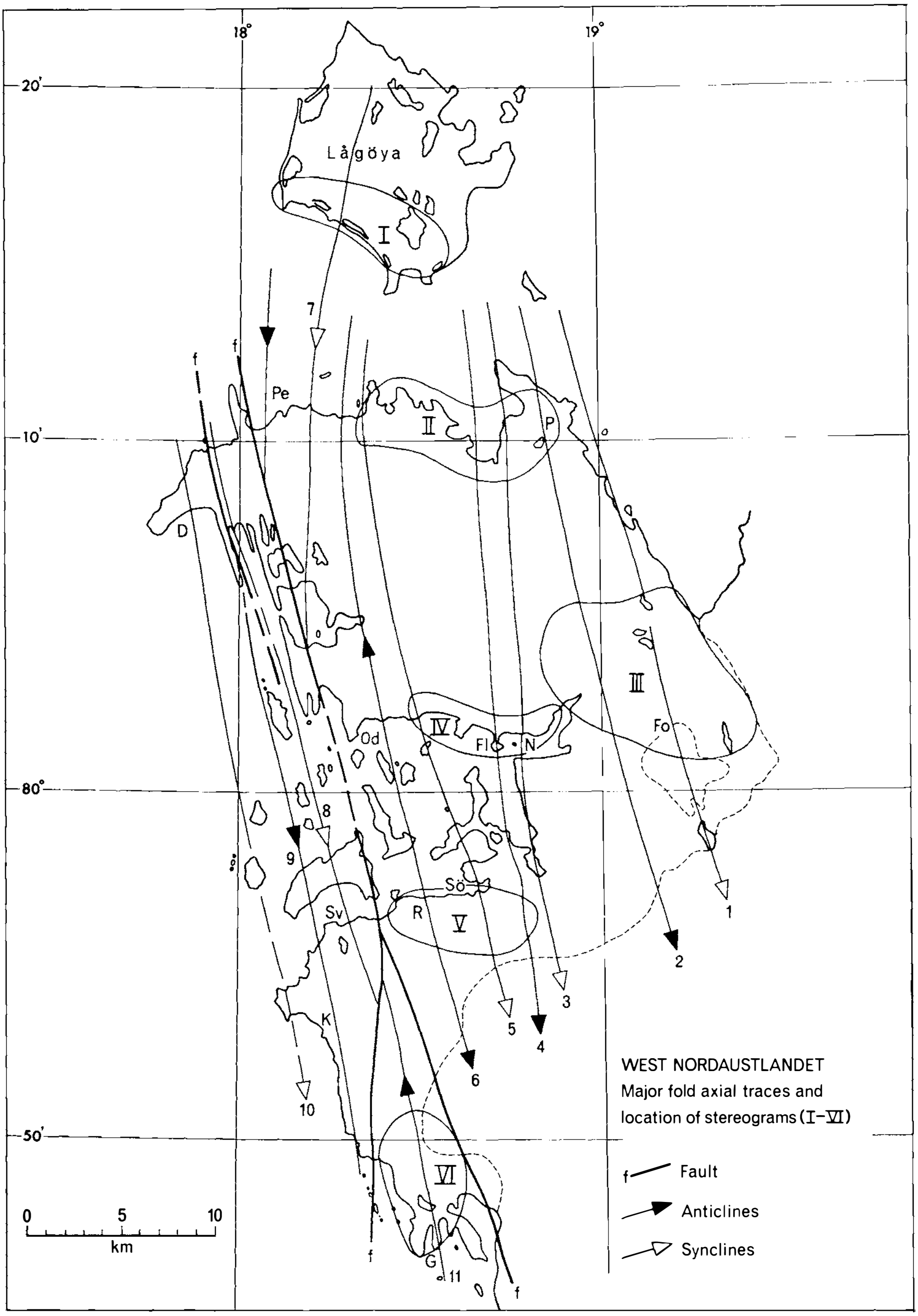


Fig. 33. *West Nordaustlandet area. Location of the axial traces of the main folds and the faults. The stereograms of Fig. 34 have been compiled according to the areas shown here. Numbers on the folds refer to:* 1 *- Fogberget (Fo) syncline.* 2 *– Persberget (P) anticline.* 3 *– Norvika (N) syncline.* 4 *– Floraodden (Fl) anticline.* 5 *– Sørvika (Sø) syncline.* 6 *– Roaldtoppen (R) anticline.* 7 *– Lågøya syncline.* 8 *– Sveanor (Sv) syncline.* 9 *– Kalkstranda (K) anticline.* 10 *– Detterbukta syncline.* 11 *– Gimleodden anticline. Od gives the location of Oddneset.*

WEST NORDAUSTLANDET

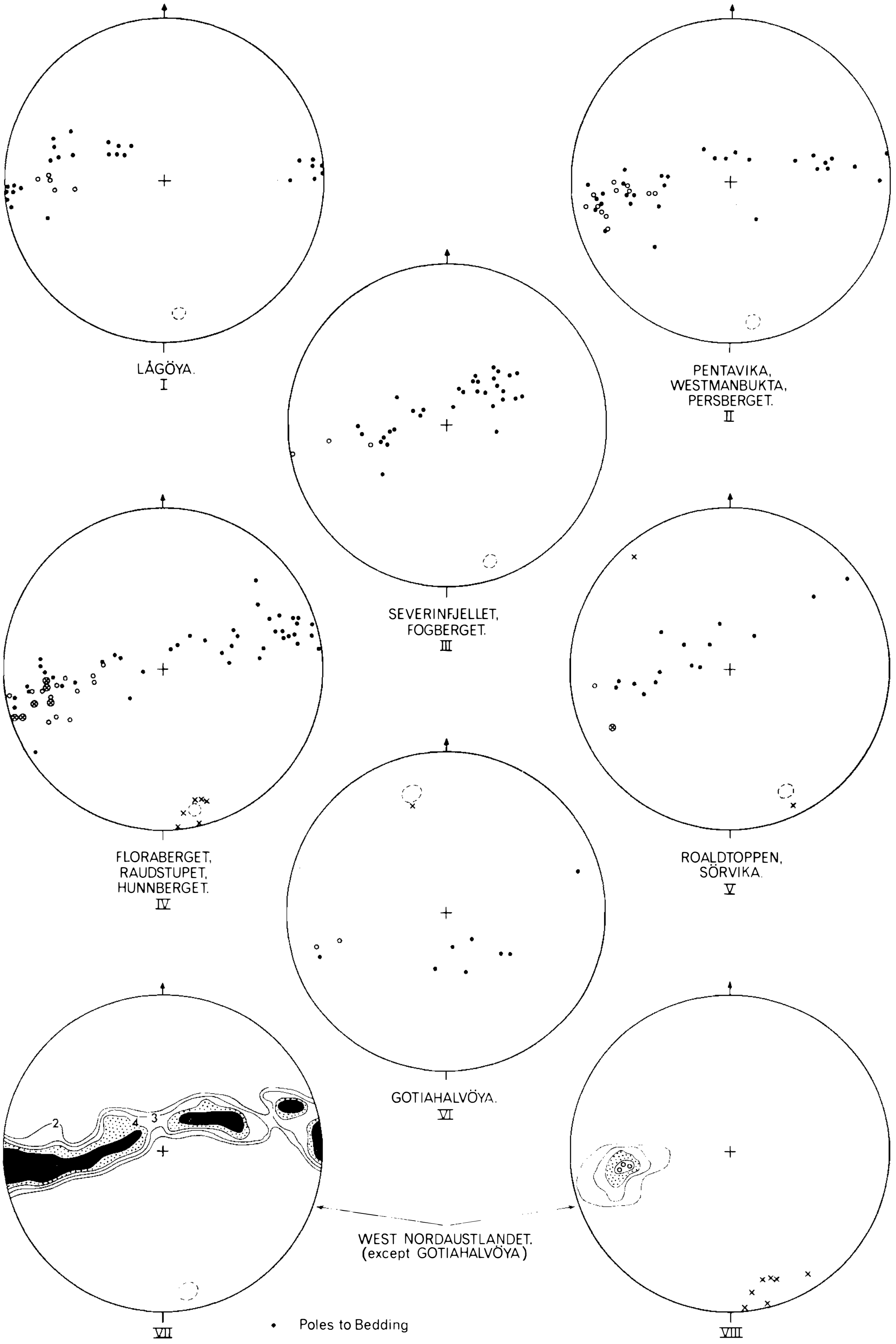


Fig. 34. *Stereographic projection (lower hemisphere equal area net) of* ***bedding,*** *cleavage, fold axis and fold* ***axial surface*** *data from west Nordaustlandet. The areas to which the stereograms refer are shown on Fig. 33.*

little thinning in the limbs, whilst their presence as subordinate constituents in the incompetent shales is notable for a marked thickening in the hinges and attenuation in the limbs.

The development of a minor fold in the siltstones of the Norvik Formation, passing down into a minor reverse fault in a massive quartzite unit, is illustrated in Fig. 36. Where thin competent units are present in shales, boudinage of the former occurs (Fig. 37).

In the western part of the area, two major NNW-striking high angle faults occur, showing apparent downthrow eastwards. The western is referred to as the Bråvika fault and the eastern, the Claravågen fault. South of Murchisonfjorden, the latter is thought to branch and cut the eastern and western limbs of the Gimleodden anticline.

Throughout the area displacement of the strata by minor WNW- and WSW-striking high angle faults has been recorded. They are particularly conspicuously developed south of Murchisonfjorden and are illustrated in Fig. 38. The displacement appears to be mainly strike-slip, sinistral on WNW-striking surfaces and dextral on WSW-striking surfaces, thus forming in response to a similar stress orientation to that required for the folding. South of Sveanor, these faults apparently displace the Claravågen fault.

AREA 2. BOTNIAHALVØYA–GERARDODDEN

Prior to the recent Norsk Polarinstitutt expeditions, knowledge of this area has been limited to fragmentary observations by KULLING (1934) and earlier notes by NORDENSKIÖLD (1863). KULLING did not attempt to erect a stratigraphic scheme for the Botniahalvøya lithologies, but considered it possible that, south of Gerardodden in Kullingfjellet, these volcanic and sedimentary rocks might pass up without a break into his Murchison Bay Formation. The stratigraphic relationships have been described and discussed in Part I, and this summary of the structure is based mainly on the observations of FLOOD and HJELLE 1965, and also of HJELLE and WINSNES 1957, and GEE and WINSNES 1965 on Kullingfjellet and Gerardodden.

Throughout the western part of Botniahalvøya, volcanic rocks are overlain by a boulder conglomerate composed of volcanic material and quartzites, dipping regionally at medium to high angles eastwards. The latter are overlain by sediments and both are intruded by quartz porphyries. The conglomerate also appears on the eastern side of Gerardodden and strikes south into the northern part of Kullingfjellet. Thus, despite possible instances of local inversion (see FLOOD in Part I) the regional structure conforms to the eastern limb of a major anticline. In the southern part of Kullingfjellet, across a WNW-striking fault, the style of the minor folds, thought to be parasitic to this major structure, and the moderate to high angle westerly dips suggest a location in the western limb near the hinge of the anticline.

The structural measurements are presented stereographically in Fig. 39. The pattern shows a wider scatter than in the area to the west, but with broadly similar

Fig. 35. *Folding of the Celsiusberget Group: the upper photograph shows the Raudstupet Formation and the lower is taken in the Norvik Formation.*

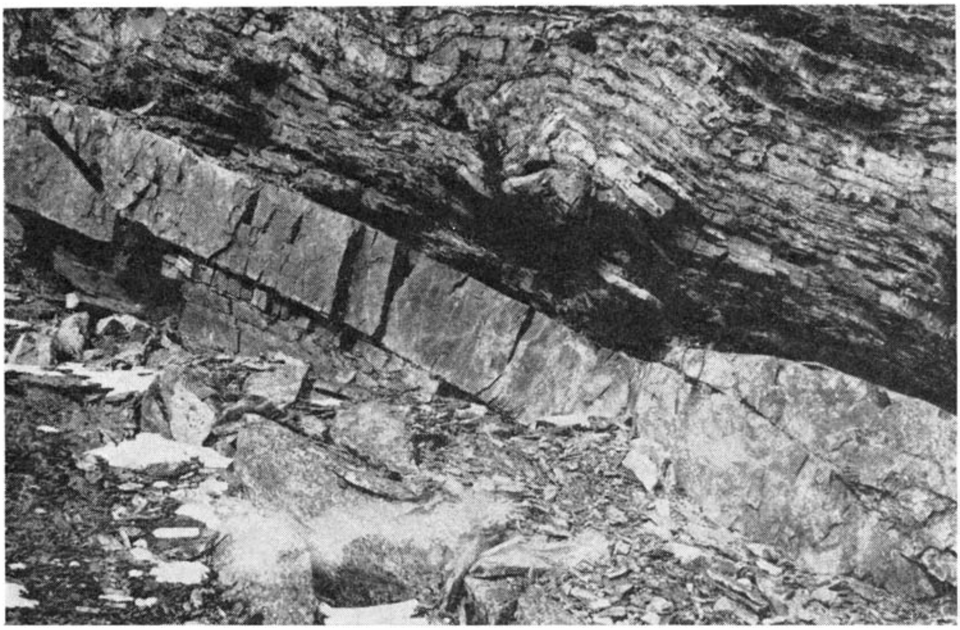


Fig. 36. *Small scale folding in siltstones and thin bedded quartzites passes down into a dislocation in the underlying massive quartzite* (*Norvik Formation*).

Fig. 37. *Boudinage of thin calcareous sandstones in shales of the Kapp Sparre Formation.*

Fig. 38. *Oblique air-photograph looking NNW towards Murchisonfjorden. Faults displace the axis of the Roaldtoppen anticline, sinistrally on WNW and dextrally on WSW striking surfaces.* Photo: Norsk Polarinstitutt.

features, i.e. the folds generally plunge to the SSE and have an axial surface cleavage dipping at medium to high angles eastwards. This comparability suggests a close relationship with the folds of similar style west of Lady Franklinfjorden. However, in Kullingfjellet, minor folds sharing a common axial surface cleavage have been found to vary very much in axial plunge (from S- to steeply N-dipping), a phenomenon not recorded throughout the area to the west. There is insufficient evidence from one day's traverse over Kullingfjellet to assess the pattern of this deformation but it can be concluded that the orientation of the bedding prior to the formation of the major anticline was probably less regular than in the case of the lithologies further west. This might have been caused by earlier folding of the rocks or by the intrusion of the quartz porphyries which occurred before the formation of the anticline.

The S-striking outcrop of the conglomerates in Botniahalvøya is sharply truncated east of Hansøya. They reappear in Gerardodden and may be present in Hansøya separating the volcanic rocks of the Kapp Hansteen Formation from the sediments of the Brennevinsfjorden Formation. This implies a dextral displacement of between two and three kilometres on a WSW-striking high angle fault. In Gerardodden, the pyroclastic rocks and conglomerates, dipping at high angles to the east, do not outcrop south of the central lake and appear to be truncated by a WNW-striking fracture. About half a kilometre to the south of the lake, faults of similar orientation but much smaller displacement are apparent on the oblique air-photographs (one such is shown on the geological map). A sinistral

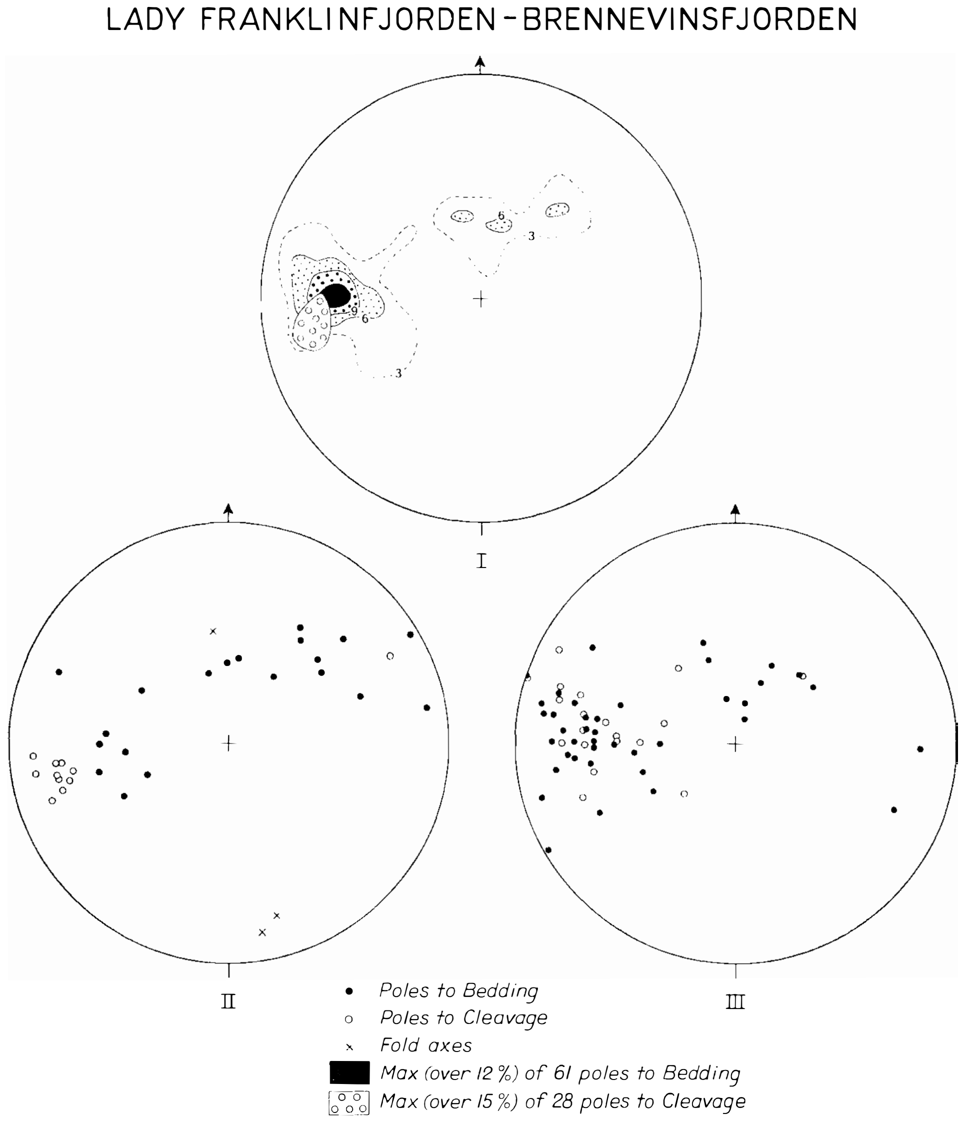


Fig. 39. *Stereographic projection (lower hemisphere equal area net) of bedding, cleavage, and fold axis data from the area between Lady Franklinfjorden and Brennevinsfjorden. I – Bedding and cleavage data from the whole area. II – Gerardodden and Kullingfjellet. III – Botniahalvøya.*

strike-slip movement is inferred, and accounts for the presence of the hinge of the anticline occurring downstrike south of the Gerardodden conglomerates.

On the basis of the comparability of the major fold structures east and west of Lady Franklinfjorden it is concluded that this faulting most probably post-dates the folding in both areas. However, there is no evidence from the west side of Lady Franklinfjorden of similar displacement in any areas to which these faults in Kullingfjellet and Botniahalvøya can be projected. This provides a basis for the extrapolation of the Idunfjellet fault northwards through Lady Franklinfjorden. However, in view of the unconformity between the Botniahalvøya Group and the Murchisonfjorden Supergroup in Rijpdalen, the possibility remains that the faulting of the Botniahalvøya Group may have occurred before the deposition of the overlying rocks.

AREA 3. LAPONIAHALVØYA AND SJUØYANE

The area is generally made up of granites and granite gneisses related, by the early observers, to a basement complex underlying the Hecla Hoek sequence. Kulling (1934), during a brief visit to the head of Brennevinsfjorden, noted that the granite in Kontaktberget intruded the Brennevinsfjorden phyllites and concluded a late Caledonian age for these crystalline rocks. Nevertheless, the study of oblique air-photographs led Sandford (1956) to suggest a marked angular relationship between the S-dipping foliation in the granites south of Sabinebukta and the overlying Hecla Hoek and he inferred unconformity. More recently, Russian investigations (Krasil'ščikov 1965) failed to confirm this S-dipping foliation as the regional orientation in the gneissose rocks, their observations establishing a general Caledonian trend. They claimed support for the Caledonian age of these structures from their c. 400 m.y. K/Ar isotope age-determinations on the granites, these being notably younger than the single Rb/Sr age from Nordkapp of 537 m.y. (Hamilton and Sandford 1964).

Data from the Norsk Polarinstitutt 1957 and 1965 Expeditions were reported by Hjelle (1966), and are supplemented in Part III of this paper. The foliation in the granitic gneisses appears to be comparable in orientation to that in the overlying Hecla Hoek, strikes related to folding about N–S axes dominating. However, contacts between the Botniahalvøya Group and the gneisses and migmatites were not found, the post-tectonic Brennevinsfjorden granite separating the former from the latter in all investigated areas.

The dominant structure of Laponiahalvøya thus conforms to the anticlinal core proposed by Sandford. Foliation orientation in the lowermost structural unit of granites, gneisses and migmatites is controlled by this N–S folding. The intrusion of largely unfoliated granites into the contact between these foliated granitic lithologies and the Botniahalvøya Group obscures the relationship between the two units. It is thought probable, however (Part III), that this contact, prior to the intrusion of the post-tectonic granites, was comparable to that described below from Rijpdalen.

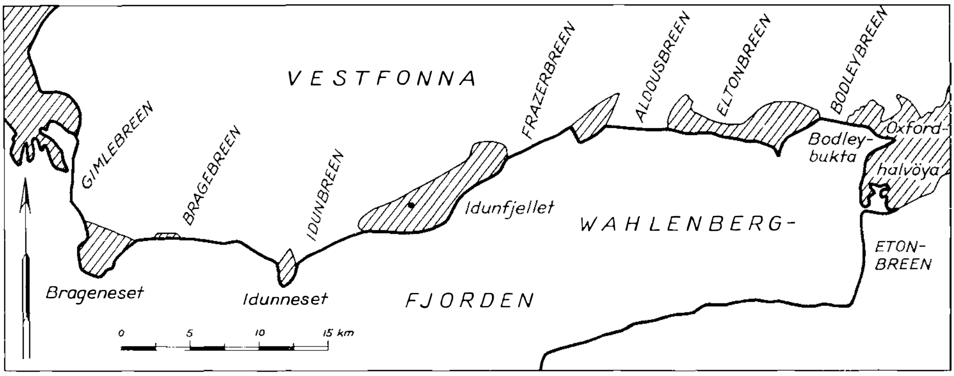


Fig. 40. *Place-names along the north coast of Wahlenbergfjorden.*

AREA 4. THE NORTH COAST OF WAHLENBERGFJORDEN

The area is taken to extend from Brageneset in the south-west of Vestfonna to Bodleybreen in the south-east. The topographic names existing along this coastline are shown in Fig. 40.

The most comprehensive account of the section along this coastline has been given in SANDFORD (1963), being based very largely on observations by J. HOLLIN in 1955 and SANDFORD (1926). In 1957, WINSNES visited the north-east end of the fjord, and whilst his observations in general confirmed those of HOLLIN, he recorded, in addition, the presence of a tillite horizon on the west side of Eltonbreen (WINSNES 1965).

During the summer of 1965, SIGGERUD reinvestigated the isolated outcrops which occur along this southern limit of Vestfonna. His observations generally coincided with those recorded in SANDFORD (1963). Between Idunfjellet and Oxfordhalvøya the stratigraphic relationships proposed by SANDFORD (1963) and WINSNES (1965) for the lithologies recorded along the coast are given support by the new data. Between Idunfjellet and Brageneset, the lithological sequences described by SANDFORD and the new information obtained by SIGGERUD do not afford sufficient evidence in themselves to place the rocks with certainty into either the Franklinsundet or the Celsiusberget Groups, but the former is more probable, the highest unit recognized being the Flora Formation, east of Brageneset. This is in accord with the structural interpretation, being dependent on the projection southwards of the Murchisonfjorden folds, and the evidence from throughout this coastline that the folding generally occurs about N-plunging axes.

An account of the lithologies is given in Part I and there follows here an account of the structure at the different locations along the coast section.

