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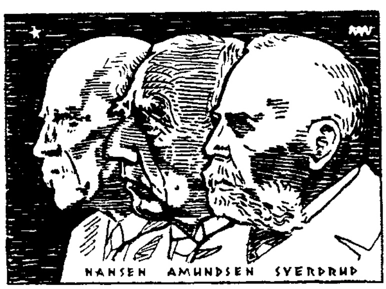

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Fra vulkanutbruddet på Jan Mayen, september 1970.
From the volcanic eruption on Jan Mayen, September 1970.
Photo: T. SIGGERUD.

Innholdsfortegnelse

The volcanic eruption on Jan Mayen 1970

BY
THOR SIGGERUD

Contents

Abstract

A major eruption took place on Jan Mayen in September–October 1970. The lava flows were first observed 20 September but evidence is discussed which indicates that the first opening of the fissures occurred two days earlier. Five crater groups were formed along a 6 km long fissure zone on the NE slope of Beerenberg, from about 1,000 m a.s.l. down to sea level. Lava from the craters built out approximately 4 km² new land into the sea, and the volume of the effusives is at least 0.5 km³, probably much more. The lavas are composed of a potassium-rich basalt. In late October the lava eruption ceased but tephra and gases were emitted sporadically up to the last observations in 1971.

Introduction

Preliminary information on the 1970 eruption on Jan Mayen has been given by GJELSVIK (1970) and by the Smithsonian Institution, Center for Short-lived Phenomena.

Jan Mayen is a remote island of 380 km² in the Norwegian Sea (Fig. 1). The volcanic origin of Jan Mayen has long been recognized from the many and typical crater mounds occurring on the island. The crater summit of the large strato-volcano, Beerenberg, reaches 2,277 m a.s.l., and this volcano is considered to be one of the most conspicuous volcanoes in the world (Fig. 2).

Although the central crater of Beerenberg has not erupted in historical time,

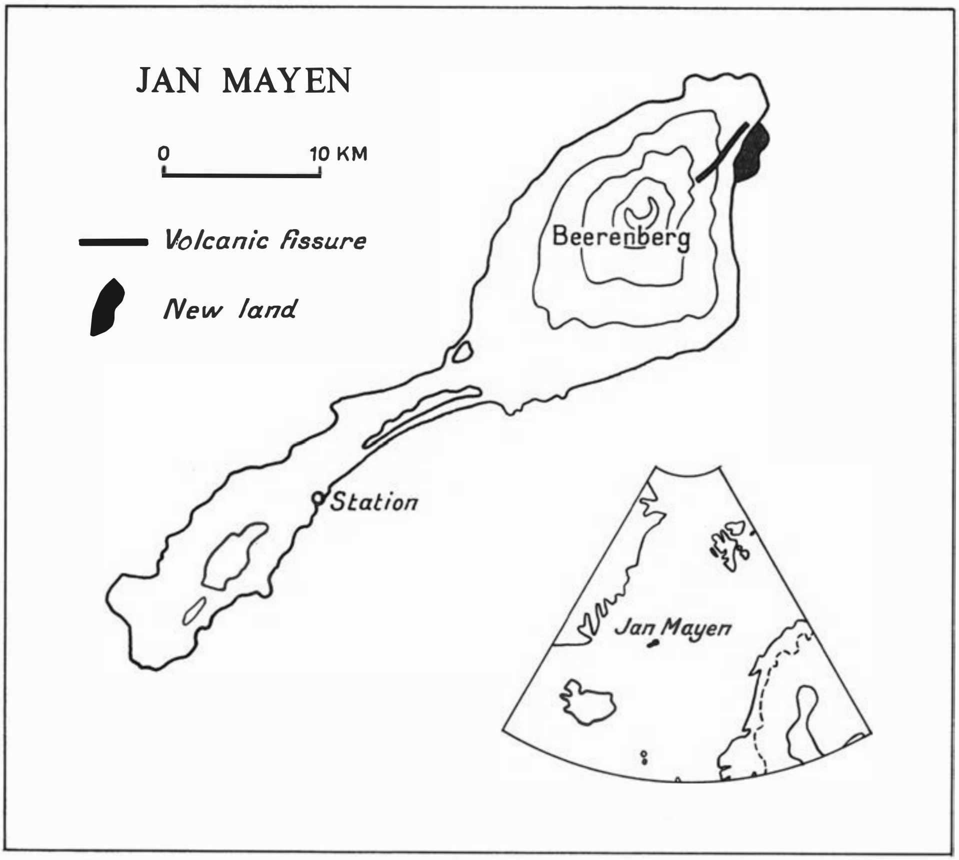

Fig. 1. *The locality of the new volcanic area on Jan Mayen and the geographical position of the island.*

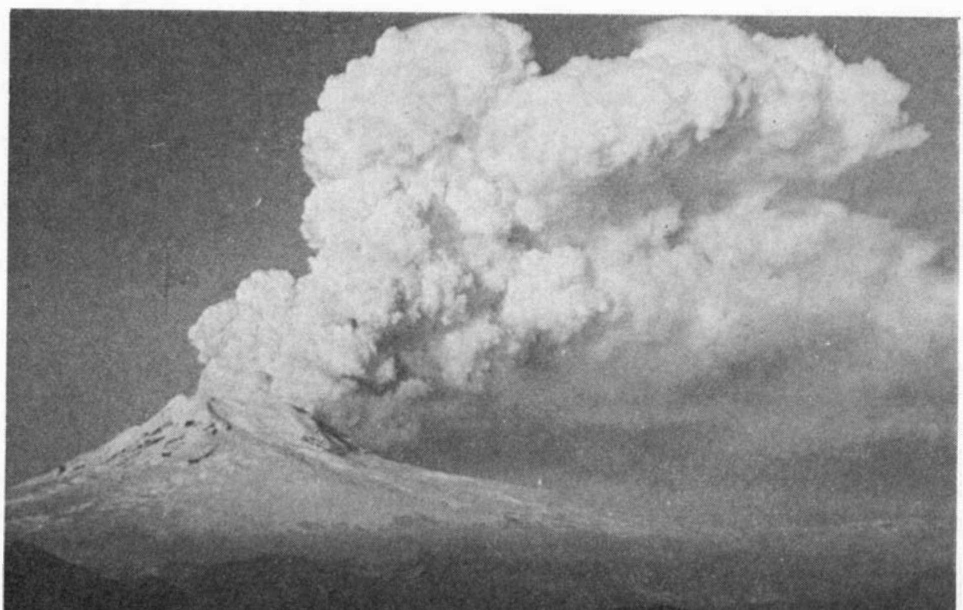

Fig. 2. *Beerenberg with steam cloud, September 20, 1970.*

written accounts about parasitic volcanic activity (ANDERSON 1746, SCORESBY 1820) confirm its volcanic origin.

Members of the Austrian expedition (1882–83) were the first to bring back geological material for a closer study, and gave a short description of it (BOLDVA 1886). This was the only geological record until the results of the "1921 Cambridge Expedition" were published (WORDIE 1922, 1926, TYRRELL 1926).

In the years 1947–1961 a number of British geological expeditions worked especially on the northern part of Jan Mayen, and their results have been published i.a. by NICHOLLS (1955), FITCH (1964), and ROBERTS & HAWKINS (1965). Samples collected during these expeditions have also been used for paleomagnetic studies (FITCH et al. 1965b) and for radiometric age determinations (FITCH et al. 1965a).

In 1959 a Norwegian geologist worked on the southern part of Jan Mayen (CARSTENS 1961, 1962). Nothing has yet been published from the central part of the island.

The petrography of the Mid-Atlantic islands in relation to their position relative to a Mid-oceanic ridge system has caused much interest (HEEZEN, THARP and EWING 1959). Today Jan Mayen's connection to the Mid-Atlantic Ridge is well known, and the island's special situation in this regard has been described by JOHNSON & HEEZEN (1967), JOHNSON (1968).

Earthquakes occur frequently in this part of the Norwegian Sea. HEEZEN & EWING (1961) point out that earthquake epicenters in the North-Atlantic Ocean (as plotted by GUTENBERG & RICHTER (1954)) tend to concentrate in a region along the central rift of the Mid-Atlantic Ridge. (It is interesting that KOLDERUP & KVALE (1938), in a paper on the earthquakes on Jan Mayen in 1936, called attention to the concentration of epicenters along a line in the middle of the Norwegian Sea.)

Similar observations were made by SYKES (1965) on the basis of more accurate determinations of epicenters in the Norwegian Sea, i.e. from central Iceland (neovolcanic zone) to Jan Mayen and northwards.

There is an obvious relationship between seismic activity, volcanic activity, and the Mid-Atlantic Ridge system, of which Jan Mayen is the northernmost island.

The beginning of the eruption

The first certain observation of the last eruption on Jan Mayen was made by the crew of a Japanese airplane at c. 0300 MET, September 20, 1970.

Later in the morning smoke columns protruding up to 10,000 m and fire were observed from Italian and German commercial planes.

In the preceding days a low pressure zone (995 millibars) had approached Jan Mayen from the south-west and this passed the island on September 20. This caused the formation of heavy clouds in the area and made earlier observations from the air impossible. On the night of September 20, a blizzard from the south-west made observations from the ground equally impossible, even if one had known what was going on.

The meteorological and LORAN station on Jan Mayen is situated about 30 km from the place where the eruptions occurred, with the towering Beerenberg between. At 0308 MET on September 18 an earthquake shook the Jan Mayen area and, in spite of the time of the day, was noticed by almost all of the crew of the station. This earthquake was recorded by most seismic stations and in Strasbourgh the position of the epicenter was calculated to be 71.2°N and 7.7°W, i.e. northeast of Jan Mayen. The actual locality where the eruption occurred is however well within the accuracy range of this location of the epicenter area. Smaller earthquakes were noticed later, particularly one at about 2300 MET on September 19.

As mentioned above, earthquakes are not uncommon in these waters and need not be connected with an eruption. However, a few other events focus our attention on the night between September 17 and 18. A Norwegian plane circling Beerenberg on the afternoon of September 17 did not notice anything extraordinary (B. WESTERN, pers. comm.). The plane stopped overnight on Jan Mayen and left the following morning at about 1000 MET; when breaking through the stratiform clouds that covered the area, the crew noticed the presence of a huge cumulus cloud in the vicinity of Beerenberg. The center of the above mentioned low pressure system was at that time situated near Jan Mayen. The same plane with the same crew made a new flight to Jan Mayen on October 2, and, when seeing the steam cloud above the eruption that day, were convinced that the cumulus cloud observed on September 18 was formed as a result of an eruption. This was the more likely as the cumulus cloud observed on September 18 was the only one to be seen above the stratus clouds for a long distance.

It is not unlikely that there was a connection between the low pressure passing Jan Mayen in this period and the beginning of the eruptions (Table 1). Low pressures have often been suggested to serve as the final trigger mechanism in releasing eruptions.

ESSA 8 satellite pictures as well as NIMBUS images have been studied and show the extent of the volcanic dust and gases. A NIMBUS picture from September 21, 1217 MET, displays a plume at least 400 km long, extending from Jan Mayen towards Norway (Fig. 3).

Table 1
Some observations from the Jan Mayen meteorological station, September 1970

Date	Time GMT	Wind in knots			Pressure in millibars
		at sea level	3,000 m	5,000 m	
17	1200	0 —	ESE 10	S 20	
18	0000	ENE 10	ESE 25	ESE 30	1002.7
	1200	N 25	NE 35	NE 50	990.1
19	0000	W 5	S 10	NW 15	991.9
	1200	WNW 10	NW 25	WNW 120?	995.3
20	0000	WNW 10	NW 40	NW 45	1002.2
	1200	W 20	NW 35	NW 25	1010.0
21	0000	NW 20	No observations because of the volcanic eruption		
	1200	W 20			

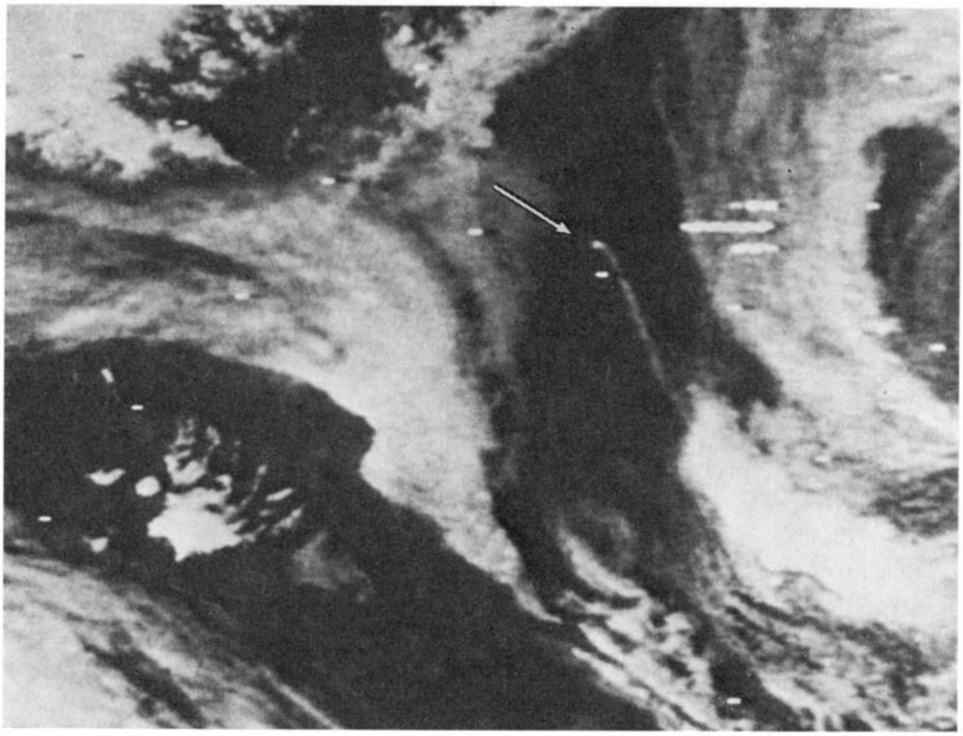

Fig. 3. *Jan Mayen with the plume of dust and steam, September 21, 1970.*
(NIMBUS IV 1217.02 MET, 1,100 km high.)

According to Y. GOTAAS (pers. comm.), dust from Jan Mayen came in over northern Norway on September 21 and lowered the visibility considerably. Volcanic dust sunset colors and prolonged twilight were noticed in southern parts of England on some of these days.

When comparing the position of the cloud on satellite photographs with wind speeds and wind directions on September 20 and 21 (Table 1), there are strong indications that the volcanic dust must have been brought into the atmosphere before the first certain observations of the eruption on September 20 (H. H. LAMB, pers. comm.).

It is concluded that dust was injected into the stratosphere in the initial phase of the volcanism, and that this must have taken place earlier than September 20 (SMITHSONIAN CARD, 1078–79).

All these different indications seem to give strong evidence for assuming that the eruption actually began during the night between September 17 and 18 and that the recorded earthquake was connected with the final penetration of the magma.

It is interesting at this point to speculate on how long it would have taken to become aware of the eruption had there been no flights by airplanes in the area, and if the unusually fine weather had not occurred on September 21 and 22, when the steam cloud was still high above Beerenberg. It seems likely to the author that as little as 20 years ago, when the weather-station was situated at the south-western foot of Beerenberg, this eruption would not have been recorded.