Between Brageneset and Idunneset. – Both Brageneset and Idunneset are composed of post-Carboniferous dolerites. Between them and isolated by the Vestfonna ice, there occurs a small outcrop of quartzites and shales. A detailed discussion of the structure is given in SANDFORD 1926 and 1963 (p. 12, Fig. 2). His faulted syncline east of Brageneset received supporting evidence. However, the inferrence that an anticline with N–S axis is located in the eastern part of the exposure, based on HOLLIN's record of an eighty degree dip ("nearly parallel bedding and cleavage") is doubted. Elsewhere in west Nordaustlandet, in an area of high angle E-dipping cleavage, such an orientation would occur in the slightly overturned western limb of an anticline, the eastern limb being usually of more shallow dip. This interpretation has been used in the construction of the geological map and sections, the main anticline, inferred by SANDFORD, lying to the east of the exposures discussed here.

Idunfjellet. – Hecla Hoek outcrops on the west side of Idunfjellet, predicted by SANDFORD (1963), were found by SIGGERUD. Lithologically they compare most closely with the Franklinsundet Group, and thus contrast with the clastics below the Hunnberg limestones recorded from east Idunfjellet by SANDFORD, and confirmed by SIGGERUD. To account for this difference, the Idunfjellet fault has been inferred. It appears not to displace the overlying Carboniferous.

On the east side of Idunfjellet, the Hecla Hoek structure is dominated by a N-plunging (20^g) syncline, flanked to west and east by subordinate anticlines. South of the Idunfjellet cairn, HOLLIN recorded the axial zone of a subordinate syncline. Though reminiscent of west Nordaustlandet in most respects, these folds in the Idunfjellet area are notable in that they appear to be nearly symmetrical.

From descriptions of the Hecla Hoek lithologies it is clear that the deformation of the units was comparable to that in west Nordaustlandet and east Wahlenbergfjorden, cleavage being conspicuous in the incompetent units and absent in the massive limestones and quartzites. The orientation of the cleavage is of a high angle and, where recorded, is inclined a little to the east.

Between Frazerbreen and Bodleybreen. – Undifferentiated light weathering Roaldtoppen Group carbonate rocks have been recorded in the land area between Frazerbreen and Aldousbreen. They occur in a shallow syncline of uncertain axial direction (probably c. N40^gE). Further east, SANDFORD (1963) and WINSNES (1965) demonstrated the presence of an anticline in the land area east of Bodleybreen, revealing Celsiusberget Group lithologies in the core, overlain by carbonates of the Roaldtoppen Group. In the area immediately east of Aldousbreen and separated from the above mentioned anticline by an unexposed area south of Eltonbreen, carbonate rocks occur again, overlain by shales and a tillite unit. Projection of the recorded dips in these rocks, in relation to the structures to east and west, require the presence of a N-striking fault down the western side of the outcrops and a NNE-striking fault through the unexposed area of raised beaches. The existence of faults of similar orientation is known from other parts of Nordaustlandet, making their inferred presence in this area more probable.

From a synthesis of all the structural data at our disposal, it is apparent that the folding of the Hecla Hoek along the whole north coast of Wahlenbergfjorden occurs about N-trending axes, plunging up to twenty degrees northwards (Fig. 41). Cleavage orientation, dipping at moderate to high angles eastwards, is comparable both to that in the east in the Bodleybukta area and to the west in Murchisonfjorden and confirms the general N–S axial orientation of the folds to which it is related.

Sandford (1963) suggested the possibility that the anticlinal axis passing through Roaldtoppen, south Murchisonfjorden, was represented along the south side of Vestfonna by a similar structure east of Brageneset. He also projected the axis of the Floraodden anticline southwards midway between Idunfjellet and Idunneset. The continuity of these structures through west Nordaustlandet and their relatively constant axial orientation supports their projection southwards, and it is probable that the Roaldtoppen anticline is in fact represented east of Brageneset. No evidence exists at present to suggest that the axial directions in this area deviate more than twenty degrees west of north, and for that reason the Floraodden axis is projected southwards through Idunneset. This projection finds support in the character of the Hecla Hoek sediments of west Idunfjellet which compare most closely with the Persberget Formation.

East of the Idunfjellet fault, the highest stratigraphic levels (Sveanor tillite and ?Kapp Sparre Formations) occur between two faults on the east side of Aldousbreen. To the east of this location the structure conforms to a subordinate anticline in the western limb of the Rijpdalen anticline, complicated by an important fault just east of Bodleybreen. To the west, between Aldousbreen and Idunfjellet, Roaldtoppen Group carbonates occur in a more open synclinal structure with flanking anticlines. Sandford (1963) considered it possible that the axis of the Lovén syncline could be projected southwards towards Eltonbreen. This syncline is cut by a series of faults both in the Lovén peninsula and along the Wahlenbergfjorden coastline and since its axial orientation is uncertain the regional projection of the axis rests only on the occurrence of the highest stratigraphic levels in the area between Eltonbreen and Aldousbreen.

The N-plunging folds of north Wahlenbergfjorden are faced in the north-east

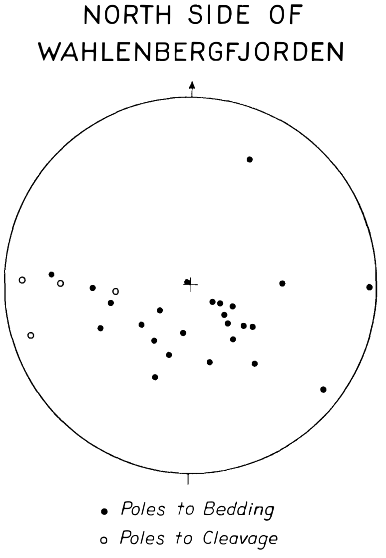


Fig. 41. *Stereographic projection (lower hemisphere equal area net) of the bedding and cleavage measurements from the Hecla Hoek along the north side of Wahlenbergfjorden.*

and north-west by S-plunging structures, requiring that the plunge depression occurring in west Nordaustlandet should extend eastwards through Vestfonna. In the latter part of this description of the Nordaustlandet structure the regional fault pattern is considered, and in the light of this information a line of probable fold depression has been tentatively predicted (Fig. 48). A consideration of the fault displacement along the Wahlenbergfjorden coast is deferred until then.

AREA 5. WEST RIJPFJORDEN

The sediments and low-grade meta-sediments to the west and north-west of the Rijpfjorden granite were shown by NORDENSKIÖLD (1863) to occupy a syncline. This structure was given support by GLEN's 1935–6 observations in the area (summarized in SANDFORD 1950) and by SANDFORD's study of the oblique air-photographs (SANDFORD 1956, the "Lovén syncline").

During 1965, FLOOD carried out a reconnaissance of the area between Planciusbukta and Bengtssenbukta, WINSNES worked in the area south of Bengtssenbukta to the head of Rijpfjorden, and SIGGERUD briefly visited Sabinebukta on the south and south-east sides. This summary of the structure is based on their observations which, in relation to the stratigraphy, are discussed in Part I.

Confirmation was obtained that in general the lithologies in the west along the eastern side of Sabinebukta dip to the south-east, whilst in the east along the west coast of Rijpfjorden the dip is to the west and south-west. However, this simple synformal pattern is disrupted by three major faults, all of which were noted, at least in part, by GLEN. During the topographic mapping of west Rijpfjorden he recorded the presence of a variety of discordant relationships which he attributed to faulting (SANDFORD 1950, p. 477). One of these, apparently separating our Botniahalvøya Group from the Franklinsundet Group, has been mapped during 1965 as an unconformity. Of the others, the following three appear to be the most important. Along the east side of Carolusbukta the SE-dipping Botniahalvøya Group lithologies are in faulted contact with the Franklinsundet Group of similar dip. From western Bengtssenbukta to Planciusbukta there occurs a wedge of Botniahalvøya Group lithologies contained between two faults, the eastern of which has been traced south of Bengtssenbukta and may coincide with a similarly orientated fracture in Rijpdalen. The movement on these faults is considered later.

The Botniahalvøya Group – Franklinsundet Group contact. – North-west of Thank God Bay, WINSNES mapped these two groups and established a discordant relationship between them. The actual contact was not seen but the presence of a quartz pebble conglomerate similar to that in south-west Rijpdalen (see below) at the base of the Persberget Formation, and the absence of any evidence of faulting makes it very probable that this discordant contact is of sedimentary origin.

Within the faulted wedge of Botniahalvøya Group shales and phyllites between west Bengtssenbukta and Planciusbukta a well-developed axial surface cleavage with parallel fine-grained mica crystallization has been recorded; this is notably crenulated. By contrast, within the Murchisonfjorden Supergroup only the typical cleavage has been observed in the incompetent units. On the northeast side of Planciusbukta, steeply dipping "black shales" (SANDFORD 1950) are overlain by basal Franklinsundet quartzites and shales apparently dipping at lower angles to the SW. These observations support the existence of an unconformity between the two groups. However, without a knowledge of the relationship of the secondary structures to the unconformity, the importance of this break in sedimentation is uncertain.

AREA 6. RIJPDALEN–INNVIKA

SANDFORD (1956) summarized what was then known of the geology of this area, describing a symmetrical anticline with a N–S axis through central Rijpdalen, flanked to the east by a syncline, south of Duvefjorden. This syncline was thought to be truncated in its eastern limb (the "Dove Bay Fault"). A pre-Hecla Hoek basement complex was inferred to occur in the core of the Rijpdalen anticline and in Duvefjorden.

The relationships between the lowermost Hecla Hoek lithologies and the metamorphic complex in Rijpdalen were described by WINSNES (1965) as "intrusive". In an accompanying map he showed the Rijpdalen anticline to be flanked to the east by two subordinate synclines and an anticline.

Our investigations have confirmed the existence of the major fold structures (Fig. 42), the Rijpdalen anticline dominating. As described by WINSNES and FLOOD (Part I), the stratigraphic correlation in the eastern and western limbs of the Rijpdalen anticline below the basal Franklinsundet Group quartzites is problematical. In the western limb, a stratigraphic sequence very similar to that recorded in west Nordaustlandet for the Franklinsundet Group, with a prominent quartzite formation at the base, overlies pelites, psammites and some quartzites with a marble unit near the top (including the marbles of Carfax hill, SANDFORD 1926). In the eastern limb, a similar quartzite to that at the base of the Franklinsundet sequence in the west, is overlain by red and green cleaved siltstones and shales. The basal quartzites rest on pelites and psammites intruded by basic rocks. Quartz porphyries are also present, occurring only below the Franklinsundet quartzite. No calcareous rocks have been recorded. In the western limb a quartz pebble conglomerate with a quartzite matrix is present in the base of the Franklinsundet quartzites but a definite, unfaulted contact with the underlying lithologies has not been observed. However, further north, in western Rijpfjorden, similar lithologies occur and the relationship has been described as unconformable. This conclusion is supported in Rijpdalen by the presence of marginally foliated gabbros and quartz porphyries in the Botniahalvøya Group and their absence in the overlying rocks, and is consistent with the structural evidence given below.

Folding in the Franklinsundet and Celsiusberget Groups. – In the western limb of the Rijpdalen anticline the rocks dip at moderate to high angles westwards. Nearly vertical dips are not uncommon but overturning is

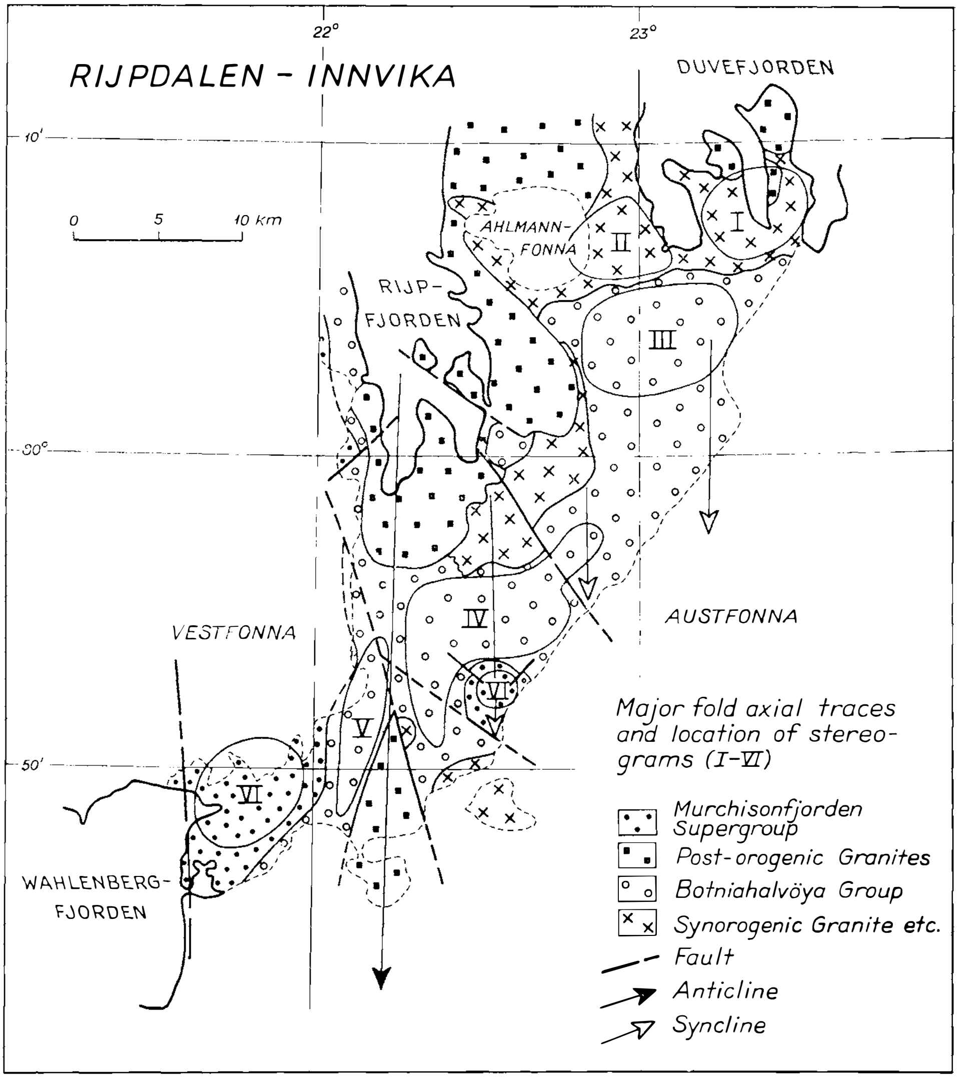


Fig. 42. *Location of the main folds and faults in the Rijpdalen–Innvika area. The stereograms of Fig. 43 have been compiled according to the areas shown here.*

unusual. Minor parasite folds are frequent, and all the argillaceous rocks are well-cleaved, the orientation of this secondary structure being inclined at moderate to high angles eastwards (Fig. 43, VI). Sedimentary structures are well preserved and confirm the stratigraphy. No important secondary structures have been observed apart from this cleavage, jointing and the faulting referred to below.

To the east of the Rijpdalen anticline, the Franklinsundet shales show a well developed cleavage, similarly dipping at a high angle eastwards. Thus the structures exhibited by the Franklinsundet Group and overlying rocks compare as closely as does the stratigraphy to the equivalent lithologies in west Nordaustlandet.

Folding of the Botniahalvøya Group. – The compositional banding in these rocks, identified in most outcrops as bedding, is folded with the formation of a schistosity (or, in the least metamorphosed rocks, a true cleavage) parallel to the axial surfaces of the folds. The minor fold style varies from isoclinal to nearly open (Fig. 44), the tighter folds dominating and accounting for the parallelism or near parallelism of bedding and schistosity in most outcrops. This schistosity is folded by the Rijpdalen anticline (Fig. 42). The minor folds generally plunge to the S. However, in central west Rijpdalen, in the western limb of the Rijpdalen anticline, the axis of these minor folds has been recorded locally to pass through the horizontal to plunge northwards, whilst retaining a constant orientation of the axial surface schistosity.

As noted earlier, the stratigraphy beneath the Franklinsundet quartzites is dissimilar in the two limbs of the Rijpdalen anticline. This difference has been oversimplified on the geological map, being shown to occur along the northward projection of a NNW-striking fault. However, during traverses across central Rijpdalen, no notable changes in lithology were relatable to this fault.

In south-east Rijpdalen, foliated granites and migmatites overlie the pelitic meta-sediments and are separated from them by minor meta-volcanic rocks and a conglomerate. About eight kilometres further north, in central Rijpdalen, the bedding in the pelites and associated concordant quartz porphyries was recorded to dip at higher angles eastwards than the axial surface schistosity. No way-up structures have been recorded in the Botniahalvøya Group. Nevertheless, the two lines of evidence favour the inversion of the Botniahalvøya Group sequence in central and southern Rijpdalen.

Deeper levels of the structure are seen traversing northwards. The contact between the foliated granitic rocks (and augen gneisses) and the meta-sediments is described briefly below, and more fully in Part III. Between this contact and the north-western side of Austfonna a sequence of pelites, quartzites and subordinate amphibolites occurs containing a c. 100 m unit of augen gneiss (Fig. 45). Marbles appear near Austfonna, and the general sequence is thought to be most closely comparable with the meta-sediments in the eastern limb of the Rijpdalen anticline and in Platenhalvøya (Flood and Winsnes, Part I).

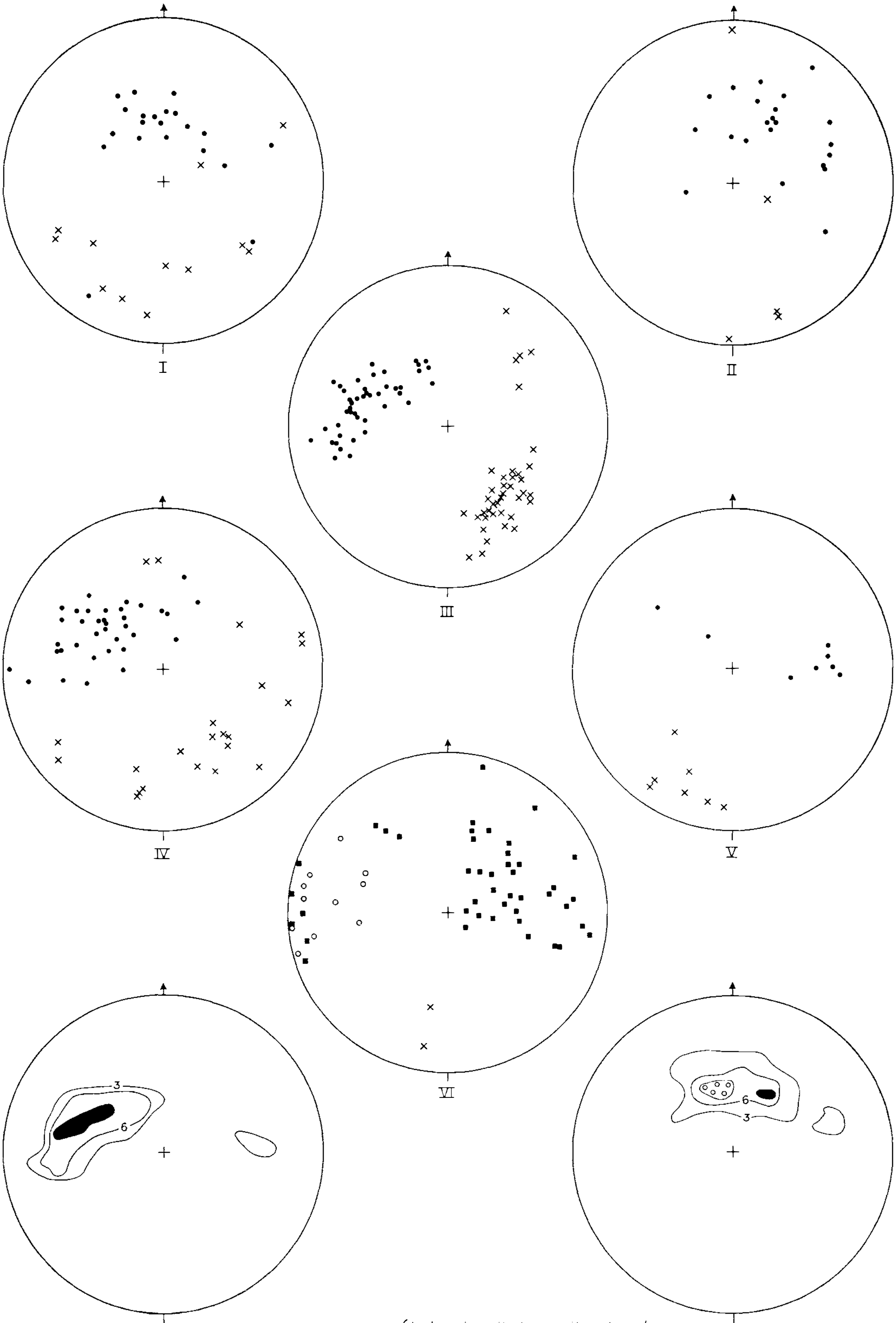
On the basis of these lines of evidence, a major antiformal fold is inferred to have formed in the Botniahalvøya Group prior to the formation of the Rijpdalen anticline. This is shown in the sections of Fig. 30, p. 68, and the relationships are discussed further in the regional synthesis given below.

Contacts between the Botniahalvøya Group and the foliated granites. – The foliated granites (and augen gneisses) are regionally discordant to the compositional banding in the meta-sediments. However, unambiguous evidence of discordance has not been recorded at any of the localities where the

→

Fig. 43. *Stereographic projection (lower hemisphere equal area net) of structural data from the Rijpdalen–Innvika area. The areas to which the stereograms I–VI refer are shown on Fig. 42. VII – All foliation data from the Botniahalvøya Group. VIII – All foliation data from the syn-orogenic granitic rocks, augen gneisses, and migmatites.*

RIJPFJORDEN — INNVIKA



- ● Poles to Foliation — *incl. gneissosity in granites etc. and axial surface schistosity/cleavage in Botniahalvöya Group*
- × Fold axes
- ■ Poles to Bedding
- ○ Poles to Cleavage
- ■ Max. (over 9 %) of 90 poles to Foliation
- ▨ Max. (over 9 %) of 78 poles to Foliation

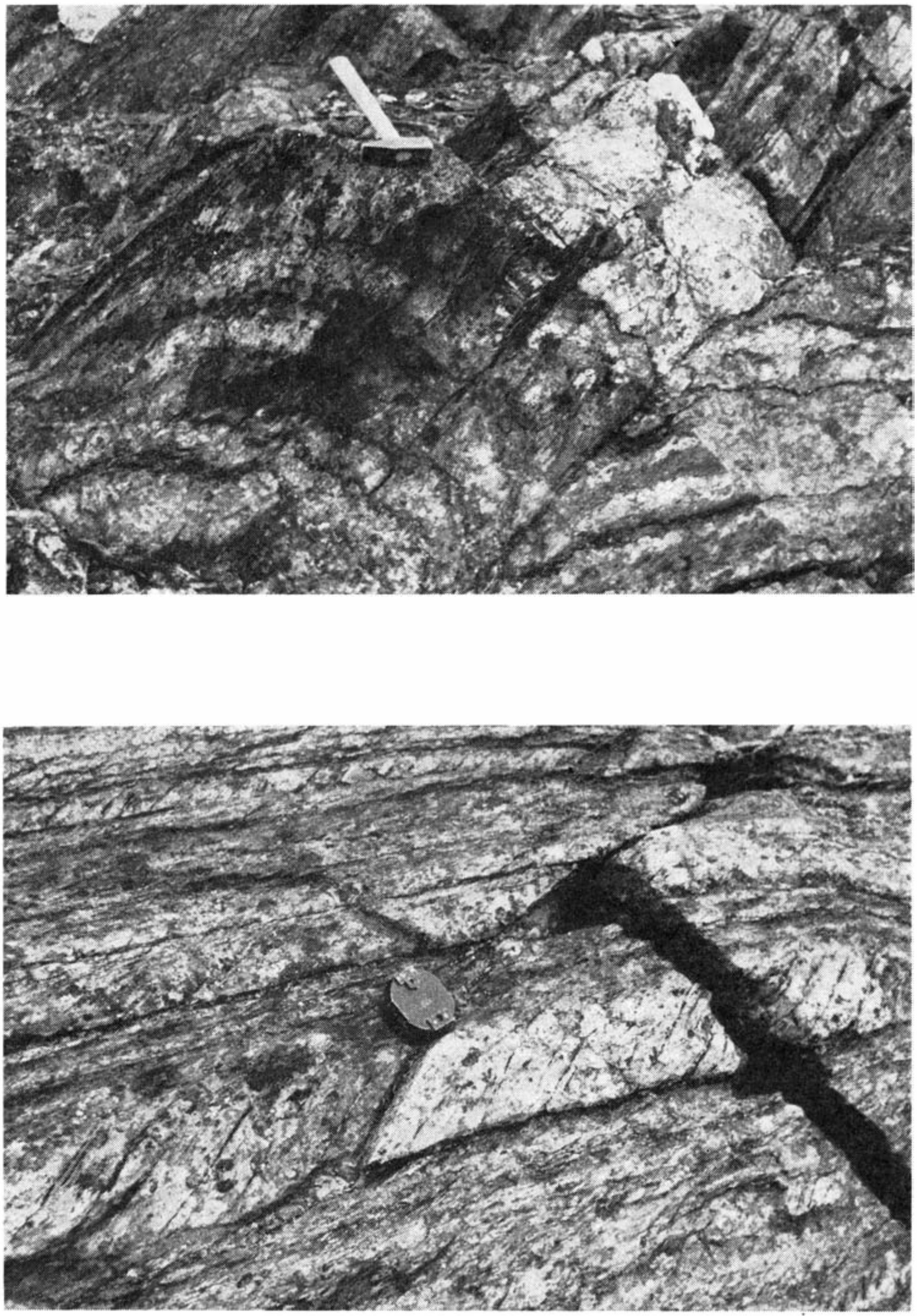


Fig. 44. *Fold, cleavage, and schistosity relationships in the Botniahalvøya Group, c. 20 km south of Innvika.*

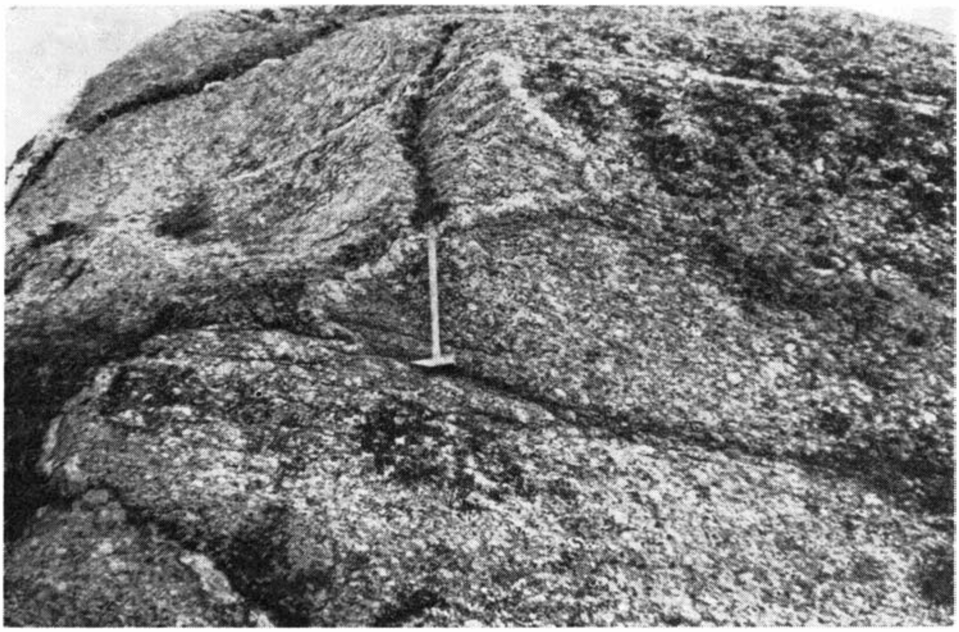


Fig. 45. *The augen gneisses occurring within the Botniahalvøya Group of north-west Austfonna.*

contact was found to be exposed. In general, the prominent schistosity in the pelitic rocks approximately parallels the foliation in the adjacent granites. The schistosity normally obscures the relationship between the bedding and the granites.

In one case, south of Innvika, the axial surface schistosity in the pelites (Fig. 46A) was recorded to penetrate the foliated granites, the schistosity making a small angle with the contact and paralleling the foliation in the granites (Fig. 46B). The foliation in the granite, examined in thin section, appears as a retrogressive gneissosity. Further from the contact this foliation is represented by a mica orientation with xenoliths orientated parallel to this (Fig. 47). The contact pelitic rocks show a marked thermal aureole, described and discussed in Part III.

The sections (Fig. 30, p. 68) illustrate the general relationship between the granitic and the supracrustal rocks, showing the interdigitation of the two. The relationship between the folding in the supracrustal rocks and the intrusion of the granites is considered further in Part III.

Faulting. – The eastern side of the southern extension of the Rijpfjorden granite is truncated by a NNW-striking fault, possibly the southward extension of a similarly orientated fracture in the west Rijpfjorden area. A fault of similar strike passes through Bodleybukta, separating the Flora from the Norvik Formations. Within the fault zone, dolomite masses occur (several tens of metres in diameter) relatable to the Roaldtoppen Group and indicative of greater movement than might otherwise have been inferred.

Faults of high angle orientation striking NW and SW are frequent in the area, and show sinistral (on NW) and dextral (on SW) displacements apparently comparable with those of similar strike in the west Nordaustlandet area.

AREA 7. PLATENHALVØYA

The work of Nordenskiöld in 1861 in the northern part of this inaccessible area was followed by observations by Wright (1939, in Sandford 1950) during a topographic survey of the area. With the aid of oblique air-photographs, Sandford (1956) summarized previous work and presented a tentative synthesis of the structure and stratigraphy of the area. The stratigraphy was interpreted without access to specimens on the basis of experience from further west, and in relation to the structure which was inferred from dips mostly estimated from the air-photographs.

In 1965 Winsnes made a flight reconnaissance of much of Platenhalvøya. He collected specimens and made structural measurements in various parts of the peninsula and these are presented in Fig. 29, p. 66, and discussed in Part I. Also in 1965, Hjelle mapped the northern extension of the Rijpfjorden granite, establishing Wright's earlier observations and confirming the mapping illustrated in Krasil'ščikov et al. (1964), by finding it to extend from Rijpdalen to Vindbukta.

The granitic rocks of the area are described in Part III. The Rijpfjorden granite

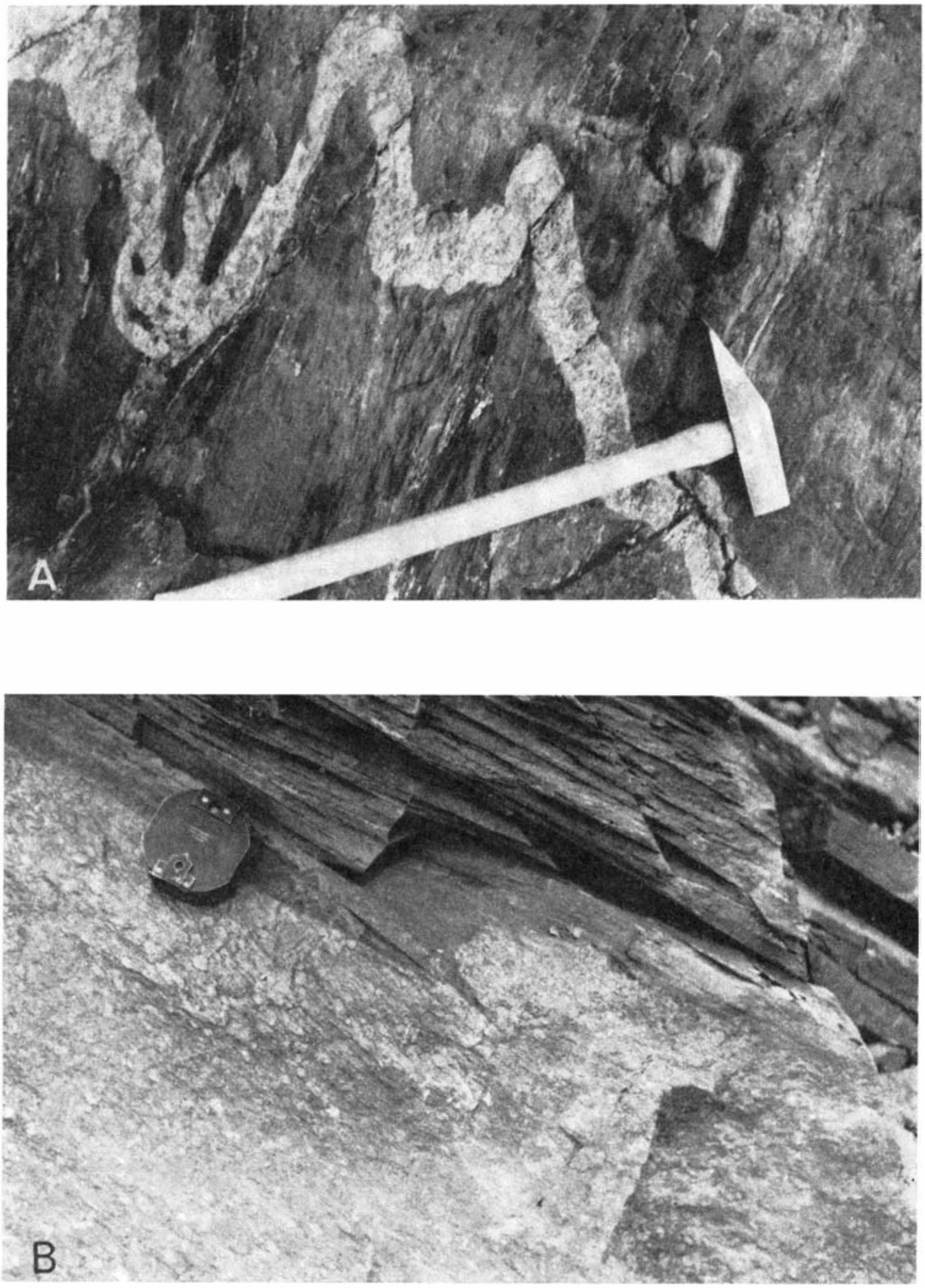


Fig. 46. *The contact between the Botniahalvøya Group and the foliated granitic rocks, south of Innvika. The upper photograph (Fig. 46A) is taken c. 10 m from the contact and shows a pegmatite folded and penetrated by the regional schistosity. The lower photograph (Fig. 46B) shows folding of the sharp contact with the penetrative foliation at a small angle to the contact. Only within c. 1–2 m of this contact are andalusite and staurolite developed in the pelitic rocks.*

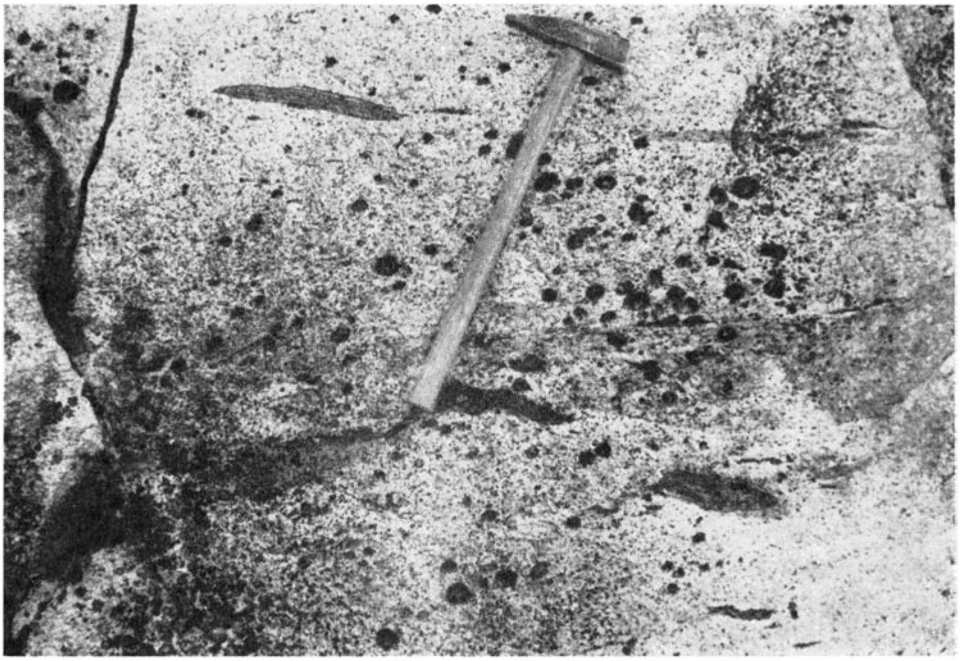


Fig. 47. *Foliated granitic rocks of south Innvika.*

intrudes both the meta-sedimentary rocks of Platenhalvøya and the migmatites and associated foliated granites.

The sedimentary and meta-sedimentary rocks occurring in Platenhalvøya (see WINSNES, p. 64) are comparable with some of those present in the Murchisonfjorden Supergroup and in the Austfonna Formation. The interrelationship of the Platenhalvøya lithologies has not permitted correlation with the established stratigraphy of the Murchisonfjorden Supergroup; correlation with the Austfonna Formation is preferred.

The structure described from the area by SANDFORD after a study of the air-photographs has been assessed by WINSNES as more complex. Phyllitic lithologies near the contact with the migmatites in eastern Mefjordheia, in contrast with the somewhat less recrystallized rocks further north, suggest that the contact relationships are probably comparable with those examined in the Rijpdalen–Innvika area. However, poor exposure did not permit investigation of this in the time available.

The regional structural interpretations for Nordaustlandet considered below (Synthesis) accept correlation of the Platenhalvøya lithologies with the Botniahalvøya Group. This area is particularly worthy of a more detailed survey.

AREA 8. DUVEFJORDEN–LEIGHBREEN

Reconnaissance observations of this area were made by NORDENSKIÖLD (1863, 1866) and supplemented by NATHORST (1910) and WRIGHT (in SANDFORD 1950). The area was reported to be composed of generally flat-lying granites, gneisses and schists. These, like the overlying meta-sediments, were intruded by the red granites (of Rijpdalen granite association).

On three days in 1965, FLOOD and GEE flew east from a camp in Innvika, and visited a variety of localities in the area (see Fig. 5, p. 16). The earlier observations were largely confirmed. Foliations in the granites and in the large supracrustal inclusions generally dip at low to medium angles with a dominance towards SW.

Whereas some of the areas were notable for their granite homogeneity, the rocks showing only a weak foliation, others (the largest have been marked on the geological map) contained extensive supracrustal masses. Descriptions of the lithologies are given in Part III. The supracrustal inclusions may all derive from the Botniahalvøya Group but this is by no means certain. The establishment of the contact between the granitic and migmatitic rocks and the Botniahalvøya Group as intrusive in the area south of Duvefjorden, whilst denying the possibility of unconformity in that area, in no way precludes the presence of pre-Botniahalvøya Group rocks within the mobilized complex east of Duvefjorden.

Synthesis

From the foregoing areal descriptions, it can be concluded that the Nordaustlandet structure is dominated by a Caledonian (in Spitsbergen, a post-Canadian pre-Downtonian) fold system, the fold axes being orientated between N–S and NNW–SSE. In general these folds plunge S in the north and N in the south, with an E–W axis of depression occurring in southern Vestfonna. The folding is accompanied by the presence of a well-developed cleavage in the incompetent units which dips at medium to high angles eastwards throughout the eastern and western areas. This cleavage is approximately axial planar to the folds which in both the Rijpdalen-Rijpfjorden and the west Nordaustlandet areas are notably asymmetric towards the west. In central north Wahlenbergfjorden a more symmetrical attitude has been recorded.

This Caledonian fold system is dominated in the west by the Hinlopenstretet syncline, which separates Ny Friesland from Nordaustlandet. The syncline passes east into the faulted Vestfonna anticline and then into the Lovén faulted syncline. The latter lies to the west of the Rijpdalen anticline which is itself flanked to the east by the Duvefjorden syncline. The axial separation of these major folds is in the order of 20–30 km. Folds of comparable style and wavelength persist westwards into the Ny Friesland Hecla Hoek.

The fold system is cut by faults which can be considered in two main categories. Neither have been recorded to displace the Carboniferous unconformity. One category appears to have formed in response to an E–W-orientated stress system similar to that required for the folding, producing high angle fractures of dominantly strike-slip displacement, dextrally on WSW- and sinistrally on WNW-striking surfaces. In general, displacements are small – a few tens or hundreds of metres, but in Botniahalvøya a minimum movement of two kilometres is demonstrable.

The second category are dominantly strike faults. They are shown on the geo-

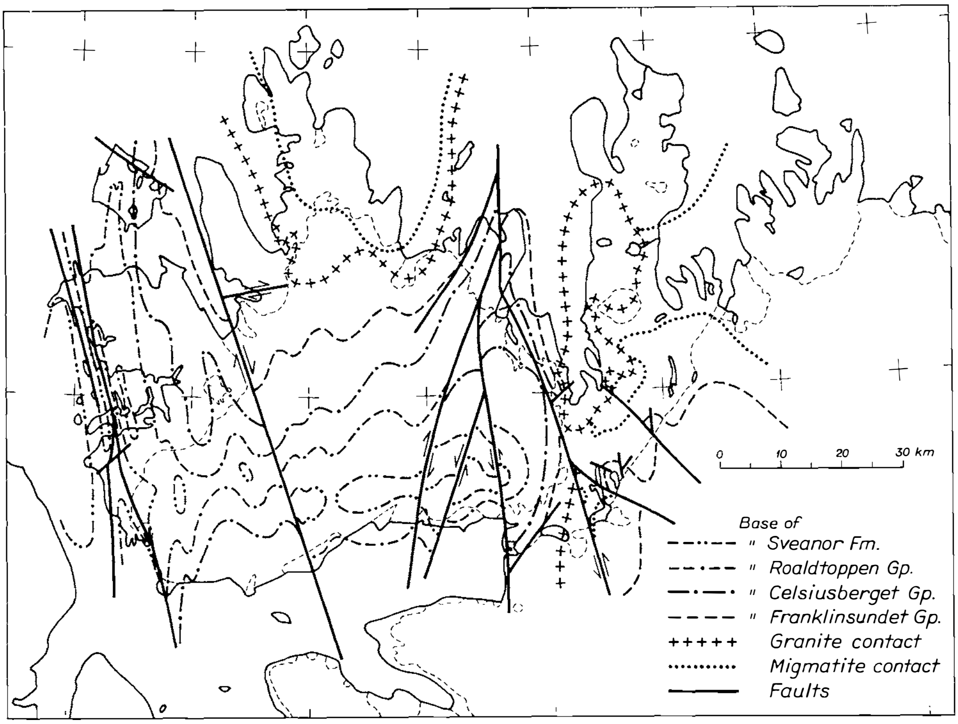


Fig. 48. *Fold and fault pattern of Nordaustlandet.*

logical map and reconstructed in Fig. 48. The latter is a diagrammatic presentation of what is thought to be the most probable solution on the present, limited data. Unlike the two NNW-striking faults of west Murchisonfjorden, which are truncated by the conjugate fault system referred to above, the majority of these faults, striking between NNW and NNE, appear to show some strike-slip movement. For example, the Idunfjellet fault can be most easily explained by inferring a minimum dextral movement of eight kilometres.

We were unable to confirm the presence of the "Dove Bay Fault" (SANDFORD 1956) south of Duvefjorden, there being no displacement of the migmatite contact with the Botniahalvøya Group in this area.

Recently, WILSON (1966) has suggested the possibility that Nordaustlandet might be separated from Ny Friesland by an important N—S fault. Whilst accepting the possibility that fractures similar to those described above, may truncate the Hinlopenstretet syncline, it is clear that none of the present data gives support to his hypothesis. The structure and stratigraphy of Nordaustlandet and Ny Friesland are intimately related and remarkably comparable.

The folding described above affects all the pre-Carboniferous lithologies, with the possible exception of the post-tectonic granites. The latter occur in the cores of the Vestfonna and Rijpdalen anticlines and do not penetrate above the Botniahalvøya Group. In the Murchisonfjorden Supergroup and overlying sediments only folds parasitic to the major anticlines and synclines have been detected. Apparently, these lithologies were undeformed prior to this Caledonian folding.

Unconformably below the Murchisonfjorden Supergroup, the Botniahalvøya Group shows evidence of a more complex pattern of folding. In Gerardodden and central Rijpdalen local variations in the plunge of the fold axes, along with constant orientation of the axial surfaces imply some cross folding prior to the folding about N–S axes. More important is the interdigitation in the Botniahalvøya Group of Rijpdalen of foliated granitic rocks and "tongues" of migmatite. The minor folds related to this infolding of the intrusive rocks carry an axial surface schistosity which penetrates the foliated granites and migmatites and is parallel to their dominant foliation. This foliation is folded by the Rijpdalen anticline and Duvefjorden syncline.

Our observations of the contact between the Botniahalvøya Group and the foliated granites, migmatites and gneisses include no evidence of unconformity.

The isotopic age-determination evidence in relation to this sequence of folding, intrusion and accompanying metamorphism is discussed in Part V. Contact metamorphism of the Botniahalvøya Group occurred during the folding together with the intrusive rocks, and age-determinations effected by this intrusion have yielded ages of 537 and 613 m.y.

Three possible explanations are considered here for the presence of this folding of the Botniahalvøya Group and its absence in the overlying rocks.

1). The deformation was of late Pre-Cambrian age, occurring prior to the deposition of the Murchisonfjorden Supergroup.

2). It was an early phase of the Caledonian orogeny and restricted to the lower part of the geosynclinal pile.

3). It occurred simultaneously with the deposition of the Murchisonfjorden Supergroup.

1). Deformation previous to Murchisonfjorden Supergroup deposition. – Unconformity exists between the Murchisonfjorden Supergroup and the underlying rocks, being marked by a quartz pebble conglomerate at the base of the Persberget Formation in Rijpdalen and west Rijpfjorden. The lithological data and our stratigraphic correlations suggest that this unconformity coincides precisely with a change in structural condition, the folded secondary structure (schistosity and parallel cleavage) being present only below the Persberget Formation. Only below the unconformity has schistosity been recorded to parallel bedding. Some isotopic age-determinations, apparently related to the time of intrusion of the granitic rocks and migmatites, are unambiguously pre-Caledonian.

2.) Caledonian deformation. – The Murchisonfjorden Supergroup in south-west Rijpdalen is separated from the underlying rocks by a low angle dislocation, the extent of which is not known. If this fault was of greater importance than has been recognized in the field, and, passing close beneath the base of the Persberget Formation, arches back eastwards over the Rijpdalen anticline to separate the two groups on the eastern side of the structure, then the other structural and stratigraphical data might be compatible with a Caledonian age for the early folding. Nevertheless the age-determinations remain problematical. On this hypothesis, they would either be excessively in error, having been enriched in daughter isotopes during or after intrusion of the granitic rocks, or related to relics of an incompletely mobilized basement to the Hecla Hoek sequence.

3). Deformation during Murchisonfjorden Supergroup deposition. – The oldest existing pre-Caledonian age determinations apparently coincide with the time of deposition of the Murchisonfjorden Supergroup, assuming an age of c. 570 m.y. for the base of the Cambrian. If this relationship, now under investigation, was confirmed, deposition of the post-Botniahalvøya Group sequence would have had to accompany the intrusion of the migmatites and granitic rocks during folding of the Botniahalvøya Group. The lack of evidence of deformation of the Murchisonfjorden Supergroup prior to the formation of the fold structures affecting the whole late Pre-Cambrian and Lower Palaeozoic sequence, implies that tangential compression cannot have been responsible for the early deformation required by this hypothesis. Such a solution appears possible only if the intrusion of the granitic rocks occurred in response to gravitational forces alone, the accompanying deformation being localized to the vicinity of the intrusive rocks.

The third hypothesis requires substantial new age-determination data and its consideration is deferred until these are available. The apparent lack of major unconformity within the Hecla Hoek sequence in Ny Friesland (HARLAND et al. 1966) lends support to this and the second hypothesis. The latter is compatible with less of the available data than hypothesis 1). Therefore hypothesis 1) is preferred here and the sections in Fig. 30 have been drawn in accordance with this interpretation.