This should be kept in mind when discussing the frequency of eruptions on Jan Mayen, or of any remote, unpopulated volcanic island.

The observations of the eruption

After the volcanic activity had been reported on September 20, planes from Royal Norwegian Airforce were directed to the area, and from then on air-photographs were available. Especially during this early stage of the eruption the area was obliterated by smoke and tephra clouds originating from the vents or the steam formed when the lava entered the sea. The prevailing winds in these waters are easterly, and this resulted in the whole of the active area often being completely covered. However, this also happened at rather frequent intervals later during the eruption.

The crew of the station was evacuated to Norway by plane on the evening of September 20, but the next afternoon a plane returned to Jan Mayen with some of the crew and three geologists: BOYE FLOOD and THOR SIGGERUD from Norsk Polarinstitutt and Prof. CHRISTOFFER OFTEDAHL from the University of Trondheim. SIGGERUD returned with the same plane, to organize more regular observation flights with a plane from Iceland.

To get from the meteorological station to the northern side of Beerenberg over land is impossible. The area of eruption is therefore inaccessible without a ship, but landings are difficult and often dangerous, with the swell breaking at the nearly vertical old lava cliffs or on the new beach of pyroclastics.

On September 22 the Norwegian naval vessel, KNM «Heimdal», arrived at Jan Mayen and stayed in these waters, mainly outside the eruption area, until September 29. FLOOD and OFTEDAHL made three successful landings from this vessel, on September 22 to the southern lava stream, and the following day to the northernmost crater field. On the same evening the Icelandic geologist, Dr. G. SIGVALDASON, came to Jan Mayen with a plane from Iceland bringing along equipment for temperature measurements and gas sampling. Because of heavy swell, only one more landing was possible. The group went on shore at the north side of Koksslett and walked towards the eruption site (Fig. 4). However, a strong wind from the east carried tephra and volcanic gases towards the group, and it was not even possible to try to sample gases and measure temperatures. Sampling of solidified lava was carried out during all these landings.

At the same time, SIGGERUD observed the area from the air on September 21, 25, and 28, and October 1 and 8. From October 1 he stayed on at Jan Mayen onboard M/S «Polarbjørn». On October 3 he was able to go on shore from this vessel near the southernmost lava stream, and, although this was a rather wet and dramatic trip, a substantial amount of new lava samples were brought back.

Tourist flights to Jan Mayen on October 9 and 11, with geologists as guides onboard, reported steam and ash columns up to at least 500 m above the summit

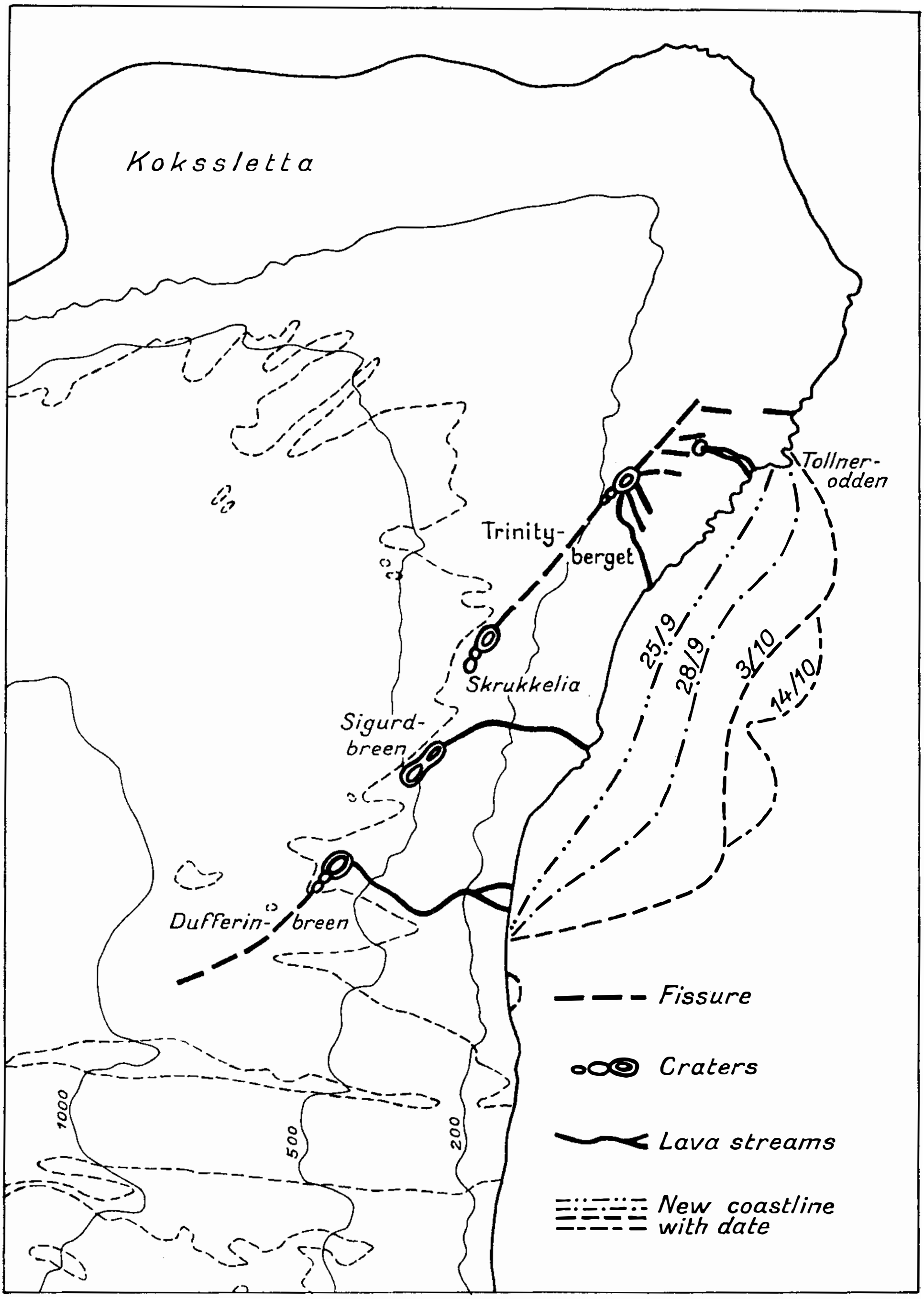

Fig. 4. *Map of the new volcanic area, north-east Jan Mayen.*

of Beerenberg. The actual craters could not, however, be seen because of clouds. After unloading provisions to the station, M/S «Polarbjørn» again patrolled outside the active area on October 14. This time no geologist was onboard and low clouds covered the craters. However, the extension of the lava front into the sea on that date (as shown by the radar screen) was plotted on the chart.

Later, only occasional clear days, as October 20 and 26 and November 5 and 17, made it possible to see the northern part of Jan Mayen with Beerenberg from the station. Columns of smoke and steam rising up behind Beerenberg made it clear that the activity had not ceased. The seismic event counter confirmed these observations. When OFTEDAHL revisited Jan Mayen on November 26, lava production had ceased.

In March 1971 new clouds were observed, but not until April 26 was SIGGERUD able to come to Jan Mayen and observe the previous eruption area from the air. At that time two craters were emitting smoke columns.

Observations on the volcanic activity

The activity was located along a fissure extending SW–NE for about 6 km along the north-eastern slopes of Beerenberg.

The fissure runs from Frielebreen about 1,000 m a.s.l. to Tollnerodden about 40 m a.s.l., and contains the following crater fields from south-west to north-east (Fig. 4): the Dufferinbreen crater about 600 m a.s.l., where lava production probably ceased on September 28; the Sigurdbreen crater about 500 m a.s.l., and the Skrukkelia crater about 450 m a.s.l., both producing lava in the beginning of October but with little activity in the middle of November; the Trinityberget crater about 50 m a.s.l., with probably still some lava activity on October 11; the Tollnerodden crater about 40 m a.s.l., where lava activity probably ceased as early as September 21.

During the first days the eruption was, as mentioned, rather explosive. The pilots on the first plane reaching Jan Mayen on the morning of September 20 reported seeing an 11,000 m high cloud, and stones that were hurled up to 5,000 m. The production of steam and gases showed large variations. After the first days came a period when the formation of steam clouds over the craters was rather limited, but it increased again and in the beginning of October the cumulus cloud was often much higher than the summit of Beerenberg. In the first week the production of tephra was also the greatest. In the neighbourhood of the volcano it was mostly as pumic lapilli in sizes up to 5 cm. These coarse-grained lapilli were formed by the gas-filled lava being thrown out in the lava fountains (see frontispiece).

The activity of the lava fountains pulsed and more local ash-falls around the craters were not uncommon. A vessel 5 km from the Sigurdbreen crater on the morning of October 2 was covered in a short time by a 1–2 cm thick layer of tephra with grain size up to 1 cm.

During most of the eruption the smell of sulphur was very pronounced as was occasionally also the smell of manure. On several occasions the small observation plane got into "gas clouds" that neither could be seen nor had any particular smell but that caused a severe irritation of the mucous membrane resulting in flood of tears.

The activity during the first week or so was not confined to craters. Steam was emitted at many places along the main fissure, and also from smaller more E–W directed fissures cutting the main one. On the other hand, some open fissures that were visited were cold.

Particularly during the first week the three southern craters were characterised by lava fountains. They all were pulsing with greater or less activity. However, lava fountains several hundred m high, and once probably up to 600 m, could go on for hours (see frontispiece). There were often two, three or even four jets of lava in each crater. Lava fountains were never very active in the Trinityberget crater. Here the lavas mostly poured out in streams, filling depressions and flowing out towards the sea.

The following description of the Sigurdbreen crater on October 2 can be taken as a very good example of the volcanic activity during this eruption: Around the Sigurdbreen crater a cone, at least 50 m high on the inner side towards Beerenberg, had been accumulated. The lavas were flowing rather quietly out of a large opening on the north-eastern side of the cone. Suddenly a series of small explosions took place on the south-western side of the cone, and a pulsing lava fountain was quickly developed. Glowing lava was spurted up to 200 m, falling down as plastic cakes and sliding down the cone and the mountain sides. Some of the blocks must have been at least 100 m^3. The more fine-grained material was blown much higher, taking the form of a tephra column. During this sequence the base of the lava fountain increased and became between 50 and 100 m in diameter. Meanwhile grey smoke began to form on the north-east side of the cone and developed into a gigantic ash column. Clouds of glowing ashes were occasionally thrown up inside the ash column. The glowing increased as the "cloud" expanded and could clearly be seen in the afternoon light. At other times similar completely dark "clouds" were emitted. After the eruption had gone on for about one hour, the amount of white steam clouds increased and covered the whole eruption area. However, judging from the noises, the eruption still continued for about three hours before it probably quietened down although the lava fountain was seen again in this crater both on October 9 and 11.

During the events described, lava production increased tremendously and consequently the lava streams rapidly increased in size, forming several branches as they ran down the mountain side. The temperature was determined with pyrometer to be between 1010 and 1030°C.

The lava streams soon acquired the very characteristic form with a darker crust in the middle of the stream and a sharper glow along the sides, caused by the frictional turbulence bringing new lava to the surface.

The lava streams were difficult to observe at the foot of the mountain, and the lava probably mostly ran in tunnels. As far as could be seen, the lavas approached and ran into the sea in two ways. Either the whole lava mass was pro-

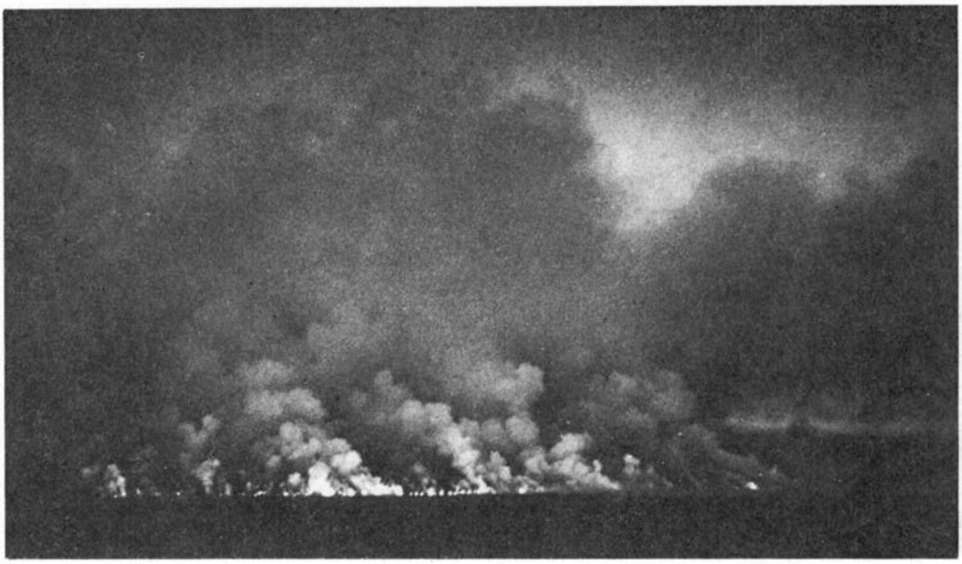

Fig. 5. *A nearly 1 km wide lava front advancing into the sea by breaking through the cooler lava surface.*

truded forward behind a cooler skin of lava, or, at places this skin ruptured and the molten glowing lavas poured directly into the sea (Fig. 5). In some of these cases the temperature was measured to 960–975°C.

The sea boiled and produced great amounts of steam along the lava front. Since the advance of the lava was irregular, there were places where the lava apparently had been cooled down before reaching the sea and thus caused no steam.

The question of how the lava moved along the sea bottom cannot yet be solved. However, there were indications of lava streams moving along the bottom 1,500 m in front of the newly formed lava coast at a water depth of c. 500 m. This assumption is naturally based on echo soundings and depth recordings, but upwelling areas of hot water well in advance of the lava coast is also taken as an indication.

On land the lava flowed rapidly over the vertical cliffs on the mountain side, but gave impression of being fairly viscous. The surface of the flows had the character of an a-a lava type. Usually the top of the lava was covered by blocks mostly 10–50 cm but up to 2 m in diameter. When ruptured, these blocks usually had a porous crust and a more massive, olivine porphyritic core. The blocks thrown out as bombs either exploded when hitting the ground, or deformed plastically, shaping themselves to the ground where they landed.

Seismic events

The earthquakes that initiated the eruption have been mentioned above.

On September 29, a seismic event counter was installed in the middle of the island, about 25 km from the nearest crater and one km from the shore. The instrument was set at a background of waves from a full storm and counted separate shocks 70% above background. Average counting level until October 12 was 600–800 per 24 hours, with variations up to 1450 and down to 200. Unfortunately the instrument broke down during a blizzard in the beginning of November, the last readings indicating 476 shocks per 24 hours.

One is inclined to assume that the shock waves are related to explosions in the upper part of the craters which were seen and heard from the observation boat. At times the explosions were very loud. On the morning of October 2, everyone sleeping onboard M/S «Polarbjørn» were woken by the loud noises even though the ship was more than 5 km north-east of the northernmost crater.

The volume of the effusives

During the whole eruption period the volume of effusives emitted per day, i.e. both pyroclastical material and lavas, showed great variation. For example, the volume of lavas increased in late September/early October; this is well demonstrated in Fig. 4, if one takes into consideration the increasing depth of the sea into which the lavas protruded. As no terrestrial measurements or new bathymetrical maps have been made, it is difficult to give even a rough estimate of the total volume of the effusives, as we have very little information on the gradient of the lava flows in the sea.