A final solution to this problem is clearly fundamental to the understanding of the deformation affecting the Svalbard Lower Palaeozoic and late Pre-Cambrian successions. The Pre-Cambrian hypothesis favoured here, attributes the Caledonian folding to pressure transmitted in a crystalline complex of migmatites, foliated granites and Botniahalvøya Group lithologies, unconformably overlain by an autochthonous blanket of sediments of late Pre-Cambrian and Cambrian age. This position is very close to that of SANDFORD (1956, p. 358–9), and implies basement control of the Caledonian folding. The third hypothesis has the same implications. The second hypothesis lacks direct basement control, the mobile conditions exhibited by the migmatites and associated rocks resulting in thrusting of the higher stratigraphic levels, rendering at least a part of the sequence allochthonous.

It is important to reinvestigate the central parts of Nordaustlandet including Platenhalvøya. Without ready access to these areas the problem is being investigated by isotopic age-determination methods.

Part III.

Migmatite and syn-orogenic granite rocks

Introduction to Part III

Migmatite, foliated granite, and gneisses occur in Nordaustlandet and north-west Spitsbergen. In both areas they were originally interpreted as forming part of an Archaean basement complex on which the Hecla Hoek sediments were deposited (NORDENSKIÖLD 1863, 1875, NATHORST 1910). NATHORST, however, stated that his view was entirely based on the petrographical composition of the rocks and that a younger origin of the rocks could not be wholly precluded.

Due to easier accessibility, investigation and discussion of the basement concept first arose in north-west Spitsbergen (see summary in GEE and HJELLE 1966). After demonstrating transitional relationships between the granitic rocks and the Hecla Hoek, HOLTEDAHL (1914, 1926) reinterpreted the area as a belt of Caledonian mobilization and intrusion.

In Nordaustlandet, SANDFORD (1926) originally was inclined to favour a similar interpretation, but after study of air-photographs and samples, and observations from the Glen Expedition of 1935, he reconsidered his view (1950), favouring the rocks to be part of a gneissic core, older than the Hecla Hoek sediments and possibly of Archaean age.

HAMILTON and SANDFORD (1964) obtained both Caledonian and older ages from Nordaustlandet, thus suggesting at least remnants of a Pre-Cambrian metamorphism. WINSNES (1965) reported intrusive relations between the granitic rocks and the Hecla Hoek complex in Rijpdalen. However, considering the occurrence of granitic boulders within the Sveanor tillite, he commented: "..., it is logical to assume that Archaean rocks belonging to the Barents Shield might exist in the area."

Contemporaneously KRASIL'ŠČIKOV (1965) stated that old crystalline rocks unaffected by the Caledonian orogeny had not been observed in Nordaustlandet.

HARLAND et al. (1966) reviewed the evidence from Nordaustlandet in relation to Ny Friesland and referred the whole of the migmatite, gneiss and foliated granite areas to the "Lower Hecla Hoek".

During the mapping of these rocks in 1965, HJELLE concentrated his investigation in the Laponiahalvøya-Sjuøyane area, whilst FLOOD and GEE worked in the Duvefjorden area and eastwards. Part III is therefore presented as two separate chapters based on this geographical division.

The use of the term syn-orogenic in some areas, as in central Laponiahalvøya with its often slightly affected rocks, may raise discussion. The vaguely defined and only erratically traced transition between undoubtedly syn-orogenic migmatites and less affected rocks seem, however, to justify the use of this term, at least at this stage of investigation.

The Laponiahalvøya and Sjuøyane area

BY

A. HJELLE

GENERAL

The rocks in this area normally are coarse-grained, of grey colour, with a hypidiomorphic to porphyritic texture, and a slight foliation, carrying phenocrysts of potassium-feldspar and plagioclase (Pl. I, No. 1, and Fig. 49). The average composition is shown in Table 4, No. 1, and three new analyses are given in Table 5 (65 Hj. 99, 103 and 111). KRASIL'ŠČIKOV (private comm.) reports that there is a fairly good correspondence between the average chemical analyses of these rocks (HJELLE 1966) and recent unpublished analyses of comparable specimens from the same area collected by Russian expeditions.

The potassium-feldspar megacrysts, which in general are microperthithic, often show microcline twinning; occasionally, the plagioclase rims typical of rapakivi granite are present (see lower right part of No. 1, Pl. I). Inclusions of altered plagioclase are common, the largest of these having the same composition as the plagioclase of the groundmass.

The quartz often has a strained appearance, with rather intense undulatory extinction, especially in larger grains. Veins of fine-grained quartz often transgress plagioclase, potassium-feldspar, and also the larger quartz grains, thus indicating two generations of quartz.

The plagioclase ranges in composition from c. An 20 to 40, with An 28 as an average of the 10 specimens examined. No systematic variations in the An con-

Fig. 49. *Coarse-grained quartz monzonite, Ekstremfjellet (south of Ekstremhuken). At the top is a trig.point after the arc of meridian expedition, 1901. In the background Sjuøyane.*

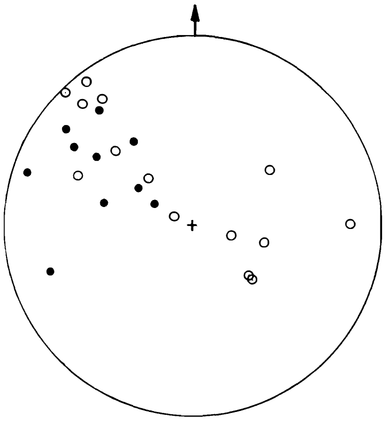


Fig. 50. *Poles to foliation, lower hemisphere.*
○ – *Quartz monzonite at Laponiahalvøya and Sjuøyane.*
● *Brennevinsfjorden granite.*

tent of plagioclases from different localities have been found. The inner parts of the plagioclase grains are often clouded by sericite and occasionally clino-zoisite, while myrmekitic intergrowths are common in the margins near the potassium-feldspar.

Biotite mostly occurs associated with muscovite, sphene, apatite, zircon, and ores. It normally is pleochroic with X= pale yellow, Y = Z-reddish brown to dark brown. $n\gamma \sim 1.655$, $n\gamma \div n\alpha \sim 0.06$. The biotite is often partly altered to chlorite along its cleavages and margins and may also contain grains of epidote.

More than two thirds of the muscovite occurs as sericite in plagioclase and the remainder is commonly associated with biotite.

The rather incomplete structural observations from the area show a general trend of foliation towards the NNE, the observations being plotted in Fig. 50. It is not possible to draw definite conclusions from the diagram, however, a regional fold axis with slight plunge towards the NNE is possible.

Dislocations accompanied by shearing and granulation have been recorded and the most prominent marked on the map. The age and directions of movements are uncertain; the continuation of the dislocation lines into the Brennevinsfjorden granite, however, indicate a relatively young age.

CENTRAL LAPONIAHALVØYA–SABINEBUKTA

In the western and southern parts of Laponiahalvøya a homogeneous quartz monzonite dominates, showing only few inclusions and slight gneissosity. Although observations from parts of eastern Laponiahalvøya are lacking, there seems to be a relatively smooth transition between the homogeneous quartz monzonite and the eastern more migmatitic type, they show close similarities, both petrographically and chemically. No marked difference in age between the Brennevinsfjorden granite and the quartz monzonite has yet been found. This is consistent with the similar ages obtained by KRASIL'ŠČIKOV both on "coarse grained biotite rapakivi granite" (= quartz monzonite) and "medium grained biotite granite" (= Brennevinsfjorden granite).

Table 4.

Average compositions of the main types of granitic rocks in Nordaustlandet. The numbers are as in Pl. I.

C = Chemical analyses (from Table 5).
A = Approximate chemical analyses calculated from mode (HJELLE 1966, p. 8).

1: Quartz monzonite rocks at Laponiahalvøya and Sjuøyane. Average of 11 specimens (3C+8A).
2: Brennevinsfjorden granite. Average of 6 specimens (2C + 4A).
3: Rijpfjorden granite. Average of 10 specimens (2C + 8A).
4: Aplite dykes. Average of 6 specimens (6A).
5: Quartz monzonite rocks, Ahlmannfonna–Duvefjorden. Average of 7 specimens (7A).

	1	2	3	4	5
Quartz	28.5	34.5	32.9	31.8	28.2
Potassium-feldsp.	31.5	34.4	26.9	25.5	33.1
Plagioclase	24.6	16.6	27.4	31.2	21.6
Muscovite	4.1	8.7	9.6	8.4	5.0
Biotite	9.6	4.3	1.8	1.6	6.8
Chlorite	0.5	0.1	0.5	0.4	3.1
Epid., cl.zois.	0.1	0.7	0	x	0.2
Apatite	0.2	0.1	0.2	0.1	0.4
Sphene	0.1	0.2	x	x	0.1
Ore mins.	0.3	0.2	0.4	0.5	1.1
Garnet	0.1	0.1	x	x	0
	99.6	99.9	99.7	99.5	99.6
% An in plag.	29	10	8	12	24
SiO_2	70.1	74.6	73.4	73.0	67.7
Al_2O_3	14.9	13.9	14.8	15.0	14.7
Fe_2O_3	0.5	0.4	0.4	0.7	1.4
FeO	2.4	1.0	0.7	0.5	3.2
MgO	1.0	0.4	0.3	0.3	1.1
CaO	1.6	0.7	0.7	0.9	1.7
Na_2O	2.7	3.0	3.4	3.6	2.5
K_2O	5.5	5.2	5.2	4.9	5.8
H_2O	0.7	0.7	0.7	0.6	0.7
P_2O_5	0.1	0.1	0.1	x	0.2
TiO_2	0.4	0.3	0.2	0.1	0.6
	99.9	100.3	99.9	99.6	99.6
al	42.8	48.1	50.0	48.8	39.0
fm	19.1	10.6	7.9	7.6	24.3
c	8.2	4.4	4.3	7.1	9.1
alk	29.9	36.9	37.8	36.5	27.6
si	341	439	421	403	306
k	0.57	0.53	0.50	0.48	0.60
mg	0.38	0.35	0.31	0.31	0.29

Table 5.

Chemical analyses of granitic rocks in Nordaustlandet.

65 Hj. 99: Coarse-grained quartz monzonite, Laponiahalvøya (80°19′40″N, 20°3′E).
65 Hj. 103: —»— —»— —»— (80°23′55″N, 19°52′E).
65 Hj. 111: —»— —»— Sjuøyane (80°39′20″N, 20°34′E).
65 Hj. 100: Granite, Brennevinsfjorden (80°10′45″N, 19°53′E).
62 Gj. 114: » —»— (80°19′N, 19°45′E).
57 Ws 71: » Rijpdalen (79°46′50″N, 22°14′E).
65 Hj. 166: » Rijpfjorden (80°0′5″N, 22°41′E).

	65 Hj. 99	65 Hj. 103	65 Hj. 111	65 Hj. 100	62 Gj. 114	57 Ws. 71	65 Hj. 166
SiO_2	71.9	70.8	71.3	78.4	76.6	73.6	72.9
Al_2O_3	13.8	14.7	14.4	12.2	12.6	15.0	14.5
Fe_2O_3	0.5	0.4	0.4	0.5	0.5	0.4	0.4
FeO	2.4	2.0	1.9	0.7	1.1	0.5	0.9
MgO	0.7	0.7	0.6	0.1	0.2	0.1	0.3
CaO	1.6	1.4	0.9	0.2	0.4	0.5	0.7
Na_2O	2.6	2.7	2.7	2.6	2.8	3.8	3.1
K_2O	5.3	5.0	5.8	4.6	5.2	4.7	5.6
H_2O	0.7	1.2	1.1	0.9	0.8	1.0	0.9
P_2O_5	0.12	0.13	0.13	0.17	0.11	0.27	0.20
TiO_2	0.46	0.36	0.37	0.08	0.10	0.12	0.22
CO_2	0.02	0.09	0.02	0.01	0.02	0.02	0.06
MnO	0.04	0.04	0.02	0.02	0.03	0.02	0.02
BaO	0.08	0.09	0.08	<0.01	0.01	0.02	0.03
	100.22	99.61	99.72	100.48	100.47	100.05	99.83
al	42.5	45.6	45.8	51.9	48.3	51.9	49.1
fm	17.7	15.9	15.3	7.5	10.2	5.0	8.5
c	8.8	7.7	5.1	1.5	2.7	3.1	4.2
alk	30.9	30.8	33.9	39.1	38.8	40.0	38.2
si	376	372	384	561	494	433	419
k	0.57	0.55	0.58	0.54	0.55	0.45	0.54
mg	0.31	0.34	0.33	0.10	0.20	0.13	0.29

Analyst: B. ÅKERLUND, Sveriges Geologiska Undersökning, Stockholm.

Near the granite, around Zeipelbukta, a rock of porphyritic appearance occurs in several places. It contains prominent bluish quartz grains of rounded shape with max. size of c. 20 mm, slightly rounded grains of potassium-feldspar with max. size of 40 mm, and some oligoclase with max. size of c. 30 mm, all embedded in a medium grained matrix consisting essentially of quartz, sericitized plagioclase, and biotite. The large grains of quartz and potassium-feldspar are surrounded by a 0.5-3 mm rim of myrmekite, and the oligoclase show some sericitization, especially in the outer parts. The pronounced rounded shape of the large quartz grains, the reaction rims and the relatively calcic plagioclase (An 25–30), suggest the rock to be parts of the quartz monzonite which were incompletely assimilated during the intrusion of the Brennevinsfjorden granite.

EKSTREMHUKEN-NORDKAPP-SJUØYANE

Traversing from western and central Laponiahalvøya towards the north-east, inclusions and gneissic structures seem to be more common in the quartz monzonitic rocks. Specimens collected at Vesle Tavleøya by HOEL's expedition of 1923, show migmatite gneiss features and imprints of extensive shearing and recrystallization. The modal composition of the migmatite metatect does not differ much from the average quartz monzonite rock for the whole area (Table 4, No. 1) except for some more plagioclase, less potassium-feldspar and a relatively higher accessory content of garnet and sillimanite. Similar rocks were observed by GJELSVIK in 1962 west of Ekstremhuken and by HJELLE in 1965 on the north and east sides of Chermsideøya. In the northern part of this island banded gneisses occur with compositions ranging from granite to amphibolite.

Common mineral associations in rocks from the Ekstremhuken–Nordkapp–Sjuøyane area are:

In quartz monzonite, gneiss, migmatite: quartz-microcline-plagioclase (oligoclase-andesine)-biotite-muscovite-almandine-sillimanite.

In mica schist inclusions: quartz–plagioclase (albite) –biotite–almandine.

In amphibolitic inclusions: quartz-plagioclase (oligoclase-andesine)-hornblende-almandine.

In calcareous inclusions: quartz–calcite–diopside–wollastonite.

The gneisses often contain lenses of tourmaline-bearing muscovite pegmatite. The latter is probably related to adjacent two-mica granite aplite intrusions which can be seen on the north cliff of Nordkapp. BISSET (1930) also described rocks from Chermsideøya, where he found two-mica granites with inclusions of mica schist, partly containing tourmaline. Pegmatite veins were reported to be prominent, some of them several metres in width. This corresponds well with our later observations on the north and east sides of the island. Other localities of tourmaliniferous rocks were mentioned by NORDENSKIÖLD (1863) and include Castrénøyane (south-east of Nordkapp), Ekstremhuken and south-west Sjuøyane. In his field notes from 1962, GJELSVIK has recorded tourmaliniferous rocks from west Chermsideøya and from the west side of Ekstrembukta (west of Ekstremhuken). Both albite-muscovite-tourmaline pegmatite with small amounts of columbite and pyrochlore, and tourmaline-biotite schist were represented. At Kontaktberget, tourmaline–bearing quartz veins occur near the contact between the Brennevinsfjorden granite and the older supracrustal rocks.

In the eastern area of syn-orogenic rocks, tourmaline-bearing muscovite pegmatite has been found south of Duvefjorden. In this area the gneissic rocks often are penetrated by minor intrusions of Rijpfjorden granite and pegmatite (Fig. 51) with prominent muscovite.

At Beverlysundet, WINSNES (field notes and collections, 1957) found metasedimentary rocks of both quartzite and mica schist type, the latter carrying large garnets (c. 1 cm size) near the borders of the inclusion. GJELSVIK mentions garnetiferous biotite schist and amphibolite rocks from near the watershed east of Zeipelbukta.

Potassium-feldspar porphyroblastesis has transformed some inclusions to para-augengneisses. The increase in size of the porphyroblasts towards the border suggests

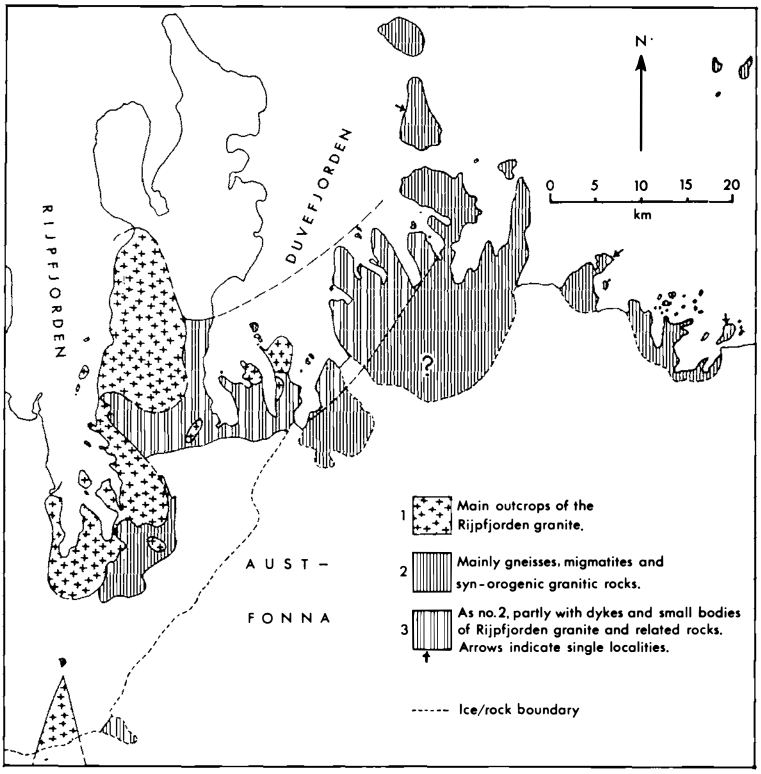


Fig. 51.

that the surrounding granitic material was the principal source of potassium. Fig. 52 shows the modal composition of a 40 mm section of the inner part of a mica schist inclusion which has been feldspathized marginally. Quartzitic inclusions are also frequently recorded, as lenses and boudinaged bands. One typical specimen was point counted in thin section, giving an approximate composition of: 65% quartz, 35% epidote, 5% sphene + garnet + amphibole + calcite, suggesting an impure lime-sandstone as the primary rock. Near the border to granitic gneiss, some plagioclase occurs at the expense of epidote.

Summarizing the observations mentioned above, we thus see that quartz monzonitic rocks with considerable amounts of supracrustal inclusions and at some places with transitions into migmatitic gneiss, occur in north-east Laponiahalvøya and the adjacent islands. In the investigated areas the meta-supracrustal rocks which include mica schist, amphibolitic and quartzitic rocks and banded gneissic rocks, seem to have their greatest extension on Chermsideøya, at Beverlysundet, and on the west side of Ekstrembukta.

Minor intrusions of muscovite granite, two-mica granite and tourmaliniferous, muscovite pegmatite are common both in north-east Laponiahalvøya and in the Duvefjorden area, and the inclusions of mica schist often carry prominent muscovite and megascopic garnet and tourmaline. The tourmaline-bearing pegmatites and the frequent tourmalinization of the synorogenic rocks and their inclusions

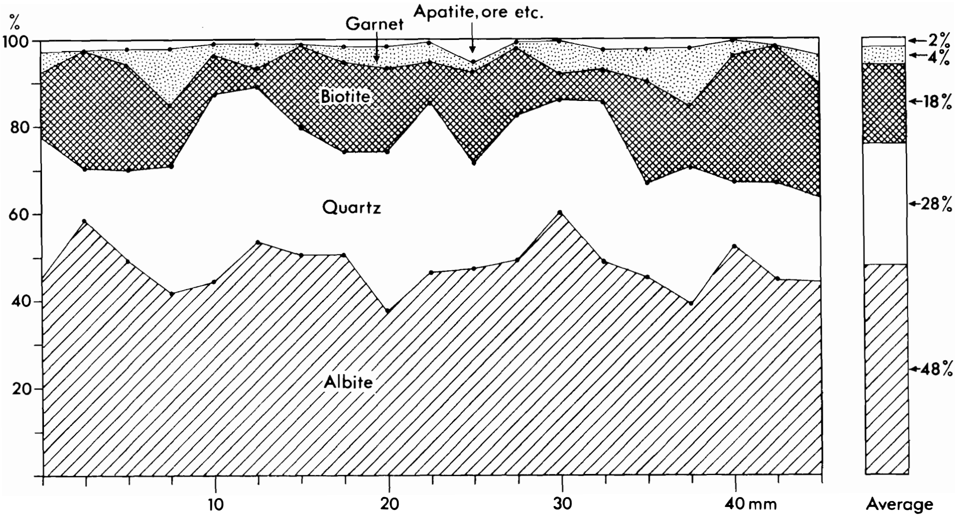


Fig. 52. *The modal composition of the inner part of a mica schist inclusion in quartz monzonite, Laponiahalvøya. Based on point counting every 2 mm, the "counting lines" being parallel to the visible layering. Thin section size: 20 × 45 mm.*

point towards a pneumatolytic origin, possibly connected with the intrusions of the late or post-orogenic granites. Orbicular concentrations of tourmaline, possibly segregations within the granite, occur also in some parts of the Brennevinsfjorden granite (p. 124).

COMPARISON WITH THE EASTERN AREA

The quartz monzonite/migmatite rocks around and east of Duvefjorden are described in more detail below by Flood and Gee (p. 105). However, a brief description of some rocks from the western part of this area may be useful here for comparison with the syn-orogenic rocks in the Laponiahalvøya-Sjuøyane area.

Relatively coarse-grained, in part gneissic rocks of quartz monzonitic composition carrying supracrustal inclusions occur as vaguely defined outcrops both within the Rijpfjorden granite and just east of the granite. The general character of those outside the granite (Pl. I, No. 5) shows many similarities to the quartz monzonitic rocks in the Laponiahalvøya-Sjuøyane area. The supracrustal inclusions in the two areas are also comparable; near the Rijpfjorden granite, which cuts the quartz monzonite gneiss, the latter carry inclusions usually of mica schist. Amphibolite and marble/skarn inclusions prevail east-south-east of Mefjordheia.

Within the Rijpfjorden granite the quartz monzonitic rocks often give the impression of being large xenoliths "soaked" in the granite.

Towards and around Duvefjorden the conditions are different, as intrusions of Rijpfjorden granite type occur more sporadically. The syn-orogenic rocks may, however, carry considerable amounts of muscovite, both in the xenolithic rocks mentioned above and in rocks outside the main Rijpfjorden granite. The muscovite was apparently developed during the intrusion of the Rijpfjorden muscovite granite by introduction of material from this, and partial refusion and recrystallization of the older rocks.

The general impression is, however, that although geographically divided, syn-orogenic rocks of the Laponiahalvøya-Sjuøyane area and those east of the main Rijpfjorden granite show so many relations in common that there is little doubt they are parts of the same complex.

The Rijpdalen–Duvefjorden–Leighbreen area

BY

B. FLOOD and D. G. GEE

The main part of the migmatites and syn-orogenic granites of this area occur east of Ahlmannfonna. They stretch southwards into Rijpdalen. In addition they occur beside south-west Austfonna (east of Wahlenbergfjorden) and in a narrow strip south-west of Botnvika. Fig. 53 illustrates these areas of occurrence, and shows those localities that are described in greater detail below.