By October 14 the lavas and pyroclastics had built up a new land area of more than 4 km^2 outside the old coast line. The new coast line was mostly at a depth of between 50 and 100 m on the hydrographical map, but in one area it extended out to the 300 m line in the map. An estimate of the volume of the effusives (under the assumption that the gradient of the lava in the sea is c. 45°) gives a figure of the order of 0.5 km^3, nearly all made up of lavas. This new land area was apparently at its maximum in the middle of October before erosion began along the new coast line. No continuous tephra cover of any great thickness was observed, except when concentrated by wind and water. However, in the initial explosive phase (probably intensified as the water from the melting glaciers poured into the opening craters) fine material was even injected into the stratosphere and carried for hundreds of kilometers.

Later in the eruption period, when the lava fountains started to puls, a new active phase was usually initiated by explosions forming ash columns and local falls of pumic lapilli. On landing in the sea, these ash falls floated initially, but became slowly soaked with water and started to sink. Tephra clouds, which were slowly settling in the sea in this way, could often be seen on echograms. On land the area covered by tephra was never very large, at most 10 × 10 km. This was probably because of the violent draught of cold air down the snow-covered slopes of Beerenberg and the prevalent westerly winds. Even in the first days of eruption, the areas covered by floating tephra in the ocean east of Jan Mayen were small compared to the volume of the later lava production. At best one can only arrive at a reasoned guess for the amount of pyroclastics deposited outside the lava

Table 2
Analyses of Beerenberg basalts of 1970

	Sample 1	Sample 2
	early, The Dufferin-breen crater	October 3, The Sigurd-breen crater
SiO_2	48.40	45.79
TiO_2	3.20	3.19
Al_2O_3	17.10	16.21
Fe_2O_3	4.33	2.22
FeO	7.89	8.59
MnO	0.23	0.23
MgO	4.99	5.89
CaO	9.10	10.57
Na_2O	3.07	3.66
K_2O	2.69	2.68
H_2O		0.38
CO_2		0.22
P_2O_5		0.26
Total	101.00	99.89

covered area; on the basis of all available information, I would suggest that the volume is only equivalent to 0.025^3 km of lavas, i.e. it constitutes 5% of the suggested total volume of extrusives.

The lavas

According to a preliminary examination, lavas sampled both from the northernmost and the southernmost craters seem to be of the same lithology as those earlier described as Beerenberg basalts. Darker pyroxene and lighter olivine phenocrysts occur together with some intermediate plagioclase in a fine-grained basalt matrix. The new lavas are also very similar to the older ones in thin section. It is evident that there are two or three generations of crystallisation with more and more anorthitic plagioclases. Earlier fissure eruptions on north-east Jan Mayen (ROBERTS and HAWKINS 1971) were characterized by potash-rich basalts with pyroclastic material and viscous lava flows in the early phase of the eruption. This was followed by hotter and more ordinary basalts until eruption ceased. Two typical chemical analyses are given in Table 2. Sample 1 is from a lava stream from the Dufferinbreen crater one of the first days, and sample 2 is pyroclastic material from the eruption of the Sigurdbreen crater in the morning of October 3.

A more detailed description of the mineralogy and petrography of the lavas is given by WEIGAND (1971, this vol., pp. 42–52).

Later events and observations

During the winter no observations of the area of eruption were made.

The crew of the Jan Mayen station reported in March 1971 that clouds and ash columns had again appeared above Beerenberg. Unfortunately it was impossible at that time to make any direct observations of the eruption area. A little later a passing ship reported heavy steam clouds 1–1.5 km south of the Dufferinbreen crater.

The author did not get the opportunity to observe the area from the air before April 28. There was still some activity in the Skrukkelia and Sigurdbreen craters, with bluish-grey columns of dust-laden volcanic gases. White vapour clouds were seen everywhere, but no lavas or glowing gases were visible in the bright daylight. The area around the Dufferinbreen crater and farther south was obscured by clouds. When returning the next day, it was more cloudy but a well developed fissure in the glacier south of Dufferinbreen could be seen through a break in the cloud; it could also be seen that warm water had cut its way down Frielebreen.

A new visit on June 10 gave the information that gases were still being emitted from the Dufferinbreen crater and the two other craters but these were more quiet than in April.

There were reports from the station of a smoke column on June 8, which lasted for more than an hour and was higher than Beerenberg. Smaller columns were not uncommon. Another new development was that, since an earthquake in March, clouds could occasionally be seen on Eggøya, the old crater at the southern foot of Beerenberg. Tephra from this eruption had been collected and, as they are completely ungraded, the possibility of long transport from the northern eruption area seems small. More probably there may have been secondary eruptions of tephra, caused by gases blowing out through old ash layers in the strato-volcanic cone of Eggøya. Hot gases, with a temperature of 62°C, escaped from 5–10 cm wide fissures in the top of Eggøya.

(In 1935–36 it was quite common for the crew that wintered near Eggøya to see irregular outbursts of steam from this island, usually about 50 m high (WESTERN, pers. comm.). During the same period earthquakes were frequent and some damage was done to the meteorological station.)

The most recent information from Jan Mayen concerns movements of the ground, although these are not properly confirmed by reference to bench-marks. On the other hand, such movements would be expected to occur in a volcanic area.

Acknowledgements

The field work on Jan Mayen was also conducted by geologist BOYE FLOOD from September 21 to 29. Before he left for Tasmania in the early winter, we discussed this paper and he placed all his information and notes at my disposal, and for this he is most heartfully thanked. For stimulating conversations with Prof. CHR. OFTEDAHL I am very thankful.

The author also wishes to thank the crew of the station on Jan Mayen and the leader Ø. SØVIK, and the officers and crew of M/S «Polarbjørn» for hospitality and valuable help. Dr. D. WORSLEY has kindly read and corrected the manuscript. Last but not least, I wish to thank my wife for all help.

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The petrology of the volcanic and intrusive rocks of Nord-Jan, Jan Mayen

BY

TERENCE R. W. HAWKINS[1] and BRINLEY ROBERTS[2]

Contents

Abstract

Nord-Jan is the northern part of the island of Jan Mayen situated on the Arctic continuation of the Mid-Atlantic Ridge. It is dominated by the volcano Beerenberg (2277 m) and is built from basaltic lavas and pyroclastic rocks.

Rock types include potash ankaramites, potash basalts, trachybasalts and trachyandesites. The Na_2O/K_2O ratio averages 1.15, which is lower than the mean ratio for comparable rocks from other Atlantic islands. The presence of appreciable amounts of xenocrystic minerals, viz. green chromian diopside with low Al_2O_3 content, and high magnesian olivines with relatively

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high NiO content is characteristic. Xenocrysts often make up 20–40% of the rock bulk. The rocks also contain phenocrystic and groundmass brown titansalite, phenocrystic and groundmass plagioclase, and groundmass olivine, alkali feldspar, analcime, iron ore, apatite, ± biotite and ± kaersutite.

Xenocrysts are thought to have crystallised within the Upper Mantle, at pressures probably greater than 20 kb, whereas the brown titansalites and other phases crystallised at lower, near-surface pressures. The short range of rock types, emphasised by the Thornton-Tuttle differentiation indices, implies that the rocks have only undergone moderate differentiation at near-surface pressures. No peridotite phases apart from green chromian diopside and olivine, are found in any of the rocks, and so the earliest differentiates of the magma could have been wehrlite.

It is possible that the initial basic melt was produced by the partial melting of mantle material at 20–30 kb which had reached the wehrlite condition. If the basic melt so produced then precipitated olivine and chromian diopside at 20–30 kb, it could possibly lead to the production of a residuum equivalent to the primitive Nord-Jan magma.

Introduction

Jan Mayen is a volcanic island on the Arctic continuation of the Mid-Atlantic Ridge between Greenland and northern Norway (Fig. 1). Nord-Jan is the youngest part of the island and is dominated by the volcano Beerenberg (2277 m).

A major eruption began in September 1970 (GJELSVIK 1970). Lava and ejecta were emitted from five eruptive centres along a north-east trending fissure line, and a new lava platform was formed in an area that was formerly part of the sea.

WORDIE (1926) published the first important work on the geology of Nord-Jan, concluding that Beerenberg was post-Pleistocene, and that volcanic activity had moved north-eastwards with time throughout Jan Mayen. He suggested that the high Beerenberg cone was built of trachybasalt flows, while below was a varied

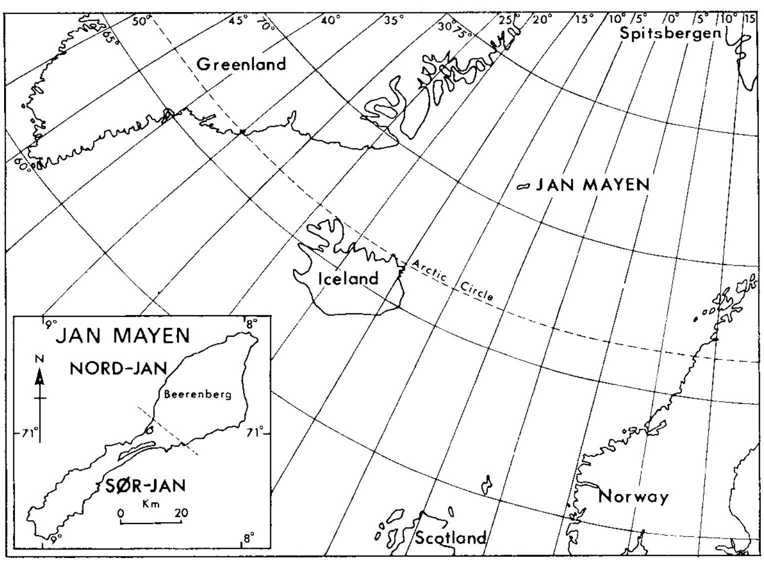

Fig. 1. *The location of Nord-Jan.*

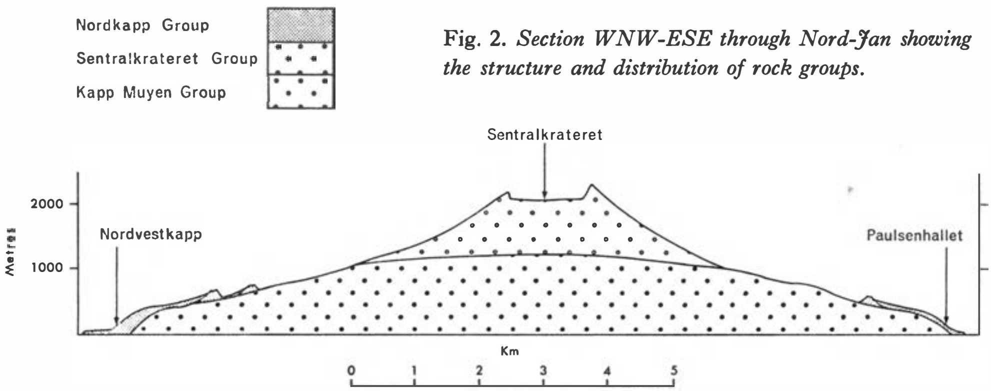

Fig. 2. *Section WNW-ESE through Nord-Jan showing the structure and distribution of rock groups.*

succession of lavas, sills and tuffs of ankaramite. Recent activity was said to have occurred at small parasitic cones on the lower slopes of the mountain. TYRRELL (1926) concluded that the parent magma-type of Jan Mayen was trachybasaltic, and that the ankaramite sills reported by WORDIE represented an ultrabasic accumulative magma. NICHOLLS (1955) observed that many of the so-called sills of WORDIE (*op. cit.*) were in fact ankaramitic lavas. He grouped the volcanic sequence into three cycles, each beginning with ankaramite and evolving to trachybasalt via intermediates. FITCH (1964) compiled the results from two University of London expeditions to Nord-Jan, and erected a succession based on rock stratigraphic units. This succession was used by the present authors in describing the geology of the Nordkapp area (ROBERTS and HAWKINS 1965) and is again adopted for this account.

The succession and structure are summarized below, and diagrammatically in Fig. 2.

3. Post-Sentralkrateret parasitic deposits and sediments	NORDKAPP GROUP	Smithbreen Formation Koksletta Formation Tromsøryggen Formation
2. Central vent lavas and pyroclastic rocks forming the Beerenberg high-level cone	SENTRALKRATERET GROUP	
1. Nord-Jan lava and pyroclastic dome	KAPP MUYEN GROUP	Nordvestkapp Formation Havhestberget Formation Storfjellet Formation Kapp Fishburn tillite Krossbukta Formation

Petrography

The volcanic rocks include porphyritic basaltic lava flows and air-fall pyroclastic deposits. The dykes, many of which were feeders to lava flows, are porphyritic and non-porphyritic basalts.

LAVAS AND INTRUSIVE ROCKS

Lavas occur as thin flows, generally less than 5 m thick, in all formations except the Havhestberget Formation. Dykes are numerous in the Storfjellet Formation, but are less frequently found in the younger formations. They vary in thickness from a few cm to 4 m, but the majority are about 0.75 m. The thinner dykes in particular tend to follow slightly sinuous courses. There are also a few sills and irregularly-shaped basaltic intrusions.

Modal analyses were obtained for 50 representative rocks from Nord-Jan. Modal analyses of basalts however present problems due to their fine grain size and porphyritic textures (LE MAITRE 1962, p. 1311, ROBERTS and HAWKINS 1965, p. 41) and the following procedure was therefore adopted. Point count analyses were first made for each rock, using a megagrid, in which the constituents measured were phenocryst species, viz. clinopyroxenes, olivine, plagioclase and groundmass. Consistent results were obtained. Point count micrometric modal analyses were then made of the groundmass constituents alone. Re-determination showed that despite the fine grain size, errors were generally of the order of $<5\%$ for the essential components. The results from both steps were then combined to give the final modes.

The rocks consist of combinations of green chromian diopside, brown titansalite, olivine, plagioclase, ore minerals, potash feldspar, apatite$\pm$analcime$\pm$biotite and $\pm$kaersutite. The dominant ferromagnesian mineral in all the rocks is clinopyroxene, and rocks with a colour index>70 are therefore classed as ankaramites (WILLIAMS, TURNER and GILBERT 1954, p. 73–74). In the majority of rocks the average An content of the plagioclase is>50, but in some rocks it falls within the range 30–50 (Fig. 3). Such rocks are andesites (cf. hawaiites of MACDONALD 1960). According to the recent classification by STRECKEISEN (1967) the andesites would be referred to as basalts, or latite basalts, as their overall colour index is greater than 40. This scheme, however, is not adopted here because the majority of rocks contain high accumulative mineral fractions.

All the analysed rocks contain potassium-rich alkali feldspar in the groundmass. Where this mineral makes up less than 10% of the whole rock, the prefix "potash" is added to the rock name (see Table 1). Rocks in which the percentage of alkali feldspar exceeds 10% are designated by the prefix trachy. These rocks have soda/potash ratios generally within the range 2/1 to 1/1, and differ from the rocks of the alkali basalt series, where the ratio is between 3/1 to 2/1 (MANSON 1967). On the other hand they are not as rich in potash as shoshonites and latites (JOPLIN 1965) where the Na_2O/K_2O ratio ranges from 1/1 to 1/2. Using the parameters outlined, six groups of rocks have been recognised, and the scheme is illustrated in Table 1 and Fig. 3.

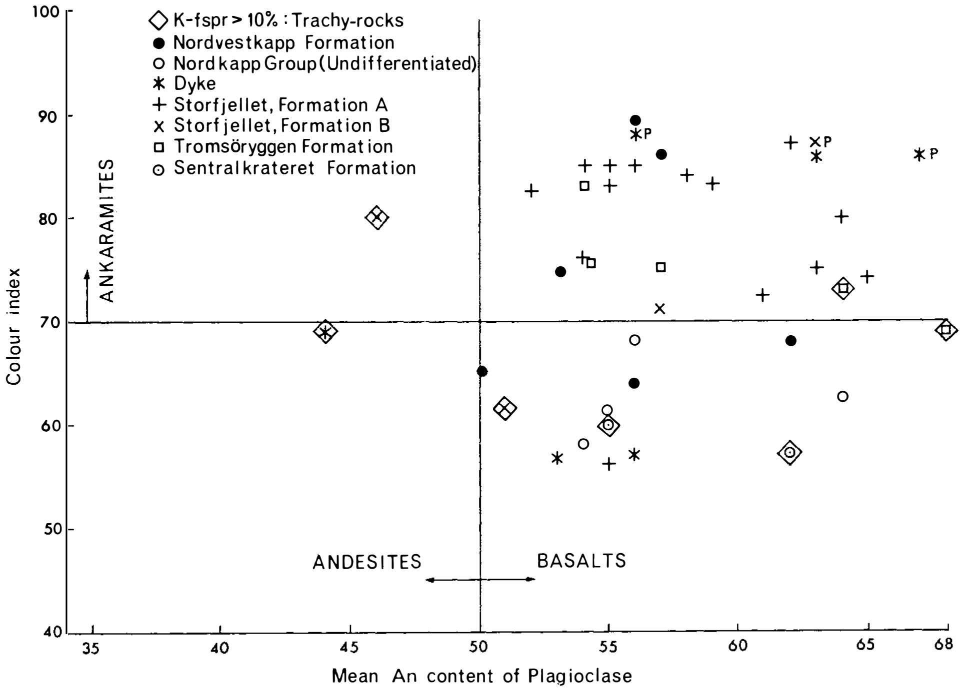

Fig. 3.

Table 1

Parameters used in naming the Nord-Jan basaltic rocks

Colour index increasing —— 70% ——▷

% of potash feldspar increasing ▽	ANDESITE GROUP	BASALT GROUP	ANKARAMITE GROUP
0%–10%	Potash andesite	Potash basalt	Potash ankaramite
10% →	Trachyandesite	Trachybasalt	Trachyankaramite

30% 50%
An content of plagioclase increasing ——▷

The boundaries are arbitrary, and there is gradation from one group to another, but the table also conceals a number of important features with genetic significance, which can only be brought out in descriptions of each of the three main groups.

There are three distinct types of ankaramites:

1) those which are ankaramites because of the high proportion of green chromian diopside xenocrysts, in what is essentially a basaltic matrix; 2) those in which brown titansalite phenocrysts are held in a basaltic matrix, and 3) those, less common, in which the matrix itself is an ankaramite. The basalts are similarly a

polygenetic group, comprising rocks with a few phenocrysts held in a basaltic matrix as well as rocks consisting of abundant plagioclase glomerocrysts set in an ankaramitic groundmass. Petrographic descriptions are therefore more meaningful if emphasis is laid on the matrices.

An ankaramitic lava matrix typically consists of abundant equant grains and prisms of yellowish-brown titaniferous clinopyroxene, up to 0.25 mm across, subhedral to euhedral octahedra of titanomagnetite, averaging 0.05 mm across and isolated, randomly orientated, plagioclase laths, which may reach 0.1 mm in length. Subhedral olivine, often partially iddingsitised, occurs scattered throughout the matrix, and reaches 0.05 mm in diameter. Rods of opaque ore (? ilmenite) occur randomly distributed and sometimes as overgrowths from titanomagnetite. Shapeless pools of alkali feldspar, carrying minute needles of apatite, are sporadically distributed and have a maximum diameter of 0.05 mm. Potash feldspar also occurs as discontinuous rims to plagioclase. In dyke rocks the same textural relationships are seen, but the average grain size is about 0.1 mm, and apatite needles are clearly visible.

A potash basalt lava matrix typically has an intergranular texture. A meshwork of plagioclase laths, 0.05–0.1 mm in length, supports subhedral grains and prisms of yellow-brown clinopyroxene and euhedral octahedra of titanomagnetite. Magnetite and pyroxene average 0.025 mm across. Pools of interstitial alkali feldspar are more common than in ankaramitic matrices, and there are rare patches of water clear analcime. Ragged plates of biotite, up to 0.025 mm across, also occur in some of the matrices. A trachybasalt lava matrix is similar, but alkali feldspar exceeds 10% of the bulk. Ilmenite rods occur throughout lava matrices of both types. In dyke rocks the same intergranular texture is seen, but the plagioclase laths now commonly reach 0.5 mm in length. They show normal zoning and may be mantled with an incomplete rim of alkali feldspar.

A trachyandesitic lava matrix commonly has a trachytic texture. Andesine and alkali feldspar, 0.05–0.10 mm in length, make up a flow aligned framework, which supports euhedral grains and prisms of brown clinopyroxene and octahedra of titanomagnetite, 0.025 mm across. Sporadic ragged plates of biotite are present, being <0.04 mm across. Colourless, isotropic analcime occurs in interstitial patches. Ilmenite appears to be absent. The colour index of trachyandesites is generally lower than that of trachy- and potash basalts.

PYROCLASTIC ROCKS

Mounds, cones and beds of tephra make up a large proportion of the exposed volcanic rocks. The Havhestberget Formation is entirely composed of yellow-coloured tuffs and the Storfjellet and Tromsøryggen Formations are largely made up of black (weathering to red) scoria, spatter, bombs and blocks, tuffs, agglomerate and agglutinate. Even the Nordvestkapp Formation, predominantly composed of lava flows, contains a few thinly bedded tuffs.

For descriptive purposes the pyroclastic rocks of Nord-Jan are grouped as follows:

(i) *Tuffs and lapilli-tuffs* (fine-grained deposits) — Red and black ash-fall tuffs; Yellow Havhestberget massive and bedded tuff

(ii) *Volcanic breccias and agglomerates* (large fragment-sized deposits)

(iii) *Scoria, spatter and agglutinate* (fire-fountaining deposits)

(i) *Tuffs and lapilli tuffs*

Red and black bedded tuffs. – These rocks are crystal-lithic tuffs consisting of broken crystals (<0.75 mm across) of green clinopyroxene and olivine, scattered small plagioclase laths (<0.3 mm length), fragments of red and black vesicular potash basalt, or ankaramite, and a few small, dark-bordered, olivines, averaging 0.1 to 0.15 mm across. The matrix is a very vesicular, red or black, fine-grained or glassy potash basalt with microlites.

The green clinopyroxenes have very thin borders of brown clinopyroxene, and do not carry exsolution iron ores. The olivines on the other hand contain abundant exsolution ores, or may be completely iddingsitised. The vesicles are generally undeformed.

Yellow Havhestberget tuffs. – These rocks are a distinctive pale-yellow to yellow-brown colour. They are well compacted crystal-lithic-vitric pumice tuffs, with variable amounts of lapilli-sized potash basalt (or ankaramite) fragments up to 15 mm across.

A few of the tuffs are bedded, but the major part of the Havhestberget rocks show no trace of bedding, and are spread over large areas. They may possibly be unwelded ash-flow tuffs (FITCH 1964, ROBERTS and HAWKINS 1965) but are now considered to be palagonite tuffs, probably produced beneath ice.

The unbedded facies consists of yellow basaltic pumice fragments and laths (generally up to 5 mm across, but rarely reaching 20 mm), numerous small, often broken, crystals of green and brown clinopyroxene, olivine, opaque iron ore, plagioclase glomerocrysts and isolated laths. The pumice vesicles are partly or wholly infilled with a fibrous or granular zeolite, usually accompanied by minor amounts of calcite. There are also abundant interstitial zeolites, and the yellow glass of the pumice encloses numerous small crystals of apatite.

The pumice fragments have no preferred orientation, and are unsorted. In most cases the vesicles are spherical to slightly ovoid; the ratio of the semi axes ranging from 1:1 to 2:1. A few pumice fragments, however, have vesicles which show a greater degree of flattening (semi-axes ratio up to 6:1).

The bedded tuffs are generally finer-grained than the unbedded tuffs. They consist of numerous yellow shards and small pumice fragments up to 0.3 mm across, a scattering of small green and brown clinopyroxene crystal fragments (up to 0.2 mm across), slender plagioclase laths (average 0.2 mm in length) and opaque iron ore. There are also a few small potash basalt rock fragments and rare olivine crystals.

The majority of the vesicles are empty and undeformed, but a small minority are flattened (semi axes ratio up to 4:1) and/or partly filled with zeolite or finely granular calcite.

(ii) *Volcanic breccias and agglomerates*

Discrete bombs and blocks are common constituents of the Kokssletta and Smithbreen Formations, although there are lesser amounts of these materials than the equivalent-sized products of fire fountaining (spatter and agglutinate). In this paper the terms bombs and blocks are restricted to fragments which were solid or viscous enough when they hit the ground to retain the shape they possessed on eruption or acquired in the air.

The bombs exhibit a large variety of shape and form, most of which have been described from Hawaii (MacDonald 1967), and include almond-shaped, fusiform, finned and elongate ribbon bombs. Large angular basaltic ejecta (blocks) are found in the vicinity of a few recent vents. The blocks are mainly composed of potash- or trachybasalt. In a few cases small blocks are held in a compacted red or black tuff matrix, and constitute agglomerates.

At the extreme south-west of Nord-Jan, in the vicinity of the partly sea-eroded vent of Eggøya, the ejected blocks are more variable in composition. Many of these rock types are probably related to the more trachytic rocks of Sør-Jan, and consequently are not discussed here.

(iii) *Scoria, spatter and agglutinate*

These materials are largely the products of fire fountaining, and are the principal constituents of the numerous cones and elongated fissure mounds of Nord-Jan. Agglutinate also occurs as uniform spreads, known as agglutinate fields (Hawkins and Roberts 1963), derived from eruption from an anastomosing fissure system. Scoria consists of red or black, highly vesicular, fine-grained potash basalt and basaltic glass, with scattered broken crystals and microlites of green clinopyroxene and olivine. Olivine crystals carry red exsolution iron-ore minerals. The clinopyroxenes have not exsolved iron-ore, but are bordered by very thin rims of brown clinopyroxene.

Agglutinate and spatter are composed of similar rock material to the scoria, but their larger constituent fragments are flattened. These fragments often possess Pele's hair structures, and consistently have a glassy skin. Two varieties of agglutinate, based on fragment size and occurrence, are distinguished: viz. large, highly vesicular, flattened pancakes, usually between 10 and 20 mm across, which occur in lips to fissures and vents; and smaller less vesicular driblets, found as layers in cones and mounds (Hawkins and Roberts, *op. cit.*).

PETROGRAPHIC COMPARISON OF NORD-JAN ROCKS WITH THOSE FROM OTHER ATLANTIC ISLANDS

Petrographically the ankaramites, potash basalts, and trachyandesites of Jan Mayen are generally similar to the same rock types described from the Azores

(ESENWEIN 1929, TORRE DE ASSUNCAO 1959), Gough Island (LE MAITRE 1962), Tristan da Cunha (BAKER et al. 1964), and Saint Helena (BAKER 1969). They all contain unzoned, sometimes iddingsitised olivine, zoned brown titaniferous clinopyroxene, which occurs as phenocrysts and as a groundmass phase, labradorite or andesine, magnetite and/or ilmenite and/or titanomagnetite, interstitial alkali feldspar and smaller amounts of accicular apatite, biotite and an amphibole. In addition, a colourless isotropic interstitial mineral, leucite or analcime, occurs in the rocks of Tristan da Cunha, Saint Helena, and Nord-Jan. In all cases modal orthopyroxene is absent.

In contrast to the rocks from these other islands the Nord-Jan rocks contain abundant dark green chromian diopside xenocrysts, and many of the olivines are xenocrysts. A few xenocrystic clinopyroxenes have been recorded from the other islands, but they are described as being black in hand specimen.

Although trachytes occur in Sør-Jan (CARSTENS 1961), they are not found in Nord-Jan, and consequently in this paper these rocks cannot be compared with trachytes and phonolites from other Atlantic islands.

Mineralogy

METHODS AND TECHNIQUES

Refractive indices were determined by the immersion method using crushed grains of phenocryst, xenocryst, and matrix phases. The results are considered accurate to ± 0.003. The maximum extinction angle for plagioclase in the zone perpendicular to (010) was measured on a Leitz four axis universal stage. Potash feldspar was identified in the rocks by staining with sodium cobaltinitrite. Olivine and clinopyroxene xenocrysts and phenocrysts were analysed on the electron microprobe.

OLIVINES

Olivine is found in all the rocks studied as phenocrysts and/or xenocrysts. It occurs in the groundmass of ankaramites and basalts, but may be absent from the groundmass of trachyandesites. It is pale-green in hand specimen, but colourless in thin section, unzoned and without reaction rims. Xenocrystic olivines are sometimes found in aggregates in parallel growth, and frequently show translation lamellae sub-parallel to (100) (TURNER 1942). The olivines may be partially or wholly iddingsitised (GAY and LE MAITRE 1961). They are seldom altered to serpentine minerals. In agglutinate and spatter deposits particularly, the olivines have often exsolved an ore phase, which is hair-like in habit, and pleochroic from red-brown to yellow-brown. LE MAITRE (1962) showed that in the Gough Island rocks similar material consisted mainly of magnetite with minor hematite, and that this effect can be reproduced experimentally by heating olivine in air for a few hours above 600°C.

The analyses and refractive indices for large olivine crystals are shown in Table 2. Iron is calculated on the basis that it is all ferrous iron. In all cases the atomic ratio was within the range Fe_{10} to Fe_{20}. Neither optical properties nor chemical analyses could be determined with satisfaction for the groundmass olivines bacause of their small size and relative scarcity.

The olivines have a significantly high NiO content which ranges from 0.13 to 0.28 weight per cent.

CLINOPYROXENES

Two species of clinopyroxenes occur in the majority of rocks. Large, dark-green crystals, which are pale yellow-green in thin section, are chromian diopsides. The second clinopyroxenes are lilac-brown titandiopsides and titansalites, which ubiquitously occur as the groundmass pyroxene, but also exist as rims to the green chromian diopsides and as glomeroporphyritic clusters or individual phenocrysts (ROBERTS and HAWKINS 1965).

Table 2

Olivine analyses

(Analyses by P. SUDDABY.) NC 15K, 15L, 19A, 19B, 19C – olivines from potash ankaramites. NC 12CF, 12CG – olivines from a trachybasalt. NC 22I, 22K and 220 – olivines from a trachyandesite.