METAMORPHISM OF THE BOTNIAHALVØYA GROUP

Outside the contact area with the syn-orogenic granites and migmatites, the Botniahalvøya Group lithologies show regional recrystallization stable to chlorite and muscovite in the pelitic and psammitic rocks and chlorite-epidote-albite

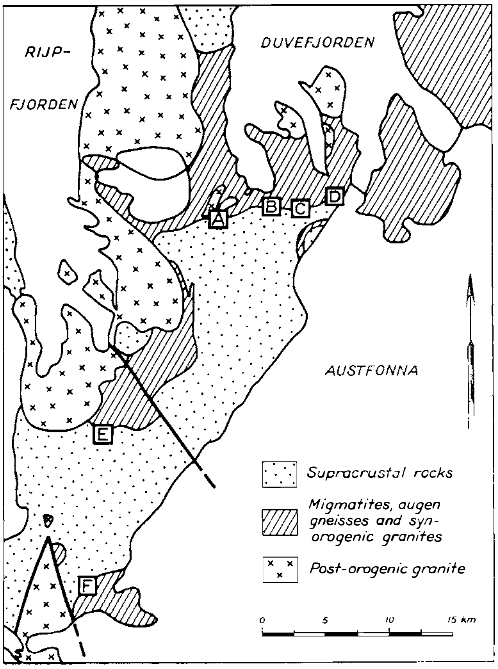


Fig. 53. *Location of those contacts between the Botniahalvøya Group and the migmatites that are described in the text.*

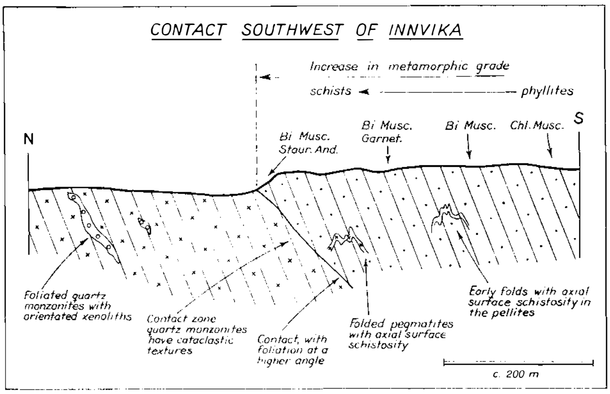


Fig. 54. *A diagrammatic summary of the contact relationships south-west of Innvika* (*position A on Fig.* 53).

assemblages in the meta-volcanic rocks. The phyllosilicates usually are oriented parallel to the regionally developed schistosity (see Part II). However, variation occurs in the development both of the preferred phyllosilicate orientation and a crenulation of this structure. This accounts for the use of the terms phyllite and shale within this group of rocks (see also Sandford 1950, p. 466).

The meta-sediments and meta-volcanic rocks generally show relic primary textures. This is also the case with the meta-gabbros and meta-porphyries, intruded into the Botniahalvøya Group before or at a very early stage of the deformation.

CONTACT RELATIONSHIPS

The contact between the Botniahalvøya Group and the granites and migmatites has been traversed in several localities, and has been described in general in Part II. In the vicinity of the contact the low grade assemblages in the Botniahalvøya Group give way to biotite and, in most recorded cases, to garnet-bearing schists, with hornblende appearing in the basic rocks. The actual contact with the granitic rocks may be sharp, or transitional over a distance of up to c. 100 m. Whilst these granitic rocks and migmatites generally underly the Botniahalvøya Group, there are occurrences south-west of Austfonna, south-west of Botnvika, and east of the head of Rijpfjorden where they appear as wedges interdigitated with the supracrustal rocks.

Some of the contact relationships are described below.

A. South-west of Innvika. – The relationships at this sharp contact are illustrated in Fig. 54. About five hundred metres from the contact (dipping at c. 40^{g}S) the chlorite-muscovite bearing assemblages (Fig. 55A) give way to biotite-muscovite schists. Within a hundred metres of the contact macroscopic garnet has been recorded (Fig. 55B); occasional quartz lenses are present, lying in the schistosity and these may be feldspathic. Up to about fifty metres from the contact occasional pegmatites have been recorded, folded and penetrated by the axial surface schistosity (Fig. 46A). The immediate contact zone (two to three metres) carries staurolite-andalusite-biotite-muscovite-quartz assemblages.

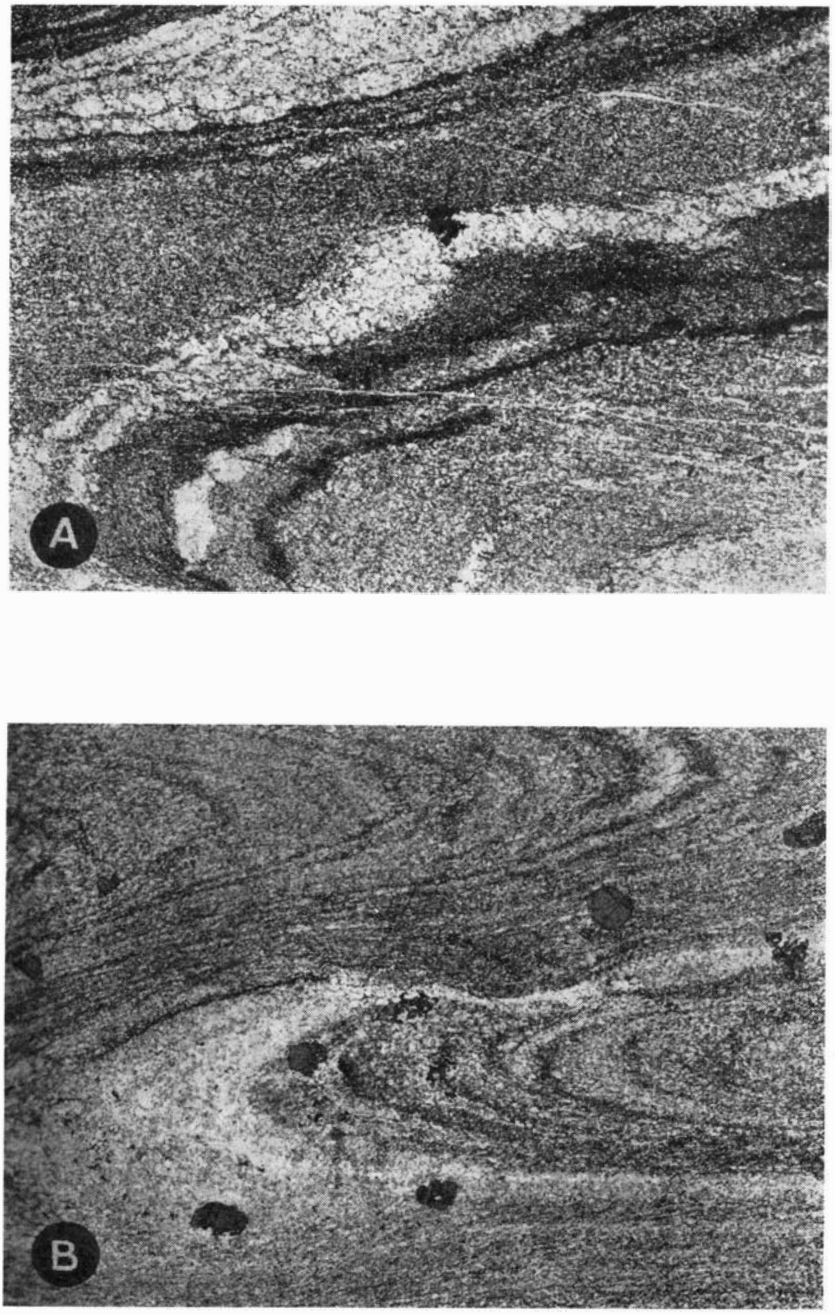


Fig. 55. *The upper photograph* (*Fig. 55A*) *shows the axial surface schistosity developed in the chlorite-muscovite bearing assemblages of the Botniahalvøya Group.* (*Magn.* × *3*). *The lower photograph*(*Fig. 55 B*) *shows the development of garnet and biotite in the Botniahalvøya Group c. 100 m from the contact with the granitic rocks.* (*Magn.* × *5.*)

The contact is folded by minor tight folds (Fig. 46B). The pelitic rocks near the contact contain isoclinal or tight minor folds with a well developed axial surface schistosity which also penetrates the pegmatite veins in the neighbourhood of the contact. This schistosity likewise penetrates the contact itself. In the pelitic rocks it is seen as a parallel orientation of the platy minerals including tabular quartz, biotite and muscovite, this foliation being overgrown by idioblastic staurolite and andalusite (Fig. 56A). In the contact igneous rocks the foliation occurs as a cataclastic deformation of a quartz-oligoclase-microcline-biotite-muscovite assemblage, the feldspar megacrysts being disrupted and drawn into parallelism within the foliation of the mortar texture (Fig. 56B).

In the vicinity of this contact the granitic rocks are generally homogeneous. They pass northwards into less homogeneous types, in places with abundant large inclusions, but sometimes almost lacking inclusions, and always showing a well defined foliation. In some rocks the latter gives no evidence of being cataclastic and appears only as a macroscopic mica orientation with minor parallel xenoliths (Fig. 47).

The sharpness of this contact, the metamorphic aureole and composition and textural relationships of the contact rocks, favour intrusion of the granitic magma during the deformation which resulted in the folding and formation of the axial surface schistosity. That the igneous rocks were still at a relatively high temperature after the schistosity had formed is indicated by the overgrowth of staurolite and andalusite in the pelites. However, the contact quartz monzonites must have largely crystallized before (and perhaps during) the folding of the contact. (D.G.G.)

B. South of Innvika. — A transitional relationship was recorded in this area, comparable with many of the contacts between similar lithologies met with in north-west Spitsbergen (GEE and HJELLE, 1966). Granitic rocks with a prominent gneissosity in which the feldspar augen are oriented, contain abundant inclusions of meta-sedimentary material. The latter are approximately oriented in the regional S-dipping foliation. Within the schistose inclusions there occur isoclinal and tight folds which clearly existed before the injection of the granitic material. From the zone of granitic types with abundant inclusions there is a rapid transition into meta-sedimentary rocks with granite and pegmatite veins. The granitic and the sedimentary types are folded together, with accompanying crenulation of the mica fabric of the schistosity.

Comparison of the relationships at this locality with those described above from south-west Innvika suggest that intrusion of the granitic rocks into the contact zone continued after the formation of the early isoclinal and tight folding and accompanying penetrative schistosity. The resulting more mobile conditions were accompanied by refolding. (D.G.G.)

C. Innvikdalen. — This valley extends towards the south-east from the head of Innvika. In its uppermost part the contact in question traverses the valley. The area to the north consists of augen gneisses, homogeneous gneisses, and the coarse porphyritic quartz monzonites. These lithologies are well exposed along the valley with prominent inclusions of meta-sediments on both sides. The inclusions

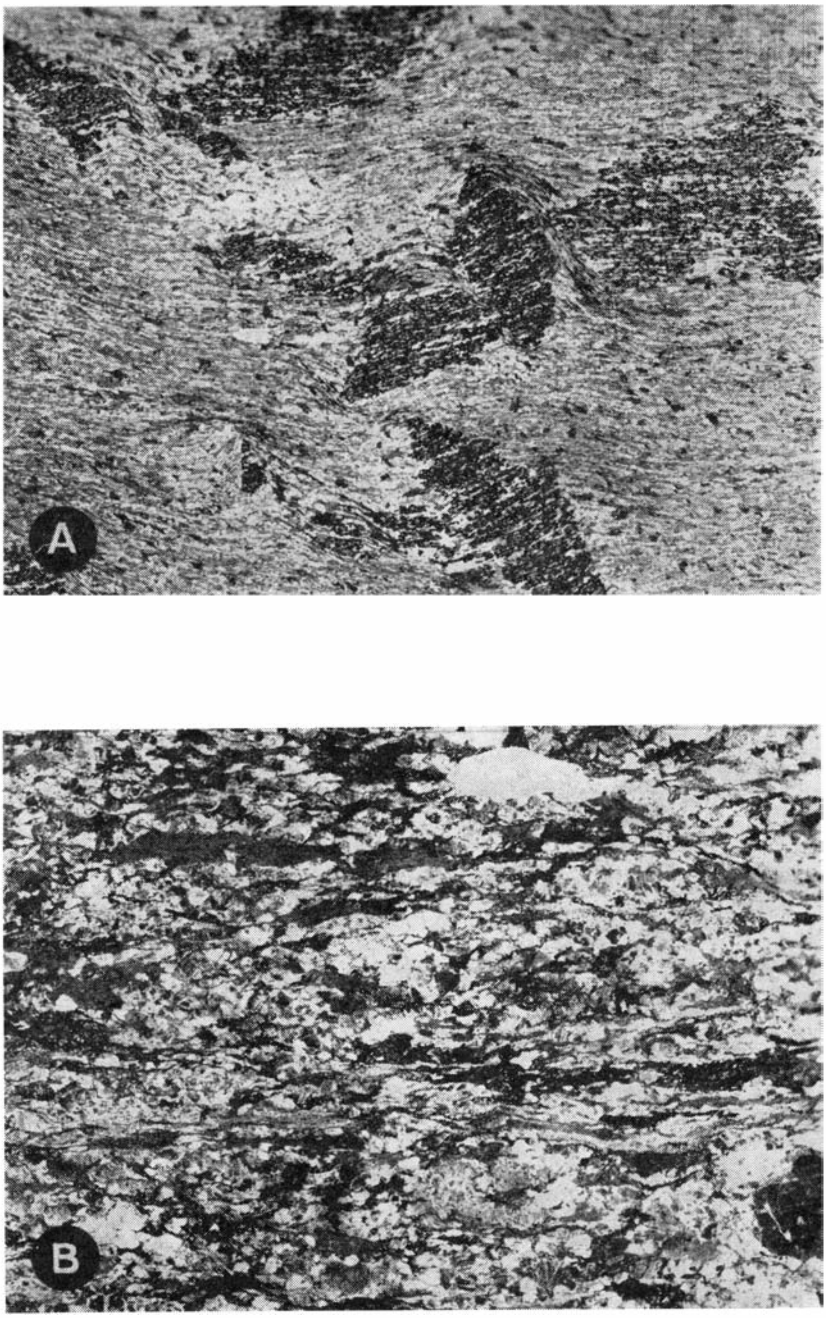


Fig. 56. *The upper photograph* (*Fig. 56A*) *shows staurolite porphyroblasts overgrowing the schistosity. The sample is located about two metres from the contact granitic rocks. (Fig. 56)* (*Magn.* × *5.*)

Fig. 57. *Looking north-east from the mouth of Innvikdalen. Dark pelitic inclusions in light-coloured gneisses.*

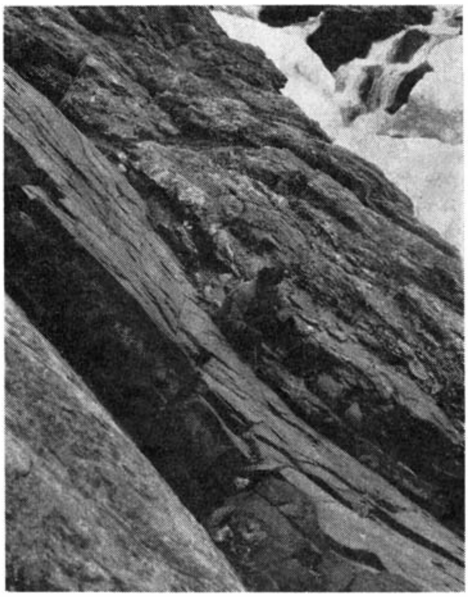


Fig. 58. *Looking south along the upper part of Innvikdalen. Lower left corner shows quartz monzonite followed by dark garnet mica schist. Upper half shows migmatized pelitic rocks.*

seen on Fig. 57 are generally pelitic while along the other side of the valley a discontinuous mixed unit (see p. 116) appears in part calcareous. To the south and above the contact, thick beds of quartzite occur as the first unmigmatized meta-sediments of the Austfonna Formation.

The contact of this locality is more correctly defined as a contact region than a definite line. This region consists of probably primary pelitic sediments, now metamorphosed and migmatized and appearing as small-folded banded and veined gneisses (Figs. 59 and 60) (BERTELSEN 1961). Within the latter gneisses a pronounced interfingering of meta-sediments and the weakly foliated coarse quartz monzonites was observed (Fig. 58). These "fingers" roughly parallel the general foliation of the gneisses and the bedding in the sediments. (B.F.)

D. South-west of Botnvika. – A brief investigation of the area west of the glacier extending down to the head of Botnvika largely confirms the observations from Innvikdalen.

The relationship towards the gneisses and quartz monzonites to the north was not observed, but also here an extensive area of banded and veined gneisses underlies the unmigmatized Austfonna Formation. Beds of amphibolite and quartzite occur within these gneisses (Fig. 61), both well boudinaged where the folding of the latter becomes pronounced. The gneisses locally grade towards mica schist with decrease of granitic material, indicating their primary sedimentary origin. Towards the overlying supracrustal unit consisting of quartzitic and calcareous rocks the contact with the gneisses appears comparatively sharp.

Fig. 59. *Veined gneiss from upper part of Innvikdalen.*

Fig. 60. *Small folded banded gneiss from Kapp Bruun.*

The position and sharpness of the contact here is believed to be partly dependent on the primary change in lithology from pelitic to quartzose and carbonate sediments. This assumption is based on the fact that similar contact relationships are also observed towards the supracrustal inclusions within the migmatite complex (p. 116). (B.F.)

E. Central Rijpdalen. – In east, central Rijpdalen, foliated quartz monzonites in general separate the Botniahalvøya Group from the Rijpdalen granite. The latter has been recorded to intrude both the foliated granitic rocks and the Botniahalvøya Group. The contact between the foliated granitic rocks and the metasediments has not been examined in detail. It includes the two localities where WINSNES (1965) in 1957 recorded intrusive relationships. The south-western part of the outcrop shows an interdigitation of the granitic rocks and the Botniahalvøya Group. (D.G.G.)

F. South-west Austfonna. – In this case, the foliated granitic rocks overlie the meta-volcanic and meta-sedimentary Botniahalvøya Group. The contact has not been observed. The Botniahalvøya Group lithologies nearest to the contact carry biotite. The granitic rocks are coarse-grained and in general to some degree foliated, this structure being oriented approximately parallel to the schistosity in the adjacent Botniahalvøya Group. (D.G.G.)

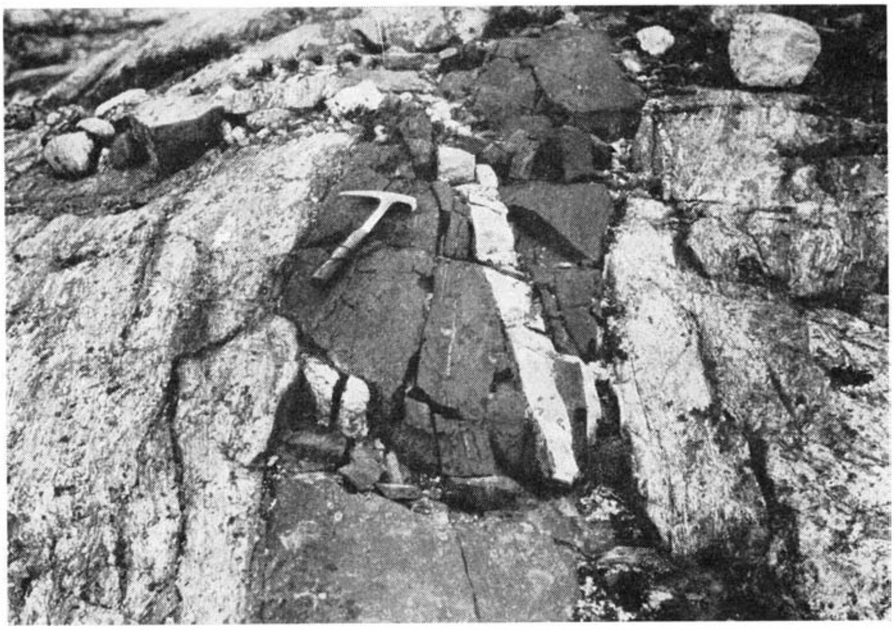


Fig. 61. *From the supracrustal/migmatite border zone south-west of Botnvika. Dark amphibolite enclosed in gneissose pelitic rocks. White is aplite.*

THE MIGMATITES, GNEISSES AND SYN-OROGENIC GRANITES

A great variety of granitic rocks, more or less foliated and containing supracrustal inclusions up to several kilometres long, make up this north-eastern complex. Intrusive and metasomatic processes are evident, and the scale of the one in relation to the other is disputable on the present data. It is clear, however, that highly mobile conditions prevailed during the formation of the complex and a temperature was attained sufficient to produce a marked thermal gradient in the contact areas with the Botniahalvøya Group.

For the purposes of this account, a subdivision of the phenomena has been made here; the granitic types along with the metatect of the migmatites are described first and this is followed by a review of the metaster.

Granitic rocks. – Within this category are included all rocks of granitic aspect, showing hypidiomorphic or porphyritic textures with or without a foliation. Also included are the augen gneisses, there being a notable comparability between the composition of these and that of the least foliated porphyritic granitic types.

Foliated and unfoliated granitic rocks. – Considerable areas, usually occupying the higher ground, are made up of granitic rocks showing little or no foliation and very subordinate amounts of supracrustal material. They are included within the category of syn-orogenic granitic rocks on the basis, firstly that they have been recorded to pass transitionally with an increasingly prominent foliation into the gneissose rocks, and, secondly that their composition is notably similar to these. This gneissosity is discordantly intruded by the granites categorized here as post-orogenic and described in Part IV. The interrelationship between the different granitic types has been discussed elsewhere in this volume.

Modes of three unfoliated granitic rocks are given in Table 6. Two of these represent the more plagioclase-rich range of the lithologies described here. The third is typical of the hypidiomorphic types. They are light grey in fresh and weathered surface. Megacrysts of potash-feldspar, up to several centimetres in diameter are usual, but the porphyritic texture is not always present. The hypidiomorphic coarse-grained groundmass is composed of quartz, basic oligioclase and potash-feldspar in rather variable proportions, along with essential mica, biotite generally predominating over muscovite. Where estimates have been made of the proportions of the minerals in the porphyritic and non-porphyritic types, the overall mineralogical compositions have appeared to be similar with approximately equal amounts of plagioclase, potash-feldspar and quartz, and about ten per cent of micas. Accessories include apatite and zircon. According to the igneous nomenclature used by HJELLE, these rocks are classified as quartz monzonites.

The megacrysts of potash-feldspar usually show microcline twinning. Tabular

Table 6.
Modal analysis of some granitic rocks and augen gneisses.

1. Hypidiomorphic quartz monzonite.
2–3. Groundmass of porphyritic quartz monzonites.
4–5. Augen gneisses.

Analysis No.	1	2	3	4	5
Sample No. 65–	BF 129	BF 165	BF 119	BF 145	BF 89
Quartz	30.8	28.8	30.4	30.8	29.6
K-feldspar	32.6	12.0	11.2	23.3	17.4
Plagioclase	28.6	46.9	48.2	24.8	31.0
Muscovite	1.9	2.9	1.3	7.8	9.5
Biotite	4.5	4.5	8.9	13.3	12.5
Chlorite	1.6	4.9	x	x	–
Epidote, cl.zois.	–	x	–	–	–
Apatite	–	x	x	–	x
Sphene	x	x	–	–	–
Opaque minerals	x	–	x	x	–
Zircon	x	x	x	x	x
Carbonate	–	–	x	–	-
	100.0	100.0	100.0	100.0	100.0
%An in plagioclase	25–30	5–10	30		15–20

(In general between 7–900 points were counted in one thin section for each sample.)

Analyst: BF.

crystal form is frequent and preferred orientation has not been generally recorded. The megacrysts are sometimes poikilitic with quartz, biotite, and plagioclase, and the plagioclase inclusions in some cases have similar optical orientation throughout a part of the megacryst. Plagioclase in the groundmass is often albite twinned and sometimes slightly zoned towards a more albitic margin. Sericitization of plagioclase is usual.

Undulatory extinction of quartz and minor disruption of feldspar has been recorded in nearly all the thin sections. Biotite is usually chloritized. Disruption of potash-feldspar often is associated with the presence of finer grained muscovite crystallizing in the cracks. Myrmekite may replace potash-feldspar. There appears to be a correlation between the extent of this post-crystallization deformation and the amount of myrmekitic embayment of potash-feldspar.

Where the granitic rocks are foliated, this generally appears as a preferred mica orientation. Whereas in some specimens the foliation may be related also to an increased cataclasis, in others it appears to be quite unrelated to this post-crystallization deformation.