	NC 15K	NC 15L	NC 19A	NC 19B	NC 19C	NC 12CF	NC 12CG	NC 22I	NC 22K	NC 22O
SiO_2	41.44	40.93	41.28	40.95	41.18	40.74	41.55	40.49	40.39	40.78
TiO_2	—	—	—	—	—	—	0.04	0.01	0.01	—
Al_2O_3	0.05	0.05	0.03	0.05	0.07	0.05	0.03	0.01	0.03	0.01
FeO	10.03	12.96	11.46	11.73	10.56	15.36	16.26	10.13	10.49	10.06
MnO	0.24	0.31	0.25	0.24	0.23	0.42	0.37	0.18	0.20	0.17
MgO	48.68	45.85	47.99	46.86	47.67	43.44	43.16	48.25	47.79	48.06
CaO	0.42	0.41	0.39	0.40	0.36	0.31	0.32	0.37	0.40	0.36
K_2O	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01
NiO	0.26	0.24	0.24	0.25	0.28	0.13	0.12	0.21	0.17	0.17
Cr_2O_3	0.05	—	0.02	0.02	0.07	0.03	0.01	0.05	0.03	0.06
Total	101.18	100.56	101.68	100.51	100.43	100.50	101.87	99.72	99.52	99.68
α	1.654	1.654	1.653	1.653	1.653	—	—	1.654	1.654	1.654
β	1.684	1.684	1.682	1.682	1.682	—	—	—	—	—
γ	1.693	1.693	1.692	1.692	1.692	—	—	1.692	1.692	1.692
Number of cations in the formula on the basis of 4 oxygens										
Si	1.00561	1.0105	1.0035	1.0080	1.0096	1.0188	1.0265	0.9986	0.9995	1.0048
Ti	—	—	—	—	—	—	0.0007	0.0002	0.0002	—
Al	0.0014	0.0015	0.0008	0.0015	0.0002	0.0015	0.0009	0.0003	0.0009	0.0003
Fe^{2+}	0.2035	0.2676	0.2330	0.2415	0.2165	0.3211	0.3356	0.2089	0.2171	0.2073
Mn	0.0049	0.0065	0.0051	0.0050	0.0048	0.0090	0.0077	0.0038	0.0042	0.0036
Mg	1.7605	1.6868	1.7385	1.7191	1.7418	1.6185	1.5890	1.7735	1.7625	1.7647
Cr	0.0109	0.0108	0.0102	0.0105	0.0095	0.0083	0.0085	0.0098	0.0106	0.0095
K	0.0003	0.0003	0.0006	0.0001	0.0003	0.0006	0.0003	0.0006	0.0006	0.0003
Ni	0.0051	0.0048	0.0047	0.0050	0.0055	0.0026	0.0024	0.0042	0.0034	0.0034
Cr	0.0010	—	0.0004	0.0004	0.0013	0.0006	0.0002	0.0009	0.0006	0.0012
Atomic ratios										
Mg	89.5	86	88	87.5	89	83	82.5	89.3	89.03	89.49
Fe^{2+}	10.5	14	12	12.5	11	17	17.5	10.7	10.97	10.51

Table 3

Chromian diopside analyses.

(Microprobe analyses by P. SUDDABY. Na_2O value obtained by wet method at Robertson Research Laboratory)
NC 15M and 15N, 19D and 19G – chromian diopsides from potash ankaramites. NC 12cA – chromian diopside from a trachybasalt. NC 22H and 22L – chromian diopsides from a trachyandesite.

	NC 15M	NC 15N	NC 19D	NC 19G	NC 12cA	NC 22H	NC 22L
SiO_2	52.44	52.63	51.01	53.01	52.44	51.68	52.86
TiO_2	0.49	0.50	0.74	0.42	0.74	0.67	0.50
Al_2O_3	1.69	1.82	3.08	1.78	2.09	2.55	2.08
Fe_2O_3	1.24	1.31	1.83	1.35	1.75	1.45	1.35
FeO	1.97	2.03	2.88	2.11	2.77	2.30	2.12
MnO	0.10	0.07	0.11	0.10	0.11	0.14	0.10
MgO	16.83	17.00	15.97	17.42	16.52	16.61	17.13
CaO	22.94	22.81	23.11	22.28	22.75	22.84	22.80
Na_2O	0.45	0.45	0.45	0.45	0.45	0.45	0.45
K_2O	0.01	0.02	0.02	0.01	0.02	0.01	0.02
NiO	0.02	0.05	0.02	—	0.03	0.03	—
Cr_2O_3	0.75	0.69	0.49	0.58	0.11	0.15	0.71
Total	98.89	99.34	99.67	99.77	99.74	98.84	100.08
α	—	—	1.678	—	—	1.678	—
β	1.687	1.687	1.688	1.688	1.686	1.688	1.688
γ	—	—	1.709	1.709	—	1.710	—
	Number of cations in formula on the basis of 6 oxygens						
Si	1.9334 } 2.000	1.9308 } 2.000	1.8805 } 2.000	1.9378 } 2.000	1.9322 } 2.000	1.9091 } 2.000	1.9248 } 2.000
Al	0.0666	0.0692	0.1195	0.0622	0.0678	0.0909	0.0752
Al	0.0068	0.0095	0.0143	0.0145	0.0229	0.0201	0.0141
Ti	0.0136	0.0138	0.0205	0.0115	0.0051	0.0186	0.0137
Fe^{3+}	0.0344	0.0361	0.0507	0.0371	0.0485	0.0403	0.0370
Fe^{2+}	0.0607	0.0623	0.0888	0.0645	0.0853	0.0710	0.0645
Mn	0.0031	0.0022	0.0034	0.0031	0.0034	0.0044	0.0031
Mg	0.9247 } 2.004	0.9295 } 1.995	0.8774 } 1.944	0.9490 } 2.025	0.9072 } 2.007	0.9144 } 2.021	0.9296 } 2.004
Ca	0.9062	0.8967	0.9129	0.8727	0.8982	0.9040	0.8896
Na	0.0322	0.0320	0.0322	0.0319	0.0321	0.0322	0.0318
K	0.0004	0.0009	0.0009	0.0004	0.0009	0.0004	0.0009
Ni	0.0006	0.0014	0.0006	—	0.0009	0.0009	—
Cr	0.0218	0.0199	0.0143	0.0167	0.0032	0.0043	0.0204
	Atomic Ratios						
Mg	48.0	48.2	45.4	49.3	46.7	47.3	48.3
Fe	5.0	5.2	7.4	5.4	7.1	6.0	5.5
Ca	47.0	46.6	47.2	45.3	46.2	46.7	46.2

Green chromian diopsides

These large crystals may be found in any of the rock types of all rock formations. They usually show strong resorbtion, are frequently strained, but are never zoned apart from a thin titansalitic rim. Resorbed cavities in these clinopyroxenes rarely carry small crystals of kaersutite.

The total iron percentage determined by the microprobe analyses was apportioned as percentage FeO and Fe_2O_3 on the basis of a proportionality constant derived from a series of partial wet analyses of separated green chromian diopsides. In addition to FeO and Fe_2O_3, Na_2O was also determined by wet analysis (Table 3).

These chromian diosides are characterised by their very low alumina content (generally less than 3% by weight), low titanium content (less than 1% by weight) and their relatively high content of Cr_2O_3. The chromian diopsides are xenocrysts, and their low Al_2O_3 content may be a reflection of crystallisation at high pressure. The solubility of Al_2O_3 in pyroxenes is thought to decrease with increase in depth above a confining pressure of about 20 kb (O'HARA and MERCY 1963; BROWN 1967).

There is no systematic chemical variation in the green diopsides from one rock type to another, and this fact emphasises the xenocrystic nature of these minerals. They are plotted on a Ca-Mg-Fe diagram (Fig. 4).

Although xenocrystic clinopyroxenes have been recorded from volcanic and sub-volcanic rocks at other Atlantic islands, they do not appear to be exactly similar to the Nord-Jan chromian diopsides. The xenocrysts from Gough Island, for example, are pale green-brown, slightly zoned, diopsidic augites (LE MAITRE 1962), and the single analysed mineral contained appreciably higher Al_2O_3 (4.46% by weight) than any of the Nord-Jan chromian diopsides.

Brown titandiopsides and titansalites

These phenocrystic and groundmass pyroxenes were described previously as titanaugites (ROBERTS and HAWKINS 1965), but the atomic ratios determined from microprobe chemical analyses indicate that they are diopsides and salites in the sense of POLDERVAART and HESS (1951). The mean atomic percentage of calcium in the brown pyroxenes (46.7) is in fact almost the same as that for the green diopsides (46.4). The titandiopsides and salites, however, are consistently richer

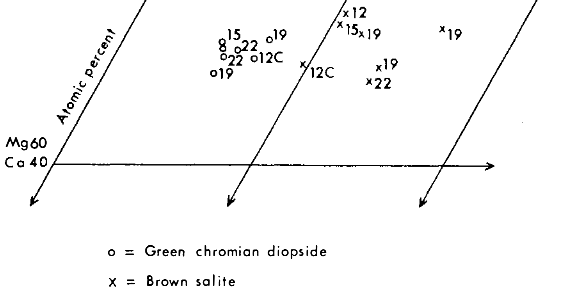

Fig. 4. *Clinopyroxene plots on Ca-Mg-Fe diagram.*

in Al_2O_3, richer in TiO_2, FeO and Na_2O than the green diopsides, but contain less magnesium and chromium.

The Fe_2O_3 and FeO values in the analyses (Table 4) were calculated from the total iron content given by the microprobe analyses, by allocating as Fe_2O_3 the amount required to combine with Na_2O to form the acmite molecule. The remaining iron was then calculated as FeO.

The titansalites are frequently closely zoned, and sometimes show hourglass structure. In most respects, apart from their slight excess of calcium, these minerals are similar to the titanaugites described in rocks from other Atlantic islands (Le Maitre 1962, Baker 1969, Ridley 1970).

When the atomic ratios of the phenocrystic titansalites are considered on the Ca-Mg-Fe diagram (Fig. 4), a trend of iron enrichment at a near constant Ca value is indicated. Le Maitre (1962) commented on the initial trend of crystallisation of alkali pyroxenes in the Gough Island rocks as being one of iron enrichment approximately parallel to the Di-Hd join. He contrasted this with the more drastic Ca impoverishment accompanied by enrichment of Fe for tholeiitic pyroxenes. The titaniferous pyroxenes of Tenerife also show very little compositional variation, especially in their major components (Ridley 1970). Ridley suggested that this feature may be due to the low PO_2 under which these minerals crystallised. It is suggested that under these conditions appreciable enrichment in the acmite molecule, where Na^+ and Fe^{3+} replaces Ca^{2+}, is inhibited. Nevertheless, acmite enrichment does occur in some cases under very low PO_2 conditions (Abbott 1969). All the analysed brown pyroxenes from Nord-Jan and Tenerife are phenocrysts, and it is possible that the groundmass equivalents, which must have crystallised at very low PO_2, could be poorer in Ca^{2+}. Alternatively Ridley (*op. cit.*) suggests that the overall chemistry of the rocks may influence pyroxene crystallisation trends.

It would seem generally, therefore, that the pyroxenes from the alkaline volcanic rocks of the Atlantic islands show little tendency towards Ca impoverishment, and this trend is in contrast to slowly cooled fractionated alkali-basalt magmas (Wilkinson 1956, Aoki 1964).

FELDSPARS

The majority of rocks examined contain abundant groundmass plagioclase and smaller amounts of interstitial alkali feldspar. Plagioclase also frequently occurs as phenocrysts or phenocrystic glomerocrysts, and very rarely as a xenocryst phase. Large numbers of glomerocrystic clusters occur in the lavas of the Nordvestkapp and Nordkapp rocks (Roberts and Hawkins 1965), but rocks from other formations may also carry plagioclase glomerocrysts.

Plagioclase

Phenocrysts and groundmass plagioclase crystals generally show weak normal zoning, but rarely the zoning is oscillatory. Occasionally phenocrysts are slightly resorbed. Xenocrysts usually show intense resorbtion, while normal zoning is either absent or only very weakly developed, and multiple twinning is often obscure.

Table 4

Brown titansalite analyses

(Microprobe analyses by P. SUDDABY, except soda which was determined by wet method at Robertson Research Laboratory.)

	NC 15O	NC 15P	NC 19H	NC 19I	NC 19J	NC 12CC	NC 12CD	NC 12CE	NC 22M
SiO_2	51.28	49.12	48.04	46.33	48.91	51.26	51.89	47.61	49.65
TiO_2	0.91	0.91	1.86	2.78	1.76	1.12	1.29	1.59	1.37
Al_2O_3	3.37	4.70	5.79	6.72	3.99	3.68	3.82	6.40	3.75
Fe_2O_3	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29
FeO	3.42	5.07	5.80	7.37	7.10	4.56	4.59	4.82	6.86
MnO	0.13	0.13	0.19	0.23	0.26	0.17	0.14	0.15	0.33
MgO	16.03	14.19	13.63	12.12	13.84	15.15	15.09	13.52	14.19
CaO	23.01	22.80	22.37	22.24	21.67	21.90	21.83	22.44	21.30
Na_2O	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
K_2O	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
NiO	0.01	0.01	0.03	0.04	0.03	0.01	—	—	—
Cr_2O_3	0.15	0.15	0.04	0.02	—	0.26	0.48	0.46	—
Total	100.12	98.89	99.56	99.66	99.47	99.92	100.94	99.80	99.26
α	—	—	1.690	1.703	—	1.693	—		1.700
β	1.707	1.710	1.709	1.715	—	1,707	1.707	1.710	1.716
γ	—	—	1.717	1.730	—	1.720	—	—	1.726
Number of cations in formula on the basis of 6 oxygens									
Si	1.8814 } 2.000	1.8422 } 2.000	1.7967 } 2.000	1.7485 } 2.000	1.8399 } 2.000	1.8858 } 2.000	1.8888 } 2.000	1.7828 } 2.000	1.8627 } 2.000
Al	0.1186	0.1578	0.2033	0.2515	0.1601	0.1142	0.1112	0.2172	0.1363
Al	0.0271	0.0500	0.0519	0.0475	0.0168	0.0458	0.0527	0.0643	0.0295
Ti	0.0251	0.0256	0.0523	0.0790	0.0498	0.0310	0.0353	0.0447	0.0386
Fe^{3+}	0.0356	0.0365	0.0363	0.0366	0.0365	0.0357	0.0353	0.0363	0.0364
Fe^{2+}	0.1049	0.1590	0.1814	0.2326	0.2256	0.1403	0.1397	0.1638	0.2152
Mn	0.0040	0.0041	0.0060	0.0073	0.0083	0.0053	0.0043	0.0048	1.0105
Mg	0.8765 } 2.019	0.7931 } 2.026	0.7597 } 2.023	0.6817 } 2.023	0.7804 } 2.029	0.8306 } 1.996	0.8186 } 1.987	0.7545 } 2.019	0.7939 } 2.017
Ca	0.9046	0.9162	0.8964	0.8993	0.8734	0.8633	0.8514	0.9004	0.8562
Na	0.0355	0.0363	0.0362	0.0365	0.0364	0.0356	0.0353	0.0363	0.0363
K	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009	0.0009
Ni	0.0003	0.0003	0.0009	0.0012	0.0009	0.0003	—	—	—
Cr	0.0043	0.0044	0.0012	0.0006	—	0.0076	0.0138	0.0136	—
Atomic Ratios									
Mg	45.5	41.6	40.4	36.2	40.5	44.3	44.3	40.8	41.5
Fe	7.5	10.4	11.9	16.0	13.9	9.7	9.7	10.4	13.7
Ca	47.0	48.0	47.7	47.8	45.6	46.0	46.0	48.8	44.8

Indirect determination of the anorthite content was made by reference to the extinction angle in the zone perpendicular to (010) and refractive indices to optical properties/composition curves (DEER, HOWIE and ZUSSMAN 1963, CHAYES 1952). Reasonable agreement was obtained between the results from both these methods. Anorthite values of zoned crystals are approximate means. The plagioclase compositions used for determining rock types (Fig. 3) are means of all plagioclase species present in the particular rock. Xenocrysts are bytownite or calcic labradorite, An_{75} to An_{66}. Phenocrystic and groundmass plagioclases generally have a mean anorthite content within the labradorite range, An_{69} to An_{50}, but rarely phenocrysts are bytownite. In the andesites the groundmass plagioclase has a mean andesine composition, An_{49} to An_{40}. The plagioclase compositions and refractive indices in the analysed rocks are summarised in Table 5.

Alkali feldspar

This mineral occurs interstitially or rimming plagioclase laths in the groundmass of lavas and dyke rocks of all formations. It generally forms less than 10% of the total rock by volume, except in rocks with trachybasalt or trachyandesite matrices. Typically, twinning cannot be discerned in thin section, and the mineral exhibits undulatory extinction. Refractive index, β, was measured for the alkali feldspar in all the chemically analysed rocks and was 1.530 ± 0.004.

It was not possible to obtain chemical data for these feldspars, but they are optically very similar to the anorthoclase-sanidine alkali feldspars described from the volcanic rocks of Gough Island (LE MAITRE 1962) and Tenerife (RIDLEY 1970). A significantly high proportion of the orthoclase molecule is likely to be present in the Nord-Jan alkali feldspars because of their ability to retain the sodium cobaltinitrite stain.

Table 5

Optical properties of plagioclase feldspars

Rock number	Rock type	Xenocryst			Phenocryst			Groundmass		
		β	max. ext. angle	An%	β	max. ext. angle	An%	β	max. ext. angle	An%
NC 15	Potash ankaramite	—	—	—	—	—	—	1.564	30°	55
NC 19	—»—	—	—	—	1.567	39°	69	1.565	32°	58
NC 12c	Potash basalt	—	—	—	1.566	38°	67	1.564	30°	55
NC 13	—»—	nd	40°	71	nd	nd	nd	nd	nd	nd
NC 27k	—»—	1.566	38°	67	1.566	38°	67	1.565	35°	62
NC 17	Trachybasalt	—	—	—	nd	36°	65	nd	28°	50
NJ 17	—»—	—	—	—	—	—	—	1.563	30°	54
SJ 48	—»—	—	—	—	nd	38°	68	nd	35°	62
SJ 53	—»—	—	—	—	1.565	35°	62	1.561	30°	53
NC 22	Trachyandesite	—	—	—	—	—	—	1.558	25°	46

nd = not determined

TITANOMAGNETITE

The titanomagnetite occurs as euhedral to subhedral and skeletal microphenocrysts and as groundmass grains. It also occurs as inclusions in olivine and pyroxene xeno/phenocrysts.

The titanomagnetite is more or less isotropic, and appears from viewing in reflected light to be homogeneous. Rapid counts of Fe and Ti were undertaken on the microprobe, and these indicated in all cases the presence of an appreciable quantity of titanium.

OTHER MINERALS

Some of the dyke and lava rocks contain small interstitial amounts of a clear, colourless, practically isotropic mineral, with low, but not precisely determinable refractive indices. This mineral is thought to be analcime, because when treated with concentrated hydrochloric acid it gelatinised, and took a stain from malachite green. Without X-ray data, however, it remains inconclusive. Most of the Nord-Jan rocks are nepheline normative, and this mineral is probably a modal reflection of this fact, and analogous to the leucite present in rocks from Tristan da Cunha (BAKER et al. 1964).

Apatite is a common groundmass mineral in the lava and dyke rocks and generally occurs as fine accicular needles in the interstitial feldspar. Biotite may be an accessory mineral in rocks with a basalt or andesite matrix. The plates are usually ragged and have a pleochroic scheme of pale-straw (α) to red-brown ($\beta = \gamma$). Small crystals of a pleochroic, light yellow-brown (α) to dark red-brown (γ), amphibole with a small extinction angle ($\gamma : z$) of about 11°, occurs in resorbtion cavities of some green diopsides. This mineral is probably kaersutite.

Petrogenesis

The majority of the Nord-Jan rocks are strongly porphyritic and it has been suggested from petrographic and chemical evidence that many of the large crystals are xenocrysts. Thus petrographic evidence shows that the large green chromian diopsides are homogeneous, apart from a thin outer rim of brown titansalite. In contrast, the large brown titansalites and titandiopsides are often strongly zoned and may show hour glass structure. In addition the pyroxene of the groundmass is always titansalite, never green chromian diopside. The large olivines are always unzoned and sometimes show spectacular development of translation lamellae.

The chemical analyses (Tables 3 and 4) show that the green diopsides have very low Al_2O_3 contents, while the brown salites and diopsides are significantly richer in titanium and poorer in chromium. The olivine analyses (Table 2) show that often the composition of the large olivines is unrelated to the composition of the rock in which they occur. Thus if the rock types potash ankaramite to trachybasalt to trachyandesite form a simple evolutionary sequence, a progressive increase in the Fe : Mg ratio in the olivines, even in the large olivines, could reasonably be expected. Table 2 indicates that this, however, is not the case. Thus in the potash ankaramites the range is from $Fe_{10}: Mg_{90}$ to $Fe_{14}: Mg_{86}$; in a potash basalt the ratio is $Fe_{17}: Mg_{83}$ and in the trachyandesite it is $Fe_{11}: Mg_{89}$. The atomic ratio Mg : Fe of many of the large olivines compares more closely with chemically analysed olivines from peridotites and dunites than from basalts (Table 6) and the relatively high NiO content of many of the large olivines may also suggest a peridotite origin.

DEER et. al. (1963) state that the average composition of peridotite olivines is Fo_{88}, and similar compositions are common for meteorite olivines. The evidence outlined suggests that some of the large olivines, together with the green chromian diopsides are xenocrysts whereas the remainder of the olivines and the brown salites are true phenocrysts.

In view of the fact that xenocrysts sometimes make up 20–40% of the bulk of the rocks, chemical analyses were made not only of whole rocks but also of separated matrices. Analyses and norms of whole rocks and matrices are given in Table 7, and both are represented in Fig. 5, where the Thornton-Tuttle differentiation indices are plotted. The matrices show a range in differentiation index from 27.23 in ankaramite to 47.13 in trachyandesite, but the majority of the analysed Nord-Jan rocks are chemically trachybasaltic, with an index for the matrix of about 35. The implication is that the rocks have undergone only moderate differentiation at near-surface pressures, and it is clear that the variation in rock type cannot be adequately explained by appealing to crystal differentiation under such conditions.

A second implication of the strongly phenocrystic and xenocrystic nature of the rocks is that any conventional plot of pyroxene compositions fails to show the expected change in composition with change in rock type.

A third implication is that the indiscriminate plots of whole rock analyses on AFM and Na-K-Ca diagrams serves little useful purpose. Even plots of the

Table 6

Mg:Fe ratios of chemically analysed olivines from peridotites and basalts

Rock type	Atomic ratios		Locality
	Mg	Fe	
Dunite	92.0	8.0	Mt. Dun, New Zealand
Dunite	91.1	8.9	Little Castle Creek, California
Olivine nodule in basalt	89.4	10.6	Ichinomegata, Japan
Pallasite meteorite	87.1	12.9	Central Australia
Trachy basalt	89.5	10.5	Nord-Jan, Jan Mayen
Trachy basalt	82.5	17.5	—»—
Basalt	77.2	22.8	Buffalo, Colorado
Melilite basalt	75.9	24.1	Klaasvoogdi, Cape Province, South Africa

Data taken from DEER et. al. 1963 except the ratios for olivines in rocks from Jan Mayen.

Table 7 *Chemical analyses and norms of whole rocks and rock matrices from Nord-Jan*

Oxides: Weight%	NC 15 total rock	NC 15 Matrix	NC 19 total rock	NC 19 Matrix	NC 27K total rock	NC 27K Matrix	NC 12C total rock	NC 12C Matrix	NC 13 total rock	NC 13 Matrix	NC 22 total rock	NC 22 Matrix	NC 3 total rock	NC 17 total rock	SJ 53 total rock	JB 202 total rock	SJ 48 total rock
SiO_2	46.81	46.00	46.84	46.11	46.12	46.00	46.59	46.62	46.49	46.00	49.39	49.38	46.78	46.53	45.93	46.36	48.71
TiO_2	1.87	2.86	2.21	2.94	2.17	3.00	2.41	2.84	2.20	2.91	2.72	2.86	2.82	2.56	3.18	2.11	2.90
Al_2O_3	8.02	14.21	6.54	14.84	10.00	16.40	14.41	15.68	15.21	15.41	14.13	15.38	16.77	13.77	15.60	14.95	18.61
Fe_2O_3	4.42	4.35	4.76	3.74	2.60	4.64	4.93	4.61	3.03	5.35	3.17	4.98	4.04	4.77	3.05	11.27	1.80
Cr_2O_3	0.25	0.02	0.19	0.02	0.07	0.01	0.05	0.01	0.04	0.01	0.07	0.01	—	0.06	0.02	0.01	0.08
FeO	5.51	6.82	7.37	7.90	8.76	6.68	6.61	7.04	9.58	6.60	8.07	6.03	8.33	7.33	8.77	3.13	8.48
MgO	15.18	7.50	14.09	6.00	12.30	5.80	8.22	5.30	6.01	5.00	5.43	4.70	4.33	8.01	5.20	4.81	3.30
MnO	0.17	0.17	0.18	0.15	0.16	0.15	0.21	0.17	0.22	0.16	0.22	0.21	0.22	0.22	0.20	0.21	0.19
CaO	14.48	13.10	14.59	12.30	13.70	11.80	11.43	11.00	11.08	11.20	9.26	9.00	9.08	10.96	11.15	11.21	9.35
BaO	0.06	0.01	0.10	0.20	tr.	0.01	0.06	0.01	0.16	0.01	0.16	0.01	0.12	0.06	0.13	0.15	0.19
Na_2O	1.41	2.40	1.48	2.55	1.85	3.00	2.47	3.20	2.68	3.50	3.48	4.00	3.14	2.47	3.48	2.68	2.81
K_2O	1.21	1.90	1.21	2.20	1.10	2.00	1.76	1.90	2.54	2.50	3.18	3.10	3.02	2.46	2.28	2.66	3.09
H_2O+	0.45	0.32	0.38	0.44	0.57	0.08	0.42	0.43	0.36	0.78	0.25	0.10	0.36	0.36	0.33	0.15	0.13
H_2O-	0.08	0.05	0.03	0.05	0.05	0.06	0.07	0.05	0.05	0.07	0.05	0.05	0.34	0.13	0.09	—	0.05
P_2O_5	0.29	0.53	0.29	0.64	0.70	0.58	0.43	0.87	0.53	0.76	0.56	0.44	0.68	0.46	0.59	0.46	0.69
CO_2	—	0.22	—	0.16	0.30	0.07	0.08	0.27	—	0.19	—	0.05	0.15	0.03	0.15	—	0.15
Total	100.21	100.46	100.26	100.24	100.45	100.27	100.15	100.00	100.18	100.45	100.14	100.30	100.18	100.18	100.15	100.16	100.53
Norms																	
Or	7.23	11.12	7.23	12.79	6.67	11.68	10.56	11.12	15.01	15.01	18.90	18.35	17.79	14.46	13.34	16.12	18.35
Ab	6.81	11.00	7.86	12.58	9.43	15.20	17.29	22.01	11.53	14.67	20.17	22.53	18.86	13.62	12.05	16.24	21.48
An	11.68	22.24	7.51	22.52	15.57	25.58	22.80	22.80	21.96	18.90	13.62	14.73	22.52	19.18	20.29	23.35	28.91
Ne	2.84	5.11	2.56	4.83	3.41	5.40	1.99	2.84	5.96	7.95	4.97	6.25	4.26	3.98	9.17	3.20	1.14
Di	45.81	31.34	50.11	28.67	38.73	23.65	24.70	19.62	24.39	25.24	23.48	21.78	14.78	25.94	26.40	23.33	11.32
Ol	14.31	5.98	12.62	5.62	16.18	4.94	9.40	6.38	10.64	2.71	7.54	2.85	8.29	9.52	6.64	0.84	9.02
Il	3.50	5.47	4.26	5.62	4.26	5.78	4.56	5.32	4.26	5.47	5.17	5.47	5.32	4.86	6.08	3.95	5.47
Mt	6.50	6.26	6.96	5.34	3.94	6.73	7.19	6.73	4.41	7.66	4.41	7.19	5.80	6.96	4.41	4.18	2.70
He																8.48	
Ap	0.67	1.34	0.67	1.34	1.68	1.34	1.01	2.02	1.34	2.02	1.34	1.01	1.68	1.01	1.34	1.01	1.68
Rest	0.84	0.59	0.60	0.75	0.92	0.21	0.68	0.75	0.61	1.04	0.37	0.20	0.85	0.64	0.59	0.16	0.33
Total	100.19	100.45	100.38	100.06	100.79	100.51	100.18	99.59	100.11	100.67	99.97	100.33	100.15	100.17	100.51	100.86	100.40
D.I	16.88	27.23	17.65	30.20	19.51	32.28	29.84	35.97	32.50	37.63	44.04	47.13	40.91	32.06	34.56	35.56	40.97
Analyst	H	R	H	R	R	R	H	R	H	R	H	R	H	H	H	H	H

NC 15	Ankaramite	Nordvestkapp Formation	Lava	Kraterlia cliff, south of Nordbukta
NC 19	—»—	Storfjellet Formation	»	Storfjellet cliff, below Tvillingkrateret
NC 27K	Potash basalt	Nordvestkapp Formation	»	Kvalnosa buttress
NC 12C	Trachybasalt	Tromsøryggen Formation	»	15 m inland, cliff south of Nordbukta
NC 13	—»—	Nordvestkapp Formation	»	Kraterlia cliff, south of Nordbukta
NC 22	Trachyandesite	Storfjellet Formation	»	Storfjellet cliff, below Tvillingkrateret
NC 3	Trachybasalt	—»—	»	—»— near Krossbukta
NC 17	—»—	—»—	»	—»— below Tvillingkrateret
SJ 53	—»—	Sentralkrateret Formation	»	Bastionen, Beerenberg
JB 202	—»—	—»—	»	Nunataken, Beerenberg
SJ 48	—»—	—»—	»	Bastionen, Beerenberg

Analysts: H = W. H. HERDSMAN
R = Robertson Research Co.

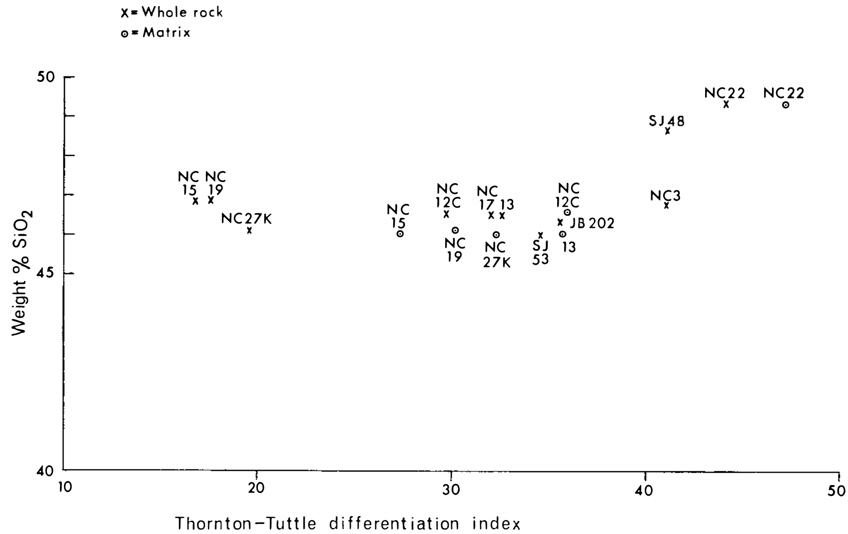

Fig. 5.