In the migmatite areas the granitic metatect is more heterogeneous than the types described above. Nevertheless, the overall modal composition is comparable with that of the other granites. Along with approximately equal proportions of quartz, potash-feldspar and plagioclase (oligoclase), the granitic metatect has up to twenty per cent of muscovite and biotite, the former often dominant. Minor amounts of garnet and hornblende have been recorded and, in one instance, a fine-grained sericitic replacement of a fibrous mineral, probably sillimanite.

The extent of chloritization of biotite and myrmekitic replacement of potash-feldspar appears comparable to that recorded in the homogeneous granitic rocks. Foliation is usually more prominent in the granitic metatect and may be represented by a platy mineral orientation or a streaky compositional banding, with all gradations into the supracrustal rocks of the metaster.

Augen gneisses. – In many parts of the area granitic rocks of composition comparable to those described above are gneissose (e.g. Fig. 45). Mortar textures, with disruption of the hypidiomorphic and porphyritic relationships during development of the gneissosity are general (Fig. 62A). Nevertheless, not all the augen gneisses give evidence of cataclasis and in some cases a derivation of the augen by porphyroblastasis appears probable.

The modal compositions of two augen gneisses are given in Table 6, p. 113. They illustrate the generally higher mica content by comparison with the homogeneous granitic types and the correspondingly lower feldspar percentages.

The megacryst augen have invariably been found to be potash-feldspar usually showing microcline twinning, and being poikilitic with quartz, plagioclase, and biotite inclusions. The augen are marginally granular and embayed by myrmekite (Fig. 62B). In one case complete recrystallization of the augen to a coarse-grained equigranular microcline aggregate was recorded.

The groundmass fabric is usually notable for the contrast between a coarse-grained assemblage interlayered with fine-grained zones of extreme cataclasis.

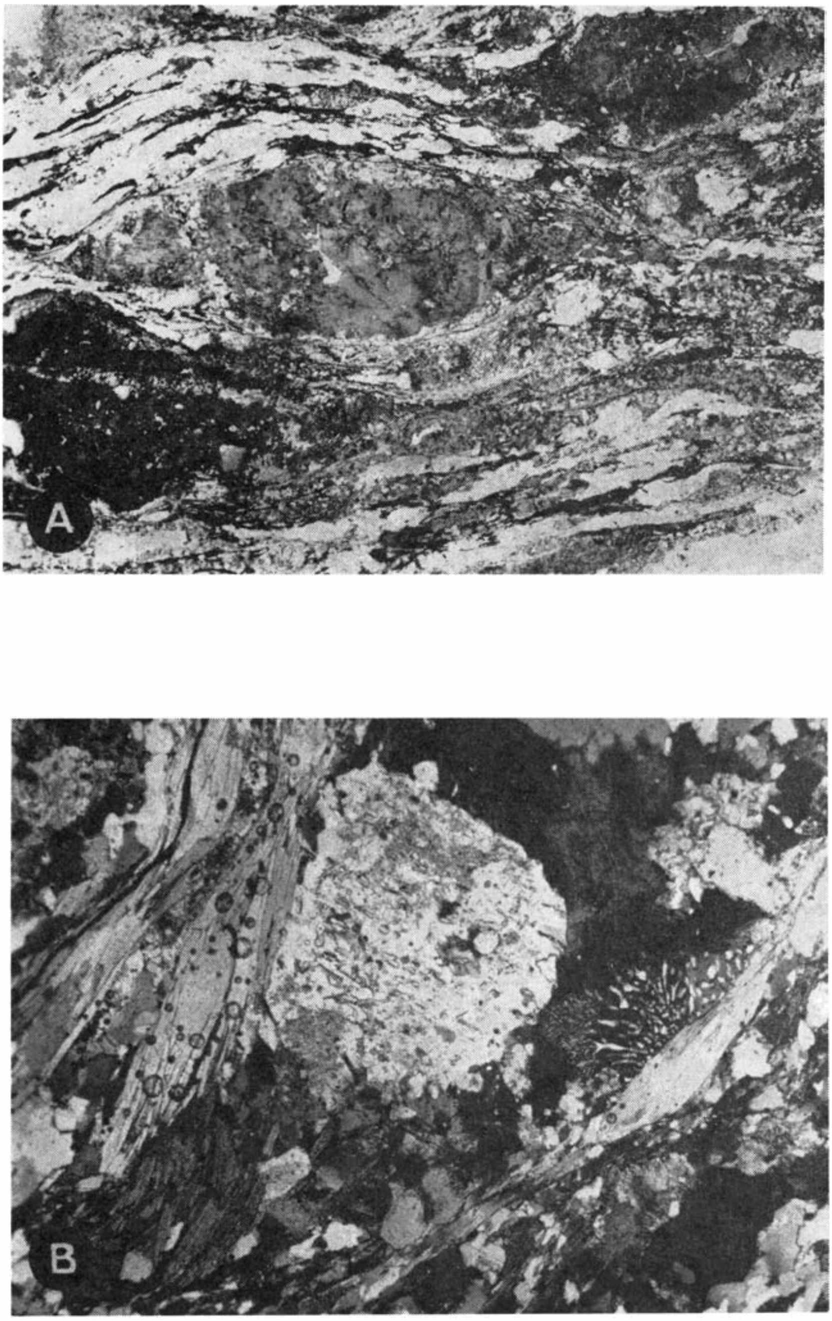


Fig. 62. *The upper photograph (Fig. 62A) shows the development of megacryst K-feldspar augen enveloped in the mortar texture of the augen gneisses. (Magn. × 3.)*
The lower photograph (Fig. 62B) shows the embayment of (dark) K-feldspar by myrmekite in the same augen gneisses. (Magn. × c. 15.)

Within both these layers there exists a mica parallelism along with tabularity of the quartz. Whereas this mineralogy and the augen usually show evidence of strain (undulose extinction of quartz, bent cleavages and twins in feldspars, and disrupted micas) the myrmekite is typically unstrained.

In a few cases a transition has been observed from the unfoliated or little foliated porphyritic granitic rocks into the augen gneisses, the apparently randomly oriented megacrysts in the granitic rocks passing laterally into the regularly elongated augen in the gneisses. This observation taken along with the evidence that the gneissosity was superimposed on the megacrysts of the augen requires derivation of the augen gneisses from the granites by post- or late-crystallization deformation. (D.G.G.)

SUPRACRUSTAL INCLUSIONS

By far the majority of the localities which have been visited throughout the north-eastern migmatite region contain supracrustal inclusions. A large number of inclusions were also spotted from the helicopters during the flights.

Most abundant are pelitic rocks represented by mica-schists, in part garnetiferous. These may grade into impure quartzites; white and more silicious quartzites are also present. Coarse crystalline limestones often with skarn bands and amphibolites of somewhat varying composition also occur. The primary bedding of these rocks is generally well-preserved within the larger inclusions. Detailed descriptions of the more typical inclusions are given below.

The present investigations are not sufficient to distinguish one area from another on the basis of the inclusions. Their frequency is to a large extent dependent on the hostrock or metatect. Their distribution can be categorized as follows:

a) In the massive parts of the quartz monzonites the inclusions are few and small, and may be absent.

b) In some of the foliated periphery zones of the quartz monzonites, in some augen gneisses and in the more homogeneous gneisses inclusions are frequent and sometimes very large (Fig. 57).

c) In the areas occupied by the typical small-folded banded gneisses a large number of inclusions occur, also strongly folded and often boudinaged.

Within the areas of type c) above, migmatites with a more typical agmatitic structure often occur. In general the borders between the metatect and the metaster are sharp towards the amphibolites, the limestones, and partly also towards the quartzites. The more intensely foliated pelitic rocks show transitional borders into the rocks of category c) and b). The various inclusions may also only appear as faint relics, this being generally the case in category a).

It is desirable to try to place the various inclusions into a larger pattern. Due to the isolated observations, except near the camp in Duvefjorden, this is not yet possible. The following observations, however, made along the south-west side of Innvikdalen may be indicative of a more general phenomenon. Here, a 25 m thick sedimentary unit striking SE–NW is found enclosed in gneisses. It consists of 10 m of crystalline limestone with mica schist on both sides and wedges out into the gneiss with the limestone as the last to "surrender". Following the strike direction up the valley, the limestone reappears in the gneiss at three other localities. In the opposite direction limestone with a similar strike was also found on the west shore of Innvika. It is conceivable that these observations refer to one and the same limestone horizon, persistent over a distance at least 6 km. A marked persistency of meta-sedimentary units was also noted, although on a much smaller scale, on Repøyane and on the island north-east of Bergstrømodden. In the latter locality limestone with a strongly boudinaged quartzite could be followed for some distance in foliated quartz monzonite.

These examples are comparable with the pattern of the supracrustal inclusions appearing in the migmatite complex of north-west Spitsbergen. More detailed investigation allowed GEE and HJELLE (1966) to produce a map showing the strike continuity of inclusions within this complex, especially of marbles and amphibolites.

Crystalline limestones and skarn rocks. – The limestones appear as coarse crystalline rocks, white to greyish in colour and often with darker bands. They occur as regular beds, but also as irregular masses associated with skarn and certain amphibolites.

The skarn rocks are observed as regular or boudinaged bands a few centimetres thick within the limestones. They partly border the limestones towards the gneisses, but are also found as larger separate inclusions. The following minerals have been identified in these rocks: diopside, garnet, scapolite, idocrase, wollastonite, calcite, and quartz. They all appear as rock-forming minerals in various combinations and proportions. Garnet and calcite play roles both as main rock-forming minerals and accessories, whereas sphene and apatite occur only as accessory minerals.

A wide textural variation occurs in these rocks. Coarse crystalline aggregates occur in approximately 10 cm wide reaction zones, especially between limestones and gneiss. Generally, however, a zonal arrangement of the different minerals is observed within the skarn. Where it can be seen in relation to the enclosing limestone or other adjacent supracrustal rocks, the skarn banding and zoning is parallel to the bedding. These bands display a general equigranular texture (mineral sizes from 0.5 to 4 mm). Zoning within the bands may exhibit contrasting large mineral grains especially of idocrase.

Amphibolites. – Although the amphibolites are frequently found as inclusions, the observations rarely give any indication of origin. However, they sometimes appear in close connection with calcareous rocks and skarn mineralized bands, and do often contain irregular masses of coarse recrystallized limestone. Thus a sedimentary origin is indicated for some. Thin-sections of these amphibolites reveal abundant monoclinic pyroxene, probably diopside, and they may be regarded as transitional to rocks better classified as diopside skarn. A magmatic origin may still be considered for other amphibolites, pending further observation.

The hornblende gabbro observed in the easternmost area and described below shows a characteristic appearance different from any of the amphibolites; thus it is within reason to reject a plutonic origin for the amphibolites in question.

The amphibolites all contain actinolitic hornblende as the main mineral, and various proportions of quartz and labradorite plagioclase. In the amphibolite of Fig. 61, a dark reddish-brown biotite occurs as the sole dark mineral in a rim c. 6 mm wide along the aplite contact. Further away from this contact, hornblende becomes more and more frequent. The biotite which has grown at the expense of the hornblende is oriented parallel to the aplite contact, not to the general trend of the amphibolite, indicating a later age for the aplites.

An ubiquitous accessory mineral is sphene; others include sericite, chlorite, calcite, apatite, opaque minerals, and zircon.

The amphibolites are generally fine-grained with a grain-size from 0.1 to 0.3 mm. Porphyroblastic hornblende about ten times the average grain-size is observed in some specimens. The orientation of this hornblende together with elongated undulatory quartz grains account for the foliation of the rock.

Pelitic rocks and quartzites. – The pure quartzite beds are more easily distinguished from the other lithologies. The pelitic bands contain quartz, plagioclase, and biotite as main rock-forming minerals; partly also microcline, muscovite, hornblende, and garnet. Accessories are zircon, opaques, apatite, chlorite, carbonate, and tourmaline.

The transition to impure quartzite occurs through a general increase in quartz and a simultaneous decrease of plagioclase and biotite. (B.F.)

META-GABBRO INCLUSIONS

On the north-easternmost peninsulas of Nordaustlandet coarse hornblende gabbros occur within the migmatites. The example described here is from the point to the east of Nilsenbreen called Behôunekodden, a flat area consisting of migmatite gneisses with frequent supracrustal inclusions. This gabbro body is cut by a dyke of the coarse porphyritic quartz monzonite (Fig. 63). The more peripheral parts have frequent and irregular intrusions of the same rock (Fig. 64).

The main constituents of this gabbro are light green, slightly pleochroic amphibole and sodic labradorite plagioclase. Their grain-sizes are usually less than 2 mm. The amphibole has high order interference colours, is optically positive, shows polysynthetic twinning and is probably a cummongtonite. Some biotite and quartz are also present. The former occurs in cleavages and along the outer rim of the amphibole, clearly replacing this. It has also grown to separate flakes up to 4 mm in size, some inclusions of the amphibole still being present. The quartz, where adjacent to the biotite, often occurs as myrmekitic intergrowths.

Accessories are chlorite, carbonate, sericite, apatite, zircon, opaque minerals, and sillimanite(?).

Chlorite, carbonate and sericite also replace both amphibole and plagioclase, and irregular aggregates of all these minerals are seen within the thin sections. Apatite and zircon appear in grains up to 0.4 and 0.7 mm respectively.

Along the margin of the gabbro the main difference appears as an almost com-

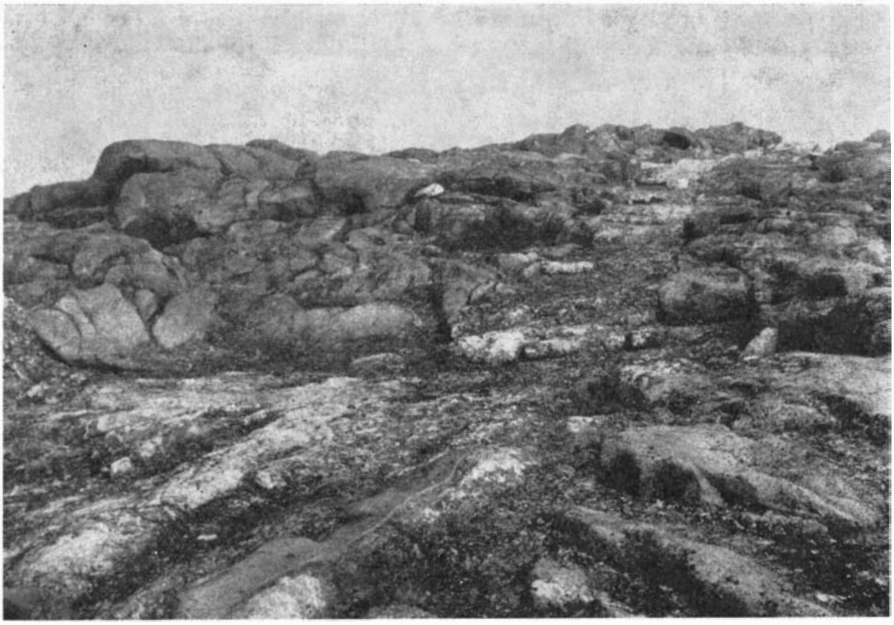


Fig. 63. *Central part of the gabbro body at Behôunekodden with a dyke of quartz monzonite.*

Fig. 64. *Peripheral part of the gabbro body (Fig. 63) intruded by quartz monzonite.*

plete replacement of the amphibole by biotite. The plagioclase grains all carry quartz as numerous poikilitic inclusions.

Parallel orientation of the minerals was not observed in the thin sections, neither was any sign of the intense folding seen in the neighbouring supracrustal inclusions found in this gabbro. Due to this evidence, it is concluded that the intrusion of the gabbro post-dated the deformation producing the foliated structure in other inclusions. It is evident that both the gabbro and the other inclusions have been subjected to the later intrusion of the syn-orogenic granitic rocks. (B.F.)

CONCLUDING REMARKS

There is a notable contrast between the greenschist metamorphic facies of the Botniahalvøya Group and the amphibolite facies which dominates the supracrustal inclusions in the migmatite areas. The rapid increase in metamorphic grade towards the migmatite front has been described above and attributed to an unusually high thermal gradient over the contact zone. The structures described testify to the existence of highly mobile conditions in the migmatite terraines and the presence of more or less foliated granitic rocks in the latter confirm the conclusion that "magmatic" temperatures prevailed during the formation of the complex. The presence of andalusite in the immediate contact and the records of wollastonite and sillimanite from within the migmatites appear to exclude the possibility of high overburden pressures during the migmatization.

Along with the evident magmatism there is ubiquitous evidence of at least local metasomatism within the area of migmatites, gneisses and syn-orogenic granitic rocks. This occurs on a restricted scale in the case of the skarn mineralization and biotitization of amphibolites and more extensively in the mica schists and gneisses. Whereas it is clear that some augen gneisses have been derived from the more homogeneous granitic rocks by cataclasis, others have an unquestionable origin by feldspar porphyroblastasis in mica schists. Transitions from mica schist to microcline porphyroblastic schist and then to microcline augen gneiss, recorded from inclusions within the migmatites, are explicable only in metasomatic terms. In this connection it is of interest to note that whilst the highly aluminous meta-sediments in the contact with the migmatite front develop andalusite and staurolite, these minerals have not been recorded from inclusions within the complex and sillimanite appears to be relatively rare. Since it is clear that parts of the Botniahalvøya Group are incorporated in the migmatite complex, it might be reasonable to suppose that the rarity of these minerals is due to the evident mobility of alkalis within the areas of intrusion and migmatization.

The metamorphic and magmatic conditions exhibited in Nordaustlandet are comparable with those existing in north-west Spitsbergen and the area south of Liefdefjorden, and contrast remarkably with the kyanite-bearing terraines of Ny Friesland and the kyanite- and eclogite-bearing terraines of the Biskayerhuken area which apparently were subjected to greater overburden pressures during metamorphism. It would be of great interest to establish whether these contrasted metamorphic environments originated at the same or different times.

Part IV.

Post-orogenic granites

BY

A. Hjelle

Introduction to Part IV

The first report of granites from Nordaustlandet is from 1828, when James Parry (1828) described grey and red granites from Laponiahalvøya and adjacent islands. The granites were classified together with gneisses as "primitive rocks". Later Nordenskiöld (1863) suggested that these rocks belonged to "the old granite gneiss Formation" and Nathorst (1910) referred to them as "Urgebirge". Sandford (1926) suggested the granites of Nordaustlandet to be of Caledonian age, and later Kulling (1932) mentioned the possibility of the granite at Brennevinsfjorden "being syntectonic with the Caledonian mountain folding epoch". Later (1934) he suggested that the granite "... does not seem to have been affected by any such Caledonian folding as can be observed in other districts examined,...". Most isotopic age-determinations from granite areas in Nordaustlandet (Hamilton et al. 1962, Krasil'ščikov 1965, and Winsnes 1965) support this view.

Recent investigations have shown that there are at least two principal areas of post-orogenic granite in Nordaustlandet: 1) in Brennevinsfjorden-Sabinebukta and 2) in Rijpfjorden-Rijpdalen. The relationship between these granites and the suggested syn-orogenic rocks is not quite clear at this stage of the investigations; however, differences in composition, texture, and relations to the older supracrustal rocks, at present justify a separate treatment here. The most frequently observed mineral association in the granites is: quartz-microcline-plagioclase (albite–oligoclase)–biotite–muscovite. The Rijpfjorden granite is the most distinctive in relation to the surrounding rocks even if transitional rocks may occur both along the borders of the granite and east of this, suggesting a series of intrusions related at depth.

Comparing the Nordaustlandet granites with the batholitic granitic rocks of Ny Friesland and north-west Spitsbergen, the more alkaline and less calcic and femic nature of the Nordaustlandet granites is obvious (Fig. 65 A, B). (Hjelle 1966). The isotopic age-determinations of the intrusions show, both in Spitsbergen and in Nordaustlandet, a concentration of ages about 350–400 m.y. Although the mean radiometric ages seem to vary somewhat from one

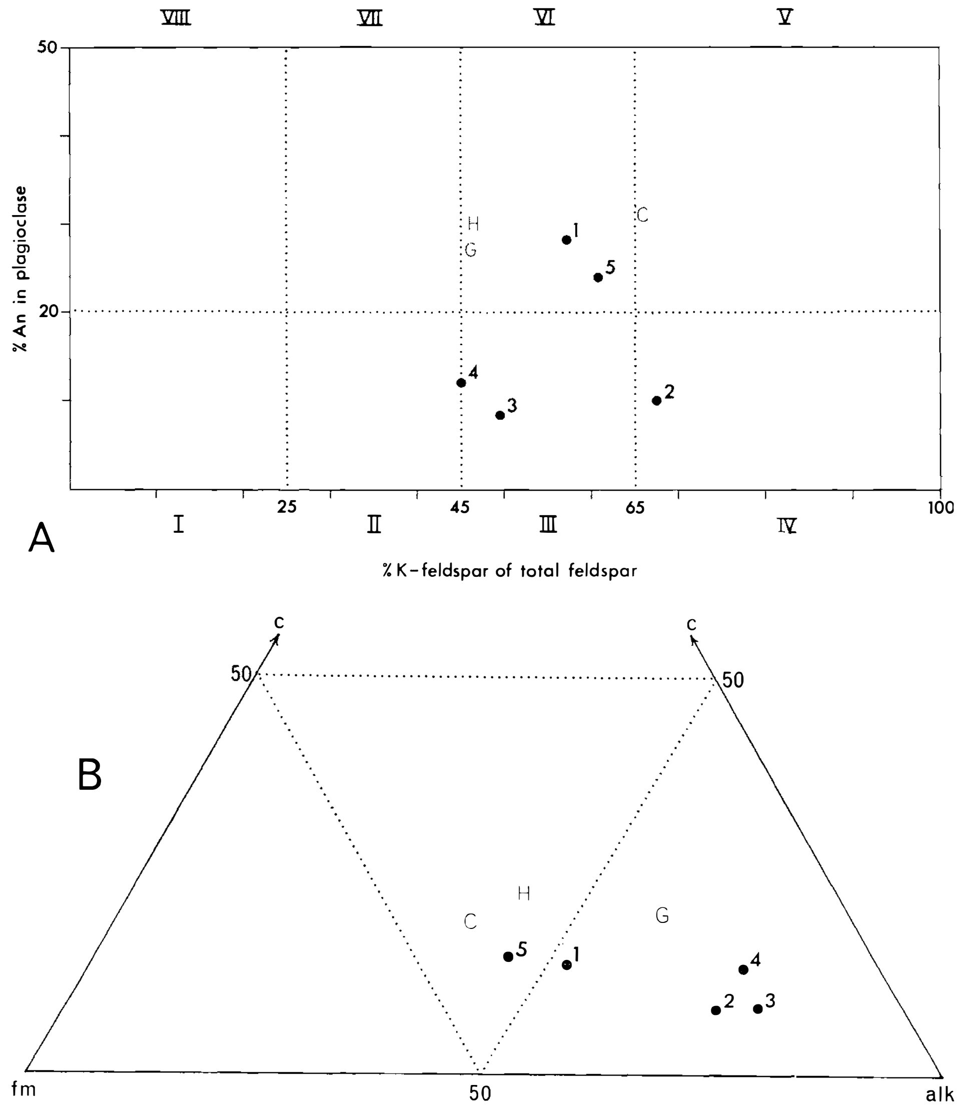


Fig. 65 A & B. *Feldspar proportions* (*A*) *and Niggli value ratios* (*B*) *in the granitic rocks of Nordaustlandet. Based on values from Table 4* (*Part III*).

1: *Quartz monzonites at Laponiahalvøya and Sjuøyane*
2: *Brennevinsfjorden granite*
3: *Rijpfjorden granite*
4: *Aplite dykes*
5: *Quartz monzonites, Ahlmannfonna–Duvefjorden.*

Granitic rocks from Spitsbergen are indicated for comparison (HJELLE 1965).
G: Dyke rocks, north-west Sbitsbergen
H: Horneman batholith, north-west Spitsbergen
C: Chydenius batholith, Ny Friesland.

The quantitative petrographical classification of granitic rocks used in this paper:
I – Trondhjemite. II – Sodium granite. III – Normal granite. IV – Potassium granite.
V – Granosyenite. VI – Quartz monzonite. VII – Granodiorite. VIII – Quartz diorite.
(*Quartz*>*10 vol.*%, *Feldspars*>*30 vol.*%.)

granitic body to another, the varying degree of alteration and the often deficient petrographical and field information concerning the analysed samples make a more detailed division into intrusion epochs impossible on the present data.