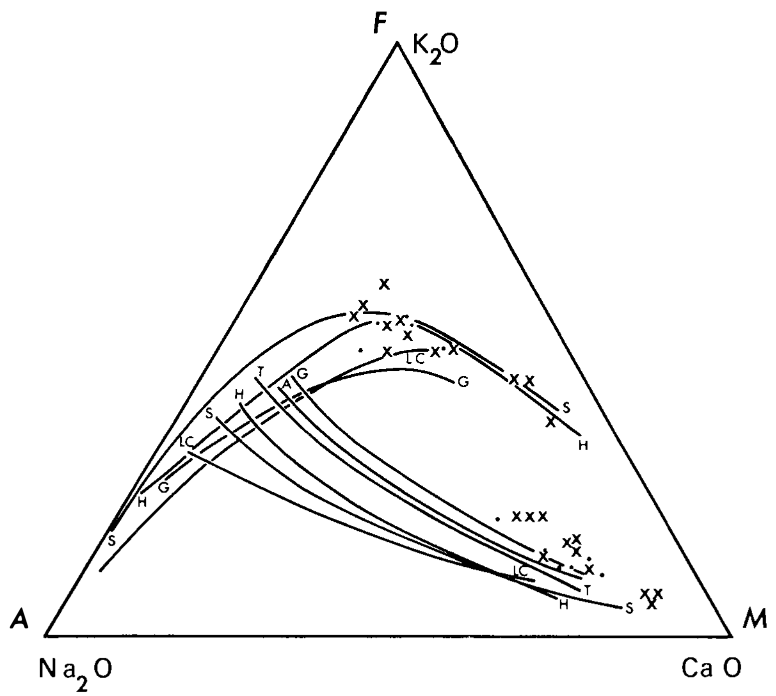

Fig. 6. *Combined F-M-A and K_2O-Na_2O-CaO diagrams for Nord-Jan rocks and rock matrices.*

X = Jan Mayen whole rocks	*LC = Las Canadas, Tenerife, trend*
• *= Jan Mayen rock matrices*	*S = St. Helena trend*
H = Hawaiian alkali trend	*T = Tristan da Cunha trend*
G = Gough Island trend	*A = Azores trend*

Table 8

Na_2O/K_2O ratios for ankaramites and basalts from Atlantic islands

Locality	Number of analyses	Range	Na_2O/K_2O mean	Standard deviation
Nord-Jan, Jan Mayen	10	0.84–1.52	1.15	0.23
Nightingale	5	1.04–1.75	1.31	0.28
Gough	13	0.96–1.70	1.37	0.30
Tristan da Cunha	19	1.20–2.02	1.37	0.19
Inaccessible	6	1.46–2.97	2.06	0.58
Las Canadas, Tenerife	20	1.76–4.35	2.30	0.54
St. Helena	9	2.51–3.04	2.74	0.22

matrices can be of only limited value because in preparing the matrix for analysis the salites and the few large olivine phenocrysts were necessarily separated along with the xenocrysts. Nevertheless, the whole rock and matrix analyses are plotted in this way in Fig. 6 in order to allow some general comparisons to be made with basalts from other Atlantic islands.

When such comparisons are made, it is apparent that the Nord-Jan rocks are different, particularly in their relatively high potassium content. Table 8 shows the Na_2O/K_2O ratios for the Nord-Jan ankaramites and basalts and the ratios in similar rocks from other Atlantic islands. The ratio is seen to be lowest in the Nord-Jan rocks and highest in rocks from Las Canadas, Tenerife. Although the data is not as extensive as one would wish, there seems to be a marked increase in the ratio in rocks away from the Mid-Atlantic Ridge. It is interesting to note that along with a low Na_2O/K_2O ratio, diopsidic augites are recorded as phenocrysts or xenocrysts from Gough Island and Tristan da Cunha, but diopsidic clinopyroxenes are absent from St. Helena and Tenerife, both of which have high Na_2O/K_2O ratios.

It is clear that the green chromian diopsides and magnesian-rich olivines crystallised earlier than the titansalites and the less magnesian olivines, and partly for this reason the former are referred to as xenocrysts. It is also thought that the xenocrysts crystallised at appreciably higher pressures than the phenocrysts. Nevertheless, neither spinels (other than titanomagnetite) nor garnets nor orthopyroxenes have been seen in any of the rocks. Thus the earliest differentiates of the magma at high but unknown pressure could have consisted of magnesian olivine and chromian diopside, giving wehrlite as a rock type.

O'HARA (1967, p. 394) gives a diagram showing the variation of sub-solidus assemblages for the composition Mg_2SiO_4–40%, $MgSiO_3$–28.5%, $CaMgSi_2O_6$–28.5% and Al_2O_3–3% with variations in temperature and pressure. This is reproduced as Fig. 7. The means of the analyses of olivines and green chromian diopsides from the Nord-Jan rocks were determined and the SiO_2, MgO, CaO and Al_2O_3 amounts were summed to 100. A remarkable coincidence of composition occurs between O'HARA's data and the Jan Mayen data when the mean composition of 2 olivine plus 1 chromian diopside is taken. This is illustrated in Table 9. It seems possible therefore, that the initial fractionation of the Nord-Jan magma took place with

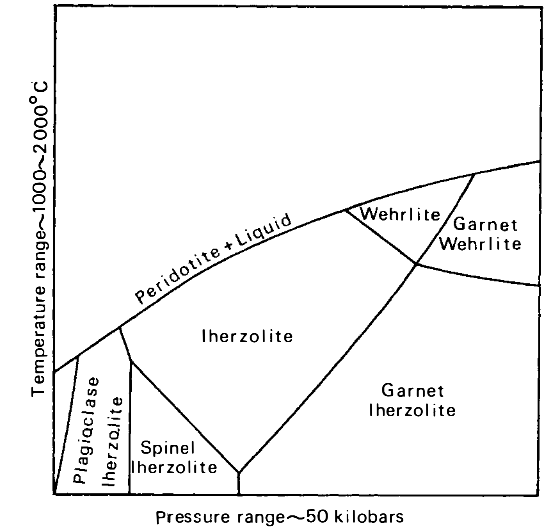

Fig. 7. *Diagram taken from* O'HARA (*1967, p. 394*) *to show the position of the wehrlite condition for the bulk composition* Mg_2SiO_2*-40%;* $MgSiO_3$*-28.5%;* $CaMgSi_2O_6$*-28.5%;* Al_2O_3*-3%.*

the separation of wehrlite at high pressures (perhaps as high as 30 kb). Reference to the tables of chromian diopside analyses (Table 3), shows that the Na_2O content averages 0.45 wt. %, whereas the average K_2O content is 0.05 wt. %, and Table 2 shows that the alkali content of the olivines is negligible. It follows that fractionation leading to the formation of wehrlite will enrich the residuum in potassium relative to sodium, will enrich it in aluminium and titanium, and in this way lead to the production of the primitive Jan Mayen magma.

The strongly xenocrystic nature of many of the rocks and the dominance of potash and trachybasalts among the matrices, suggests that the ascent of magma towards the surface was sufficiently rapid to take with it a large proportion of the olivines and chromian diopsides which were in the process of crystal settling. The formation of large magma reservoirs for any great length of time at lower pressures (i. e. higher levels) seems unlikely in view of the great scarcity of trachyandesites and the total absence from Nord-Jan of trachytes. In Sør-Jan, however, trachytes

Table 9

Mean composition of 2 olivines plus 1 chromian diopside from Nord-Jan, Jan Mayen, compared with the wehrlite composition of O'HARA (*1967, p. 394*)

Oxide	Nord-Jan diopside	Nord-Jan olivine	Diopside summed to 100	Olivine summed to 100	1 diopside + 2 olivines	Wehrlite
SiO_2	52.4	41.0	55.8	46.5	49.6	49.9
MgO	16.8	46.7	17.9	53.0	41.3	39.7
CaO	22.5	0.4	24.0	0.45	8.3	7.4
Al_2O_3	2.2	0.04	2.3	0.05	0.8	3.0
Total	93.9	88.14	100.0	100.0	100.0	100.0

have been described (CARSTENS 1961) so that the formation of a temporary high level magma chamber may be indicated in this instance. Under Nord-Jan relatively brief rests during the magma ascent may have been sufficient to evolve, at low pressures, the small quantity of trachyandesitic magma.

The problem of the origin of the primitive melt remains. At this stage the most obvious and likely way would be to assume that the Upper Mantle temperature rose towards the solidus and was held for a sufficient period for the wehrlite condition to be attained. Fractional melting would occur with any further temperature rise and would lead to the formation of a basic liquid which, as the temperature fell once more, would initially precipitate wehrlite, provided it had been held at pressures of approximately 25 to 30 kb. In this way it seems that, with the data at present available, the petrogenesis of the Nord-Jan rocks may be best explained.

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Bulk-rock and mineral chemistry of recent Jan Mayen basalts[1]

BY

PETER W. WEIGAND[2]

Contents

Abstract

Results are reported of major-element analyses of four alkali olivine basalt samples from the September–October 1970 flank eruption of Beerenberg volcano on Jan Mayen in the Greenland-Norwegian Sea. Microprobe analyses show olivine phenocrysts to be Fo_{79}; bytownite phenocrysts ($An_{83}Ab_{16}Or_{1}$) are rimmed by a thin shell of labradorite ($An_{67}Ab_{30}Or_{3}$), and groundmass plagioclase varies from An_{60} to An_{30}. Chromiferous diopside xenocrysts (Wo_{45} En_{49} Fs_{6}) and smaller titaniferous salite phenocrysts (Wo_{47} En_{41} Fs_{12}) are both rimmed with a thin late-stage overgrowth of titanaugite ($Wo_{47}En_{38}$ Fs_{15}), which is similar to the groundmass pyroxenes. The diopside xenocrysts are interpreted as fragments of ultramafic nodules, which have been reported from older Jan Mayen rocks. The distinct compositional changes between the salite phenocrysts and the titanaugite rims and groundmass grains apparently reflect widely differing physical and chemical environments.

Introduction

Fissure eruptions began on the NE flank of the Beerenberg volcano of north Jan Mayen on 19–20 September, 1970 (GJELSVIK 1970). A fieldparty organized by Norsk Polarinstitutt visited the site of the activity between September 22 and October 3 and collected several samples of basalt. Portions of this collection were donated to Professor K. S. HEIER for study, and four of the specimens were chosen

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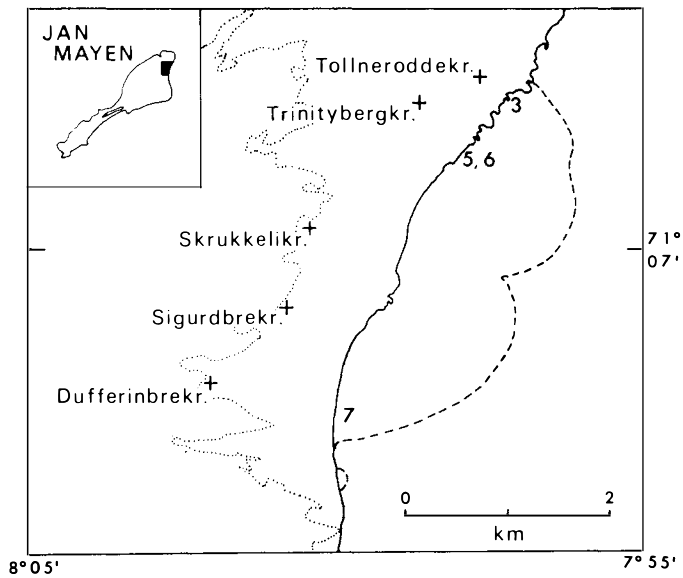

Fig. 1. *Generalized map of part of North Jan Mayen showing the five new craters active during the Sept.-Oct. 1970 activity. The dotted line represents the limit of glacial ice, dashed line represents new shoreline as of Oct. 14. 1970. Numbers represent sample localities.*

for detailed examination. This paper reports the following aspects of a larger study: petrography, major-element bulk-rock chemistry, and mineral chemistry. The complete study, combining the results of different investigators and including the results of trace-element and isotope studies, will be presented later.

Jan Mayen, located in the Greenland-Norwegian Sea, is a volcanic mass built on the flanking mountains of a major sub-oceanic rift-valley structure (HEEZEN and EWING 1961). Structurally, the island is located at the intersection of an important NW–SE striking fracture zone and a N–S trending ridge of the Icelandic Plateau that occupies the major part of the mid-Atlantic ridge in the region (JOHNSON 1968).

References and summaries of earlier work on Jan Mayen can be found, for instance, in FITCH (1964) or FITCH at al. (1965). Discussions of geology, petrology, and geologic history can be found in the same papers, ROBERTS and HAWKINS (1965), and CARSTENS (1962).

North Jan Mayen (Fig. 1), the area of interest, consists of interlayered ankaramite, trachybasalt (or alkali olivine basalt), and trachyandesite flows and tuffaceous and pyroclastic rocks. The bulk of the exposed rocks are considered to have been erupted since the upper Pleistocene (FITCH et al. 1965). The eruption of Sept.–Oct. 1970 was the first well-documented activity on Jan Mayen in recorded history.

The four samples selected for study represent an ejected bomb from the Tollnerodden crater (JM-3), lava flows from the Trinityberget crater (JM-5 and -6), and a lava flow from the Dufferinbreen crater (JM-7) (Fig. 1). The latter sample is on the order of a few days younger than the samples further north (T. SIGGERUD, pers. comm., 1971). The lava flows are all of the aa type.

Petrographically, the samples are vesicular porphyritic basalts. They are similar to the phyric basalts described from Sør-Jan (CARSTENS 1962) and appear transitional between the ankaramites and the trachybasalts of Nordkapp, Nord-Jan (ROBERTS and HAWKINS 1965). Pyroxene phenocrysts predominate, while plagioclase and olivine phenocrysts are less abundant. Pyroxene and plagioclase crystals appear in the groundmass together with variable amounts of quenched material. Opaque minerals are difficult to distinguish in the dark groundmass, but under reflected light they are seen to be a common groundmass constituent. Meaningful modal analyses could not be made because of the large size of the phenocrysts, the fine-grained nature of the groundmass, and the high degree of vesicularity.

Geochemistry

Analytical methods. The major-element chemical analyses were carried out in duplicate or triplicate by classical methods, X-ray fluorescence, and atomic absorption. The results of the three methods showed surprisingly close agreement. Mineral analyses were made by electron-microprobe. Details of the instrumental methods can be found in WEIGAND (1971).