The Brennevinsfjorden granite

This rock is light grey to red, normally medium-grained, in part porphyritic and with a somewhat cataclastic texture. Shearing may be visible to the naked eye. The average composition (Table 4, No. 2, p. 100) shows quartz and potassium-feldspar as the chief constituents.

The quartz usually shows intense banded undulatory extinction, and brittle deformation of the grains is common. In hand specimen the colour of the quartz is bluish.

Potassium-feldspar occurs most commonly as a part of the medium-grained groundmass; however, large phenocrysts up to about 3 cm long may also occur. The feldspar is often pronouncedly perthitic and may also carry larger inclusions of albite. The crystals in part show microcline twinning and, sporadically, a slight sericitization.

Plagioclase occurs in the groundmass and is often heavily sericitized, the An content varying between 5 and 15%. Some grains have bent twin lamellae. Clino-zoisite occurs sporadically.

Biotite shows pleochroism X = yellow, Y = Z = dark brown. $n\gamma \sim 1.66$, $n\gamma \div n\alpha \sim 0.050$.

Chlorite occurs as rims on biotite and as separate aggregates.

About half the amount of muscovite occurs as sericite in plagioclase, the remainder mostly in association with biotite and partly interfingering with it.

Where the contact between the Brennevinsfjorden granite and older supracrustal rocks is exposed, as in Kontaktberget (Kulling 1934) and Sabinebukta, clearly intrusive relations are seen, with a fine-grained border facies of granite, and numerous veins of aplite and quartz. The less well-defined contact towards the quartz monzonites as seen e.g. in Zeipelbukta probably is due to the less pronounced thermal and/or chemical gradient, facilitating the development of transitional rocks.

At some localities near Sabinebukta and the inner parts of Brennevinsfjorden anomalous varieties of the granite occur. Some of them are nebulitic, the groundmass showing a mica content up to c. 20 vol.% and epidote up to 5%, while the amount of potassium-feldspar is relatively low, c. 25%. Assimilation of micaceous and calcareous supracrustal rocks may have caused this anomalous composition. Near Sabinebukta partly assimilated host rocks were seen by Siggerud in the granite near the contact. The interpretation of air-photographs from this last area (Sandford 1950) must therefore be revised. The Hecla Hoek supracrustals here do not rest upon an old complex, but are intruded by younger rocks.

Kulling's record of a perfectly massive granite on the east side of Brennevinsfjorden is not wholly confirmed, as traces of NE to NNE foliation trends may be found in the granite. This foliation, which generally dips 30–80^{g} SE is discordant to the border between the Brennevinsfjorden granite and the quartz monzonite. The Caledonian orientation of the foliation of the Brennevinsfjorden granite thus may be related to the final stages of the orogenic activity rather than to flow during intrusion. The difference in age between the Brennevinsfjorden granite, and the quartz monzonites (grouped with the syn-orogenic rocks on the geological map) may be small as is also indicated by most of the isotopic age-determinations (KRASIL'ŠČIKOV 1965).

A variety of granite with orbicular texture was observed by WINSNES and HJELLE in 1957 at some localities along the east side of Brennevinsfjorden. The orbs occur as medium-grained, relatively dark granitic aggregates with light outer rims, somewhat unevenly distributed in a medium-grained matrix of two-mica granite composition. In a specimen from Depotodden the spherical dark aggregates, which mostly are 2–5 cm across, contain about 25 vol.% tourmaline. The surrounding rims, which have widths of about 0.5 cm, show a composition similar to that of the matrix, except for the lack of mafic minerals.

The uneven distribution of the orbs and the fact that meta-supracrustal inclusions at an adjacent locality in the same granite, also show light rims, may suggest the orbs to be remnants of older rocks.

On the other hand tourmaline-rich orbs with felsic rims could also be developed by migration of Fe and Mg towards sites or positions with sufficient boron, giving rise to growth of tourmaline. Suggesting the granite to contain 2 wt.% (FeO + MgO), and the tourmaline to be formed to contain 20 wt.% (FeO + MgO), which are fairly reasonable values, orbs with 2–5 cm diameter, carrying 25 vol.% tourmaline, require a "draining volume" of 12.5–195 cm^3 to provide the necessary (Fe + Mg). The width of the "drained" shell then will vary from c. 0.5 to 1 cm, a close approach to the measured values of the width of the surrounding light rims.

BÄCKSTRÖM (1905) described an orbicular rock (erratic, coll. 1898) from south-east Chermsideøya. The matrix and the cores of the orbs both had an oligoclase granite composition, the orbs being surrounded by c. 1 cm light rims of radial oligoclase. In the examined slab, two orbs with dark biotite-rich cores were also seen, resembling mafic inclusions. BÄCKSTRÖM suggested the orbs to be formed by changing conditions during the crystallization of an oligoclase granite magma.

The Rijpfjorden granite

This rock has an almost continuous N–S extension of about 60 km, from near the head of Wahlenbergfjorden to Vindbukta in the outer Rijpfjorden. All the examined specimens lie within the granite ranges (Fig. 65A, II–IV). Table 4, No. 3, (p. 100) shows the average composition, being normal granitic. KRASIL'ŠČIKOV (pers. comm. 1967) reports that recent unpublished chemical analyses from the Rijpfjorden granite area contain Ca and Mg in somewhat higher proportions than the approximate chemical analyses computed from modal analyses (HJELLE 1966). However, new analyses (Table 5, p. 101) generally confirm the computed analyses, and the differences may be due to sampling from different localities. When collecting samples for modal analyses, care was taken to sample at some distance from xenoliths and border zones, where the granite often contains a more calcic plagioclase and higher amounts of biotite, which would yield higher values of CaO, MgO, and FeO.

The texture of the granite is hypidiomorphic, medium-grained, and often shows signs of post-magmatic movements. The colour is normally a distinct pink or red. With an average of about 10%, muscovite exceeds biotite in all examined specimens. Almost constant accessories are iron hydroxides and fluorite, the latter also occasionally occurring as a coating on fissures. The quartz shows imprints of strain, with a relatively strong patchy undulatory extinction. Some feldspar margins are embayed and replaced by quartz, which also fills fissures in broken grains, especially of plagioclase.

Potassium-feldspar most often occurs as microcline microperthite with inclusions of plagioclase and occasionally also with poikilitic quartz. In some grains the microcline twinning is only feebly developed.

The composition of the plagioclase varies between An 5–10, the grains often showing bent and broken twin lamellae. In xenolithic types of the granite, myrmekitic intergrowths in the plagioclase occur relatively commonly. As previously mentioned, these granites also contain more biotite and a more calcic plagioclase than the non-contaminated granite, and exchange of material between the xenoliths, which often are of a rounded shape, and the granite, is suggested.

Muscovite occurs mainly as unorientated, somewhat bent flakes, sericite in plagioclase playing a subordinate role.

Biotite is only sparsely present, the commonest type has pleochroism $X = $ pure yellow, $Y = Z = $ reddish brown. $n\gamma \sim 1.670$, $n\gamma - n\alpha \sim 0.055$.

Small amounts of olive coloured chlorite occur in most of the specimens, the interference colour being pale greyish blue. $n\gamma - n\alpha \sim 0.007$.

Intrusive contacts to Hecla Hoek supracrustal rocks and the gneisses are observed near the head of Wahlenbergfjorden, in Rijpdalen and in the Rijpfjorden district. About 5 km south-east of the innermost branch of Rijpfjorden, and also further north–north-east, the pink granite intrudes homogeneous grey augen gneiss of approximately quartz diorite composition (Fig. 66, see also p. 113), whereas in upper Rijpdalen, near the watershed, the intruded rocks are mainly phyllites and minor quartzites. The composition of a typical micaschist inclusion is shown in Fig. 67. In the whole area scattered occurrences of large blocks of supracrustal rocks (>50 m across) occur, often as caps in the upper parts of hills, giving the general impression of being in the roof zone of a batholithic intrusion. Similar observations were made by Flood in the transition zone between the migmatites and the Austfonna Formation. South-west of the head of Botnvika, where underlying red muscovite granite cuts the rocks within this zone, apophyses of aplite and pegmatite intrude the migmatites.

The contact between the granite and the supracrustal rocks is normally rather sharp (Fig. 68), while the contact between the granite and the gneiss or the migmatite may be sharp or transitional through 0.5–10 m, due to the more ready assimilation of gneissic rocks. Fig. 69 is a simplified diagram of the relations as

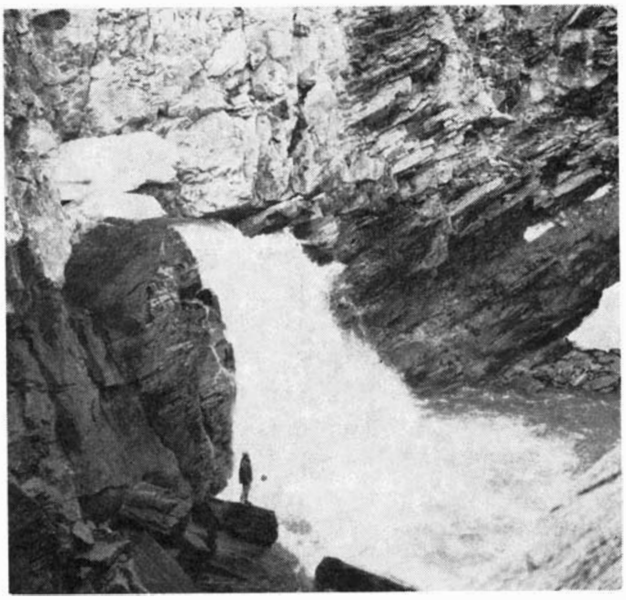


Fig. 66. *Large augen gneiss body (dark) in muscovite granite. By Stegfossane, c. 5 km south-east of the innermost branch of Wordiebukta.*

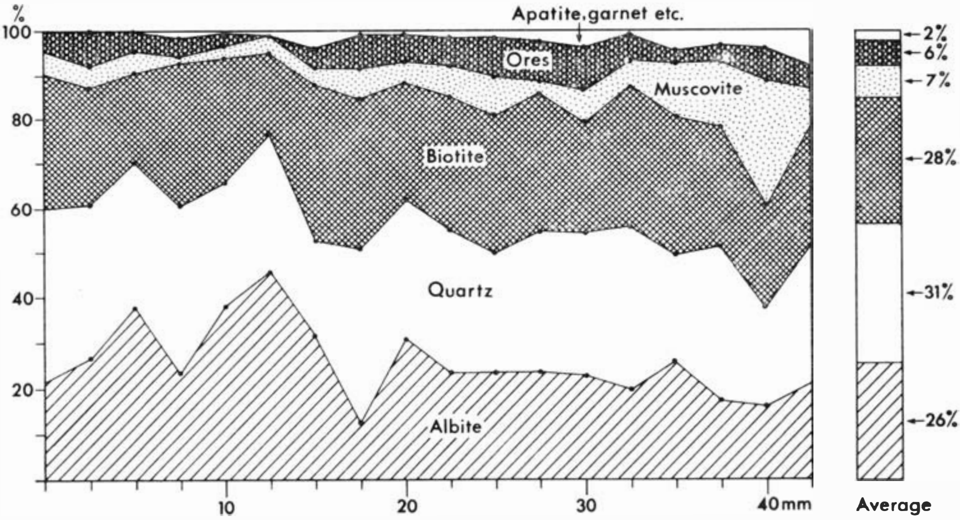


Fig. 67. *The modal composition of the inner part of a mica schist inclusion in Rijpfjorden granite. Based on point counting every 2 mm, the "counting lines" being parallel to the visible layering. Thin section size: 20 × 45 mm.*

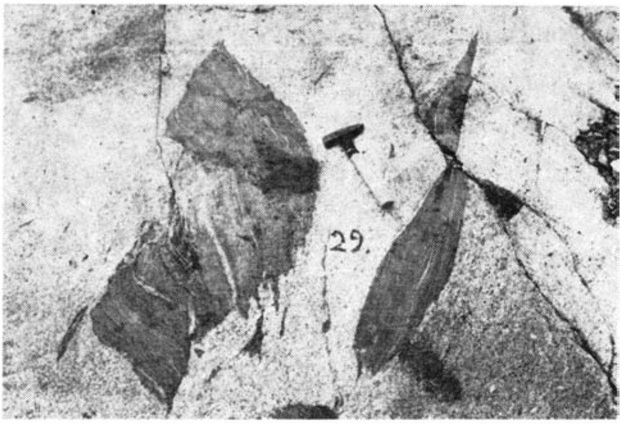


Fig. 68. *Mica schist inclusions in muscovite granite near the western moraine of Ahlmannfonna.*

seen near the west moraine of Ahlmannfonna. The relative age of the rocks involved are: A) old supracrustal relics, B) syn-orogenic rocks, often of quartz monzonitic composition, gneissic or only vaguely foliated, C) post- or late-orogenic Rijpfjorden granite, D) aplite and pegmatite dykes.

The Rijpfjorden granite frequently is penetrated by aplitic dykes and veins and irregular bodies of pegmatite. The appearance and mineralogical composition of these rocks closely resemble the granite itself, with unevenly pink-coloured potassium feldspar and abundant muscovite. Although the dykes must be regarded as the youngest intrusion within the Rijpfjorden granite (Fig. 69), a weak foliation is at two localities seen to continue through the dykes, suggesting movements to have continued also after the last intrusions. Fig. 70A shows the orientations of 45 aplite and pegmatite dykes within or near the Rijpfjorden granite. The main strikes of the dykes are: c. 30^{g}, c. 50^{g}, c. 85^{g}, and c. 120^{g}. Fig. 70 B shows joint diagrams for the same area (110 obs.). Here a pronounced maximum can be seen at c. 120^{g}. The number of observations are insufficient to be conclusive; however, the 30^{g} and 50^{g} maxima in the dyke diagrams may represent older directions, possibly tension joints filled after the consolidation of the granite body, while the

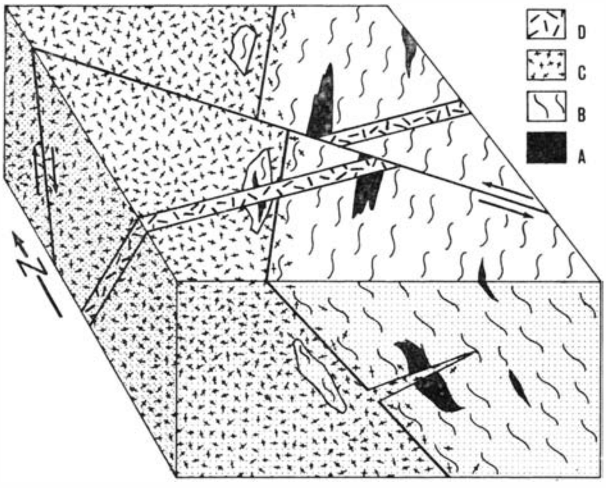


Fig. 69. *Relations near the west moraine of Ahlmannfonna.*
A: Inclusions of supracrustal rocks
B: Grey to light red granitic gneiss
C: Rijpfjorden granite
D: Younger aplite and pegmatite dykes related to the Rijpfjorden granite.

common 120^g maximum may represent both the age of pegmatite intrusion and later fault directions, pegmatite dykes often being recorded to be faulted along this direction. It should be mentioned that of 9 aplitic dykes measured in northern Laponiahalvøya, 7 had strikes close to the 30^g or 120^g directions. Small fault planes dipping c. 55^g towards 140^g are observed in several places, often accompanied by a slickenside lineation dipping approx. 50^g towards 210^g, the sliding surface of some of them indicating a downthrow on the north side.

The same relative movement also occurs on some of the approximately NW-striking larger scale faults near the head of Rijpfjorden and in the Rijpdalen-Austfonna area, suggesting a genetical relationship to the small faults in the Rijpfjorden granite.

Genesis of the post-orogenic granites; correlation with the syn-orogenic rocks

Despite the wide extension of the Pre-Cambrian Murchisonfjorden Supergroup, it is nowhere seen to be intruded by the Brennevinsfjorden granite. The youngest rocks intruded by the granite are of the Botniahalvøya Group. Thus there are two possibilities with regard to the age of intrusion: 1) The Brennevinsfjorden granite may be older than the Murchisonfjorden Supergroup, but younger than the Botniahalvøya Group. 2) The granite may be younger than the Murchisonfjorden Supergroup, but intrusive contacts are not seen, owing to a more deep-seated location of the granite in these areas. The isotopic ages around 400 m.y. seem to favour No. 2, but the possibility of recrystallization of older granitic rocks during Caledonian metamorphism should not be disregarded.

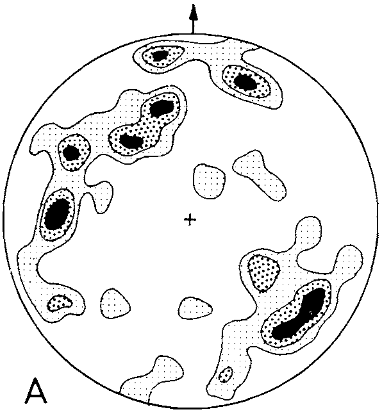


Fig. 70A. *Poles to pegmatite and aplite dykes related to the Rijpfjorden granite. 45 obs. in the granite and in the adjacent rocks. Lower hemisphere. Contour lines: 1.5–3 and 4.5%.*

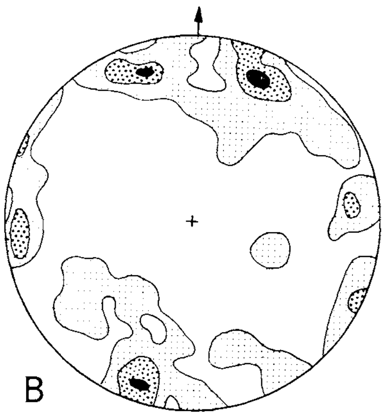


Fig. 70B. *Poles to joints in the Rijpfjorden granite and adjacent rocks. 110 obs. Lower hemisphere. Contour lines: 1–3 and 5%.*

In the Rijpfjorden-Austfonna area, Rijpfjorden granite cuts rocks both of the Pre-Cambrian Botniahalvøya Group and of the quartz monzonite/migmaitte complex. North of Mefjordheia the granite intrudes a quartzite/shale succession of uncertain stratigraphic position, correlated in the geological map with the Botniahalvøya Group. East of Mefjordheia the contact between these rocks and the quartz monzonite/migmatite rocks is only incompletely exposed; however, the gneissosity of the syn-orogenic rocks seems to parallel the contact, while the regional structural trend of the quartzite/shale beds shows a pronounced discordance to this. This may indicate a relatively late development of the gneissic rocks, the structure of these being governed by the trend of the contact. The lithology of the quartzite/shale beds in many respects resembles the beds in the lower part of the Murchisonfjorden Supergroup. Thus the Rijpfjorden granite may be younger than the syn-orogenic quartz monzonite and migmatites and possibly also younger than the Murchisonfjorden Supergroup. It has already been mentioned that the Brennevinsfjorden and Rijpfjorden granites bear stronger resemblances to each other than to the other granitic rocks of Nordaustlandet and Spitsbergen. On the other hand, the supposed syn-orogenic quartz monzonites of Nordaustlandet often have a composition and texture reminiscent of the post-orogenic Horneman quartz monzonites of north-west Spitsbergen. The almost unfoliated appearance of many of the quartz monzonites of Nordaustlandet, raises the question whether these should be regarded as real syn-orogenic rocks. In the migmatites of Laponiahalvøya and Duvefjorden, the metatect frequently is seen to continue into huge masses of quartz monzonite without textural or visible compositional change. This may be explained by suggesting the migmatite to be developed during the orogeny by introduction of granitic material of which the bulk mass was not consolidated when the main deformation of the supracrustal rocks had ceased. Considering the relationship between these possibly late orogenic quartz monzonites and the post-orogenic granites, there is considerable difference in texture and composition; however, they are so closely connected both geographically and in time, according to some of the age-determinations (KRASIL'ŠČIKOV), that a genetical relation seems likely.

On the basis of this evidence, the granitic rocks in Nordaustlandet may be fitted into the following sequence of events:

1) Deposition of Pre-Cambrian supracrustal rocks, followed by Pre-Cambrian metamorphism.
2) Deposition of Lower Palaeozoic rocks.
3) Caledonian regional metamorphism with recrystallization, introduction of palingenetic granitic material, development of gneisses and migmatites.
4) Development of coarse quartz monzonite by late syn-orogenic consolidation of deep-seated granitic material introduced during the main Caledonian orogeny.
5) Intrusions of post-orogenic granites and pegmatites.
6) Post-orogenic movements.

In Fig. 71 the Ab-Or-Q-ratio of the average granitic rocks, calculated from the mode and from partial analyses of potassium-feldspars, are plotted in the corres-

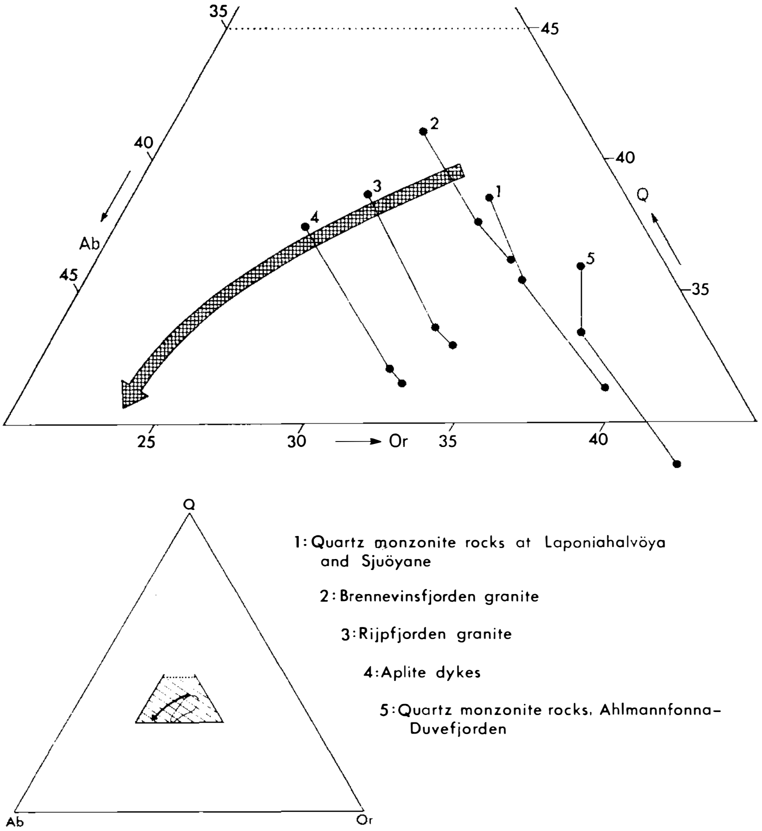


Fig. 71. *Ab-Or-Q ratios of granitic rocks from Nordaustlandet. From average compositions, Table 4, Part III. Cata and mesonormative values (lower and middle dots) based on the average chemical analyses. Modal values (uppermost dots) based on the average modal analyses, corrected according to partial analyses of potassium feldspars. The arrow represents the locus of the minimum melting composition at* P_{H_2O} *from 500 to 4000 bars* (Bowen 1958).

ponding ternary diagram. The arrow represents the locus of the minimum melting composition at P_{H_2O} from 500 to 4000 bars (Tuttle and Bowen 1958). For comparison the kata- and mesonormative ratios (Barth 1959), based on average chemical analyses, are also plotted in the diagram. The plotted values, particularly those calculated directly from the mode, approach so closely to the locus of the minimums at different pressures, that the rocks could very well have been formed from a crystal-liquid equilibrium. A reservation must, however, be made for the relatively Ca-rich quartz monzonite rocks, which may be somewhat misrepresented in a Ab-Or-Q-diagram. The relatively high normative values of Or, compared with the compositions calculated directly from the mode, in the Brennevinsfjorden and Rijpfjorden granites, most likely are due to the rather high modal content of muscovite (5—10%), which is not included in the norm calculations. The Or variation from kata- to mesonorm is only slight as the granites are poor in MgO and FeO, and only little Or was used to form mesonormative biotite. Correspondingly the quartz monzonites, which are relatively rich in MgO and FeO, show large variations in the Or content when changing from kata- to mesonorm.

Part V.
Isotopic age-determinations

BY

D. G. GEE

Introduction to Part V

The new geological data given in the earlier parts of this paper permit a reassessment of the age-determinations from Nordaustlandet. No new determinations have been made, but some more material is being analysed and the results will be published later. Fig. 72 shows the distribution of age-determinations from the area as given in GAYER et al. (1966), with the location of some of the samples a little changed, according to new information (SANDFORD, pers. comm.) and ammendments to the topographical and geological maps.

In 1964, HAMILTON and SANDFORD published the first isotopic age-determinations (Rb/Sr method) from Nordaustlandet. Subsequently, KRASIL'ŠČIKOV et al. (1964) presented new isotopic data by the K/Ar method. GAYER et al. (1966) presented three new K/Ar determinations and reviewed those published earlier, recalculating the Russian data according to the K/Ar decay constants $\lambda_\beta = 4.72 \times 10^{-10} \mathrm{yr}^{-1}$ and $\lambda_e = 0.584 \times 10^{-10} \mathrm{yr}^{-1}$, for direct comparison with their own data and the Rb/Sr determinations.

In all, 25 determinations have been made, of which 10 are by the Rb/Sr method and the rest by the K/Ar method. They fall generally in the age range 340—435 m.y. with two samples notably greater. The samples were all selected from the granites, gneisses and migmatites.

Previous authors have agreed that the dominance of "Caledonian" ages is indicative of important Caledonian deformation in the area. HAMILTON and SANDFORD considered that the two rocks yielding older age-determinations, from Nordkapp (537 m.y.) and Rijpdalen (581, 618, and 636 m.y.) supported the latter's theory of a sub-Hecla Hoek basement complex (SANDFORD 1956). Uncertainty about the nature of this Pre-Cambrian complex, indicated by WINSNES (1965), and the presence of comparable age-determinations from the amphibolite facies Lower Hecla Hoek of north-west and south-west Spitsbergen, led GAYER et al. to suggest, in addition, two alternative explanations for all the pre-Caledonian determinations; namely, that in common with the Lower Hecla Hoek of both these other areas, the ages indicated either some event at 600 m.y. or some earlier

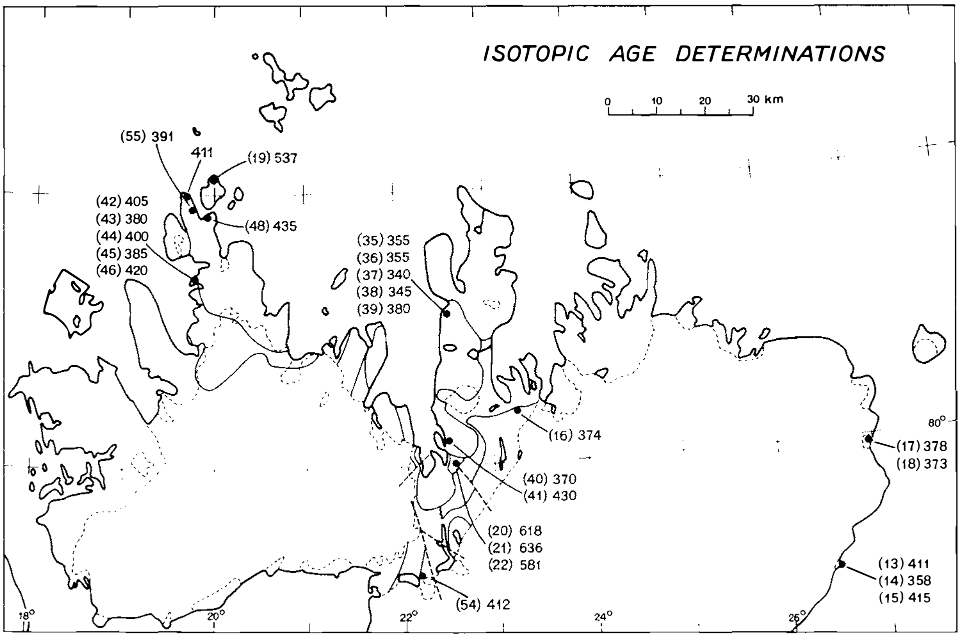


Fig. 72. *Location of samples used for radiometric age-determinations after* Gayer *et al.* (1966), *with the location of some of the samples a little changed. Values in millions of years. Nos. in brackets referring to* Gayer *et al.'s list of samples.*

event reduced by Caledonian metamorphism, but in both cases effecting the lower part of the Hecla Hoek.

Gayer et al. considered that the stratigraphic evidence from the Hecla Hoek favoured the second of these two alternatives and subsequently Harland et al. (1966) stated a preference for the older ages being indicative of "an event whose apparent age was reduced by Caledonian metamorphism: this could well correspond to thermal (volcanic) activity related to the Polarisbreen or Harkerbreen Group". However, the ages were obtained on thoroughly metamorphosed lithologies relatable, at least in the case of north-west Spitsbergen, to an important deformation sequence, and this led one author (Gee, in Gayer et al.) to favour late Pre-Cambrian metamorphism of the Lower Hecla Hoek in the north-west area. Gee and Hjelle (1966) reviewed this concept in the general context of the north-west Spitsbergen Hecla Hoek.

The age-determinations are considered below in two categories; firstly, the "Caledonian" ages and, secondly, the pre-Caledonian ages.

THE "CALEDONIAN" AGE-DETERMINATIONS

These have been obtained from both the post-orogenic granites and the syn-orogenic granites, gneisses and migmatites. In some cases it has been difficult to place the samples accurately on the new topographic map and at the same time reconcile this location with the description of the samples and the new geological data from the area. This is the case, for instance, with the Russian sample No. 41 "Biotite from a biotite gneiss in Wordiebukta". However, in general it is clear that the majority of the K/Ar ages have been made on the post-orogenic granites (the Zeipelbukta gravel No. 46 is a notable exception) and their ages, ranging from 412–340 m.y. may very well reflect late-Caledonian intrusion, similar to the Ny Friesland batholiths. At the same time it should be emphasized that the post-orogenic granites in Nordaustlandet have nowhere been recorded to intrude the Murchisonfjorden Supergroup, or overlying rocks.

Granitic, aplitic, and pegmatitic lithologies from within the general terrain of migmatites, gneisses and syn-orogenic granites have also yielded "Caledonian" ages, these determinations including analyses by the Rb/Sr and the K/Ar methods.

It is clear from all these "Caledonian" ages that an important event effected the area at c. 400 m.y. This either was the primary cause of the ages (e.g. the intrusion of the granites) or caused a regional reduction from some older intrusive and metamorphic episode(s). All the ages have been obtained either on whole rocks or phyllosilicates with the exception of one Rb/Sr feldspar age. The geological evidence is conclusive that during the Caledonian orogeny in Nordaustlandet there was a stratigraphic overburden of at least 8000 m (the thickness of the Murchisonfjorden Supergroup and overlying rocks) above the Botniahalvøya Group, and that at the base of this column chlorite crystallized during deformation, forming in the cleavage planes. Chloritization of the biotite in the granites and gneisses is frequent. It would be reasonable to suppose that if the rocks that have been analysed had existed prior to the Caledonian, and were subsequently subjected to this deformation, they would be unlikely to retain the daughter isotopes, and would therefore give broadly "Caledonian" ages.

THE PRE-CALEDONIAN AGES

Both the rocks yielding pre-Caledonian ages derive from the terrain of syn-orogenic granites, gneisses and migmatites. Of the two, the mica schist from Rijpdalen gave a Rb/Sr intersection (biotite-muscovite-whole rock) age of 613 m.y., indicating a minimum age for the metamorphism (HAMILTON and SANDFORD 1964). The location of the sample requires this metamorphism to be that affecting the Botniahalvøya Group where it is penetrated by the syn-orogenic granites. From the migmatite area of Nordkapp, feldspar from a granite pegmatite also yielded an age excessive for the Caledonian (537 m.y.) by the Rb/Sr method. The comparability of the Laponiahalvøya and Duvefjorden migmatite, gneiss and syn-orogenic granite areas, and the existence of these two isotopic ages suggests that the regional migmatization and intrusion was of pre-Caledonian age. This possibility has been discussed on the basis of the structural evidence in Part II, and a hypothesis is favoured which requires the unconformity at the base of the Murchisonfjorden Supergroup to separate the migmatite complex from the overlying blanket of sediments.

The evidence is not conclusive and more field work is required, particularly in connection with the regional significance of the sub-Murchisonfjorden Supergroup unconformity. It remains possible that the metamorphism and migmatization are indeed Caledonian, affecting only the lower part of the sedimentary Hecla Hoek sequence, and that the age-determinations are in error. A more extensive programme of age-determinations is in progress to further investigate these relationships.

Erratum

During the printing of the map, the two westernmost islands in Murchisonfjorden were given the colour of the Ryssø Formation. This should be corrected as they belong to the Kapp Sparre Formation.

Norsk sammendrag

(Summary in Norwegian)

AV

T. SIGGERUD

Norsk Polarinstitutt sendte i 1965 en ekspedisjon med de fem forfattere som geologer til Nordaustlandet. Nordaustlandet var da den geologisk sett minst kjente del av Svalbard på grunn av at området er så vanskelig tilgjengelig. I denne avhandling og på det medfølgende kart presenteres resultatene av dette geologiske rekognoseringsarbeidet, men det er også tatt hensyn til data fra tidligere arbeider, og det er således forsøkt å gi en generell oversikt over Hecla Hoek-komplekset på Nordaustlandet.

Feltarbeidet ble sterkt hemmet av de dårlige vær- og isforhold, og uten en utstrakt bruk av helikoptere som var utlånt fra det norske luftforsvaret, ville ikke arbeidet vært mulig. M/S «Brandal», en selfanger chartret som ekspedisjonsskip, fungerte som helikopterbase, men p.g.a. isen ble det lange flyvninger med geologer, assistenter og utstyr. Fordelt på de to helikoptere ble det i alt fløyet ca. 250 flytimer.

Den nordlige og sentrale del av Nordaustlandet (som er det området kartet dekker) består av en geosynklinal lagserie med prekarbonske bergarter. Mektigheten er mer enn 15 km, og lagserien kan korreleres med hva som er beskrevet fra områdene lenger vest. (Søndre del av Nordaustlandet sør for Wahlenbergfjorden er dekket av karbonske og yngre bergarter og behandles ikke i dette arbeidet.)

I hele området, og særlig i vest, har det vært en intrusjon av doleritter, antakelig av krittalder.

Det er oppstilt følgende lagserier med kambriske og sen-prekambriske lag under den karbonske diskordanse angitt fra de yngre til de eldre: Kapp Sparreformasjonen (kambriske dolomitter, kalkstener og skifre ca. 800 m), Sveanorformasjonen (tillitter og skifre ca. 250 m), Murchisonfjordens supergruppe, som består av tre grupper, Roaldtoppengruppe med øverst Ryssøformasjonen (dolomitter ca. 1000 m) og Hunnbergformasjonen (kalkstener ca. 500 m), Celsiusbergetgruppen med Raudstup-Säloddformasjonen (røde og grønne mergel- og slamstener med mindre mengder dolomitter ca. 500 m), Nordvikformasjonen (grågrønne slamstener og kvartsitter ca. 350 m), og Floraformasjonen (lys røde kvartsitter med mindre mengder røde og grønne slamstener ca. 1250 m), Franklinsundetgruppen med Kapp Lordformasjonen (skifre og kvartsitter, til dels inneholdende en del kalk og kalkstener ca. 950 m), Westmanbuktaformasjonen (røde og grønne kvartsitter og slamstener ca. 600 m) og underst Persbergetformasjonen (kvartsitter med mindre mengder grå skifre ca. 400 m. I vest er ikke bunnen kjent, i øst er det et konglomerat ved basis).

Under denne lagserien ligger Botniahalvøyagruppen med Austfonna-Kapp Platenformasjonene (kvartsitter, skifre, kalkstener og mindre amfibolitter minst 3000 m), Brennevinsfjordenformasjonen (båndete kvartsitter og skifre med et basiskonglomerat i vest ca. 2000 m) og Kapp Hansteenformasjonen (vulkanske bergarter ca. 4000 m).

Den underste del av lagserien er migmatittisert, i enkelte områder i stor utstrekning. Generelt sett har Botniahalvøyagruppen vært utsatt for metamorfose og er omvandlet til grønnskiferfacies, men metamorfosegraden tiltar mot migmatittene og inneslutninger i de synorogene granittiske bergarter er sikkert Botniahalvøyagruppens bergarter, men det opptrer øyensynlig ikke noe fra de overliggende lagserier. Gabbroer og kvartsporfyrer har intrudert Kapp Hansteenformasjonen og Brennevinsfjordenformasjonen før regionalmetamorfosen.

I to hovedområder, Brennevinsfjorden og Rijpfjorden-Rijpdalen, har man fremtrengen av større mengder granittisk materiale etter deformasjonen. Det er ikke observert at disse udeformerte intrusjonsbergarter gjennomsetter Murchisonfjordens supergruppe eller de yngre bergarter, de opptrer bare i de eldre gruppene og i migmatittene.

Den kaledonske fjellkjedefoldning har foldet de sedimentære lagserier, og det ble utviklet et asymmetrisk foldemønster, hvor akseplanene har et østlig fall. Hovedstrukturene kan grupperes med Hinlopenstretetsynklinalen, Vestfonnaantiklinalen, Lovénsynklinalen og Rijpdalenantiklinalen. I Rijpdalen er det iakttatt isoklinalfolder, som igjen er foldet i antiklinalen. Dette kan representere den mulige metamorfosefase av den eldre del av lagserien før avsetning av Murchisonfjordens supergruppe, og at man således hadde et sen-prekambrisk «basement» før avsetning av Midtre og Øvre Hecla Hoek.

Det forekommer et yngre sprekkesystem, hovedsakelig med N—S-retning, og et underordnet system med forkastninger i retningene VNV og SSV. I et avslutningskapitel diskuteres de tilgjengelige aldersbestemmelser i relasjon til de geologiske opplysninger som er fremkommet ved dette arbeidet. Bortsett fra to noe eldre prøver er alle andre aldersbestemmelser fra tidsrommet for den kaledonske fjellkjedefoldning.

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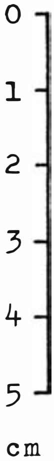
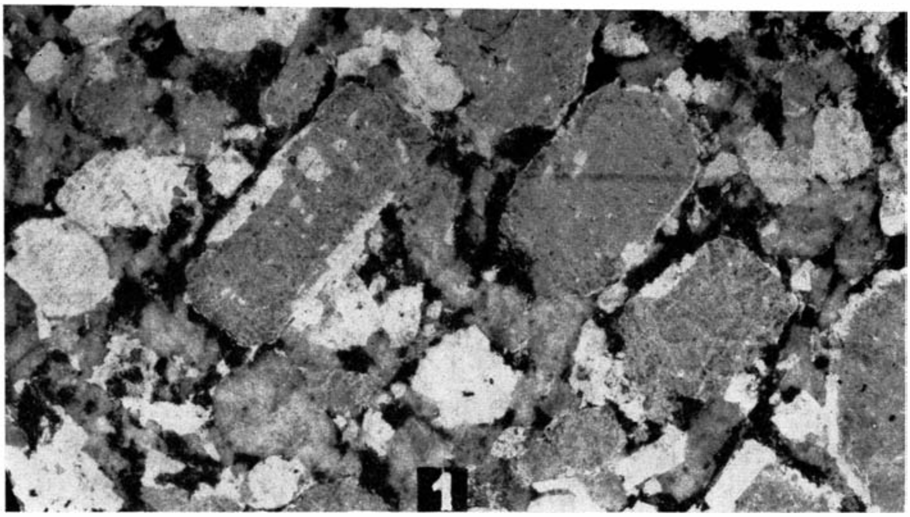
PLATE I

1 – *Quartz monzonite, Nordkapp–Brennevinsfjorden–Sabinebukta–Sjuøyane.*
2 – *Potassium granite along the eastern side of Brennevinsfjorden and near Sabinebukta.*
3 – *Normal granite in the Rijpdalen–Rijpfjorden area.*
4 – *Aplitic dyke, Beverlysundet–Duvefjorden.*
5 – *Quartz monzonite in the Ahlmannfonna–Duvefjorden area.*

Numbers refer to the text and the tables. All photographs show rock slabs etched with fluoric acid and stained with sodium cobaltinitrite. Potassium-feldspar appears grey, quartz grey to black, and plagioclase white. Natural size.

PLATE I

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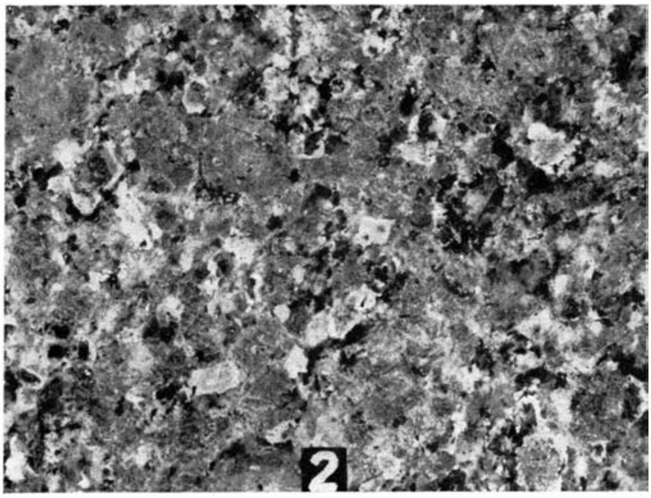
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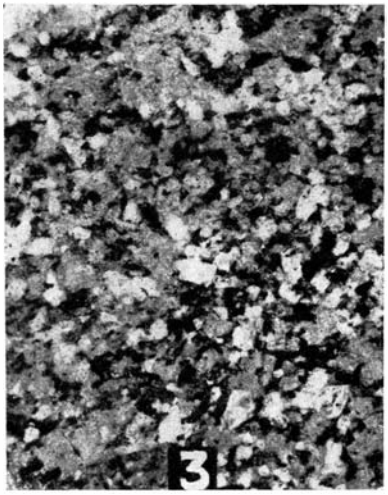
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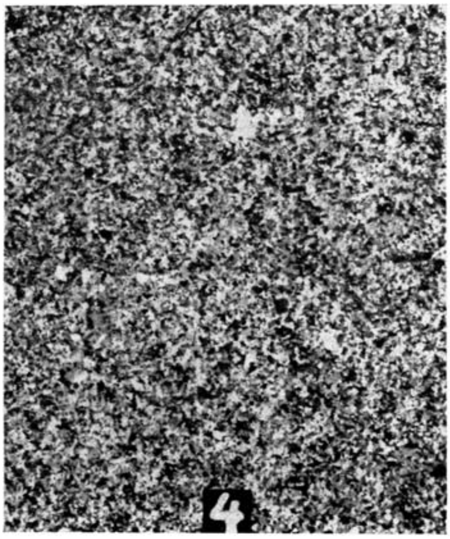
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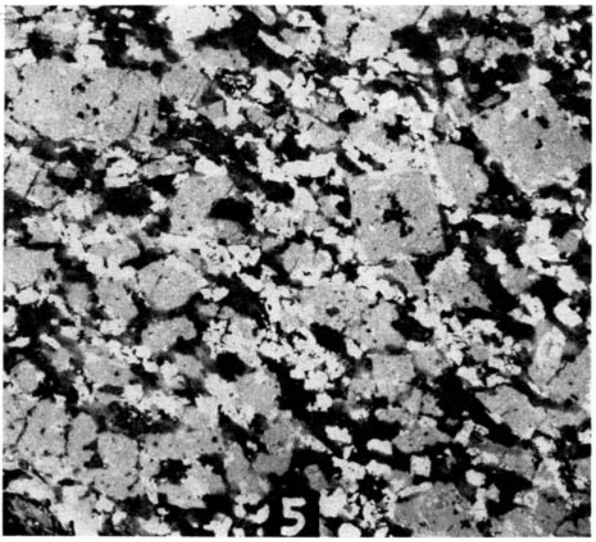

5

NORDAUSTLANDET

Northern and Central part
Nordre og midtre del

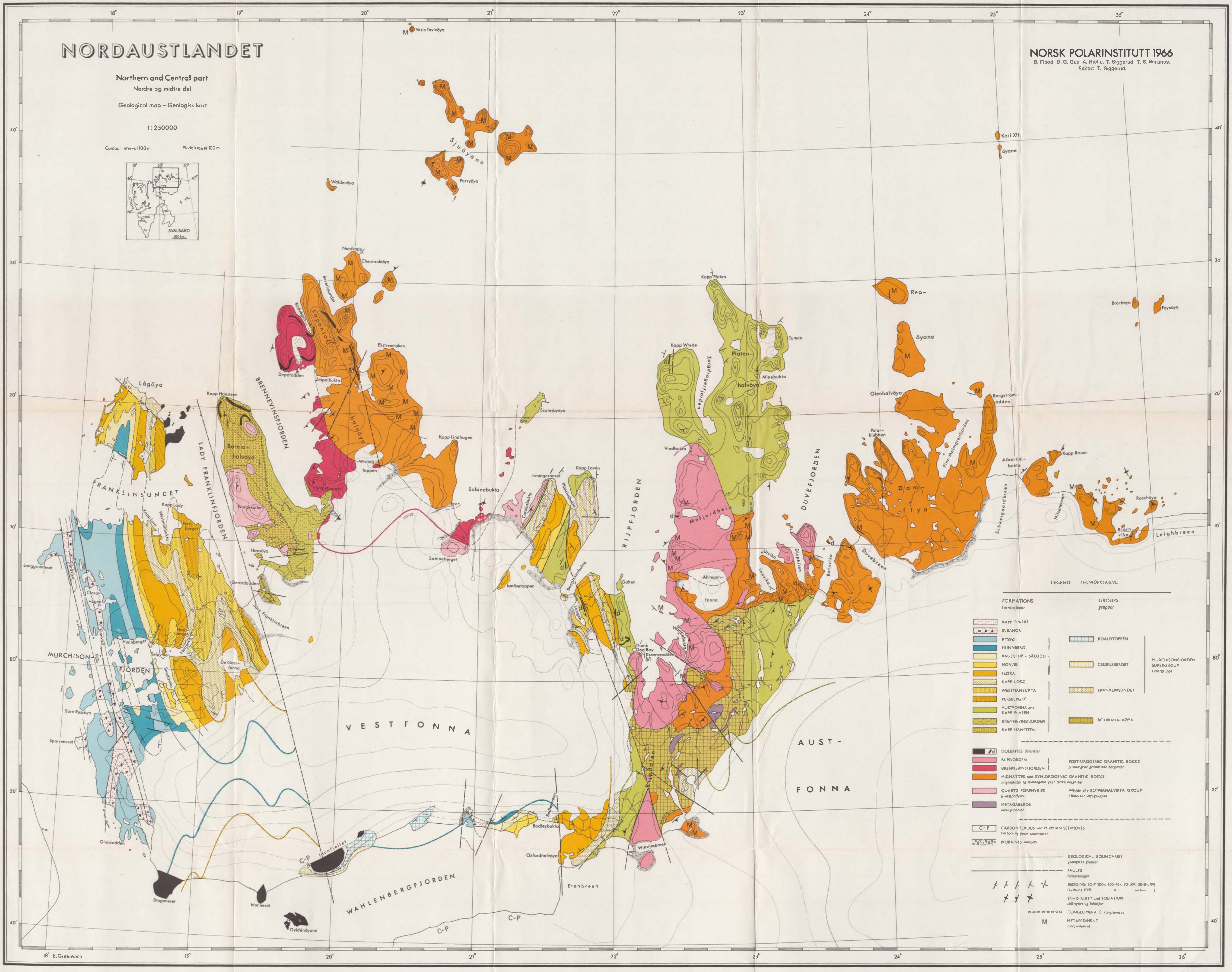
Geological map – Geologisk kart

1:250000

Contour interval 100 m   Ekvidistanse 100 m

NORSK POLARINSTITUTT 1966

B. Flood, D. G. Gee, A. Hjelle, T. Siggerud, T. S. Winsnes,
Editor: T. Siggerud.



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