Results. In the chemical classification of GREEN and RINGWOOD (1967), the Jan Mayen samples would be classified as transitional between alkali olivine basalts and basanites because they contain normative olivine and around 5% normative nepheline (Table 1). For the purposes of this paper, they will be con-

Table 1
Major-element chemistry and normative mineralogy

	JM-3	JM-5	JM-6	JM-7	Average
SiO_2	47.50	47.40	46.80	47.90	47.40
TiO_2	3.29	3.32	3.28	3.12	3.25
Al_2O_3	15.90	16.20	15.90	15.30	15.80
Fe_2O_3	3.24	2.91	3.63	3.24	3.26
FeO	8.03	8.35	7.68	7.81	7.97
MnO	0.20	0.20	0.20	0.20	0.20
MgO	5.27	5.48	5.55	6.12	5.60
CaO	9.79	9.53	9.67	10.06	9.76
Na_2O	3.18	3.37	3.34	3.11	3.25
K_2O	2.61	2.58	2.67	2.54	2.60
P_2O_5	0.50	0.49	0.52	0.48	0.50
H_2O^-	—	—	—	—	—
H_2O^+	0.44	0.11	0.15	0.09	0.20
Total	99.95	99.94	99.39	99.97	99.79
Molecular norms					
Or	15.66	15.39	16.02	15.14	15.55
Ab	20.76	19.92	18.65	20.26	19.90
An	21.75	21.68	20.85	20.48	21.19
Ne	4.95	6.38	7.09	4.75	5.79
Di	19.41	18.26	19.55	21.37	19.65
Ol	8.31	9.60	8.24	9.17	8.83
Mt	3.44	3.07	3.85	3.42	3.44
Il	4.66	4.67	4.64	4.39	4.59
Ap	1.06	1.03	1.10	1.01	1.05

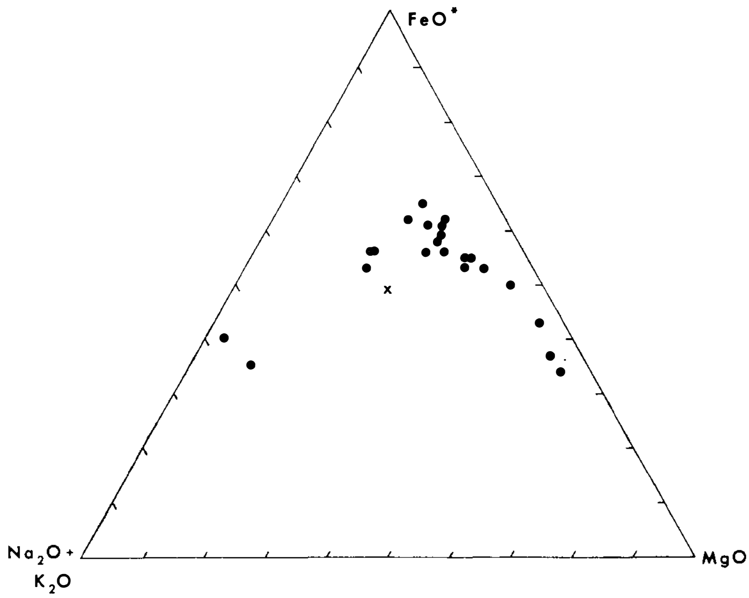

Fig. 2. *AFM diagram of Jan Mayen rocks. "x" represents samples of this study.*

sidered as alkali olivine basalts. They are characterized by rather high TiO_2 and K_2O contents and a low water content. The latter feature is reflected in the totally fresh appearance of the rocks under the microscope. Samples JM-3, -5, and -6 are virtually identical to each other in major-element chemistry; JM-7 exhibits small differences which are considered larger than analytical uncertainties. The lower Al_2O_3 and the higher MgO and CaO contents might be explained by a slightly higher concentration of pyroxene phenocrysts in the sample. These results emphasize the spatial and temporal chemical homogeneity of the Sept.–Oct. eruption.

The samples of this study do not exactly match any of the previously analyzed Jan Mayen rocks (HOLMES 1916; TYRELL 1926; CARSTENS 1961, 1962; ROBERTS and HAWKINS 1965) but fall well within the range of rocks identified as olivine trachybasalt, basanitoid trachybasalt, and trachybasalt. Most of the rocks previously identified petrographically as ankaramite and trachybasalt would be considered alkali olivine basalts in the normative classification. All available Jan Mayen analyses plotted on an AFM diagram (Fig. 2) exhibit a well-defined trend of moderate iron enrichment followed by alkali enrichment. The samples of this study appear somewhat depleted in total iron relative to magnesia and alkalis.

Mineral chemistry

Pyroxene. – Pyroxene phenocrysts occur as broken or slightly rounded grains jacketed by a thin, late-stage overgrowth which often forms straight crystal edges or euhedral grains (see Plate 1 for photomicrographs of various pyroxene features). The overgrowth often exhibits a ragged or sieve-like texture. Phenocryst cores are found as two distinct compositions – a light brown chromiferous diopside of $Wo_{45}En_{49}Fs_6$ and a medium brown titaniferous salite of $Wo_{47}En_{41}Fs_{21}$ (nomenclature after POLDERVAART and HESS 1951). These cores are enveloped by a thin rim of purple-brown titanaugite of $Wo_{47}En_{38}Fs_{15}$, which is compositionally close to the groundmass pyroxenes (Table 2; complete pyroxene analyses are in Appendix 1). The phenocryst cores are predominantly unzoned, both compositionally and optically. Salite is not found rimming diopside cores within the titanaugite overgrowth.

The diopside phenocrysts are larger than the salite phenocrysts (max. sizes are 9 and 2.5 mm across, respectively). They usually have one or more well-formed crystal edges, but are somewhat fractured and mostly appear to be broken fragments of larger crystals. The smaller salite crystals have more euhedral and complete outlines. Hourglass structure has been observed in a few groundmass grains. As is typical of alkali olivine basalts, no coexisting, low-Ca pyroxene is found.

The above compositional differences are clearly revealed by plots on the pyroxene quadralateral (Fig. 3) to which low-pressure differentiation trends typical of alkali olivine (Shiant Isles) and tholeiitic (Skaegaard and Bushveld) compositions have been added for comparison. Pyroxenes from alkali olivine basalts are

Table 2
Chemical analyses of clinopyroxenes

	1	2	3	4	5	6
SiO_2	52.2	49.3	45.5	46.1	45.13	52.17
TiO_2	0.6	1.7	3.1	2.8	2.57	0.64
Al_2O_3	2.6	4.8	7.1	5.8	10.44	3.35
FeO	3.9	7.4	8.6	8.8	7.16	3.84
MnO	0.1	0.2	0.2	0.2	nd	nd
MgO	17.6	14.0	12.4	13.7	12.35	17.12
CaO	22.2	21.9	21.8	21.6	21.53	22.12
Na_2O	nd	nd	nd	nd	0.47	0.27
Cr_2O_3	0.3	—	—	—	nd	0.70
Total	99.5	99.3	98.7	99.0	99.65	100.21
Wo	45	47	47	45	48	45
En	49	41	38	40	39	49
Fs	6	12	15	15	13	6

1. Chromiferous diopside xenocrysts. (Average of complete analyses of 11 points representing 6 different crystals.)
2. Titaniferous salite phenocrysts. (Average of complete analyses of 6 points on 5 crystals plus 10 partial analyses of 5 other crystals.)
3. Late-stage titanaugite rims. (Average of complete analyses of 7 points on 6 crystals plus 12 partial analyses of 8 other crystals.)
4. Groundmass titanaugite crystals. (Average of 6 partial analyses of 6 different crystals.)

5+6. Analyses of augite and chromium diopside, respectively. from Carstens (1962) (K_2O and H_2O omitted from original analyses; total Fe recalculated as FeO).

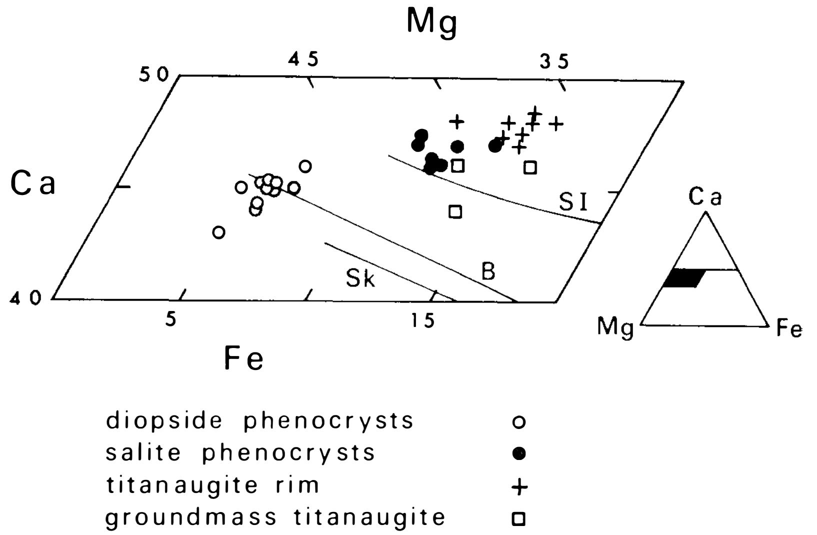

Fig. 3. *Pyroxene quadratateral showing plots of complete analyses of Appendix 1. Sk= trend of pyroxenes from the Skaegaard intrusion* (BROWN *1957*), *B=pyroxene trend from Bushveld intrusion* (ATKINS *1969*); *SI=pyroxene trend from Shiant Isles sill* (MURRAY *1954*).

characteristically higher than those from tholeiitic basalts in Wo component, Al_2O_3 and TiO_2 (LE BAS 1962). The trends exhibited by the Jan Mayen pyroxenes are nearly perpendicular to the low-pressure trends, lead away from the En apex, and maintain a fairly constant Wo:Fs ratio. Whether these trends merely represent a normal range in composition or reflect some sort of high-pressure fractionation is not known.

The compositional differences discussed above are emphasized on a plot of Al_2O_3 vs. TiO_2 (Fig. 4). A concomitant increase in these two elements is typical for pyroxenes from alkali olivine basalts (LE BAS 1962). The approximate two-fold increase of Al_2O_3 relative to TiO_2 has also been found in Apollo 11 clinopyroxenes, and it has been suggested that this relationship results from the coupled substitution

$$2Al^{IV} + Ti^{IV} \rightleftarrows R^{+2\,VI} + 2Si^{IV}$$

The existence of two distinct phenocrystic-pyroxene compositions, both being rimmed by a late-stage growth, has been recognized in the basic lavas of Nord-Jan since the earliest petrographic studies of Jan Mayen rocks (i.e. TYRELL 1926). CARSTENS (1961) presented analyses of chromium diopside from a Nord-Jan ankaramite and phenocrystic augite from a Sør-Jan ankaramite (Table 2). The close comparison to the pyroxenes analyzed in this work is obvious. CARSTENS noted the similarity between the diopside and clinopyroxenes from tholeiitic picrites and ultramafic nodules.

Plagioclase. – Plagioclase occurs as euhedral phenocrysts (up to 4 mm across) rimmed by a late-stage growth (Plate 1), and as small laths in the groundmass. The phenocrysts occassionally enclose grains of opaque oxide. Partial analyses

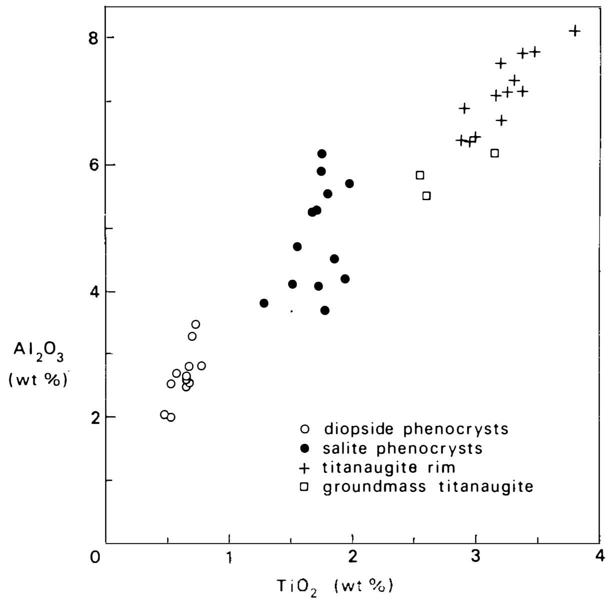

Fig. 4. *Plot of Al_2O_3 vs. TiO_2 of clinopyroxenes from complete and partial analyses.*

for An and Or content have been plotted on an AnAbOr diagram (Fig. 5). Phenocryst centers of bytownite ($An_{83}Ab_{16}Or_1$) are distinct from the thin labradorite overgrowth ($An_{67}Ab_{30}Or_3$). No compositional zoning is evident within the phenocryst cores. Groundmass grains are present both as labradorite laths ($An_{68}Ab_{30}Or_2$) and as a more K-rich phase (five analyses average $An_{44}Ab_{41}Or_{15}$). The identification of this latter material is difficult under the reflecting light of the microprobe, and it might represent quenched interstitial material. However, since the analyses fall roughly on the plagioclase differentiation trend, it is concluded that they represent a K-rich plagioclase.

Olivine. – Olivine occurs as subhedral to euhedral phenocrysts 1–2 mm across (Plate 1), and are relatively uncommon. Partial analyses of FeO, MnO, and MgO in three grains are in Appendix 2. Fo content ranges from 77 to 82, averages 79 and exhibits no systematic zonation in the crystals. The concentration of MnO ranges from 0.27 to 0.35, averages 0.30, and has a strong positive correlation with FeO.

Opaque minerals. – Opaque minerals are not found as phenocrysts, but are fairly common in the groundmass. Partial analyses for TiO_2 and MgO are in Appendix 3. Three separate phases are indicated, which average 22.4, 4.17, and 0.94% TiO_2 and 3.68, 5.93, and 0.48% MgO respectively. Precise identification is impossible without FeO and Fe_2O_3 analyses, but from comparison with magnetite analyses from DEER et al. (1962, Table 12) it is suggested that the three phases are titanomagnetite, titaniferous magnetite, and magnetite.

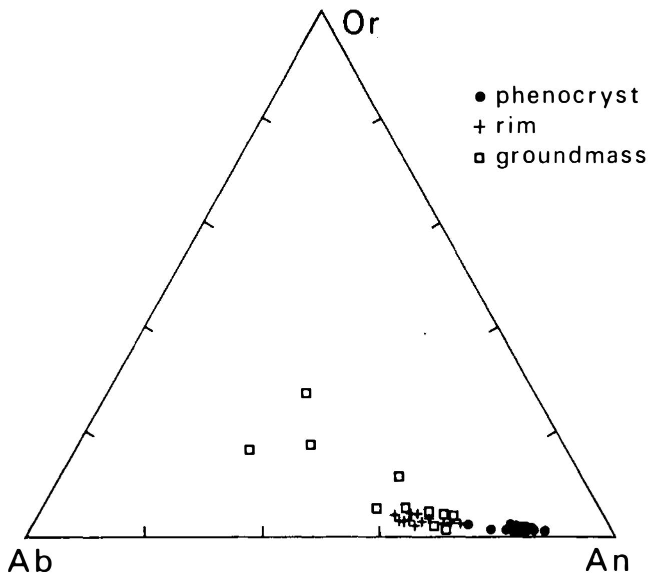

Fig. 5. *Plagioclase compositions plotted on AnAbOr diagram.*

Discussion

Although diopsidic phenocrysts are not unknown in rocks of the alkali olivine basalt association (i. e. LE MAITRE 1962), they are much more common in ultramafic zones of layered tholeiitic intrusions (i. e. ATKINS 1969) and ultramafic inclusions in basaltic rocks (i. e. WHITE 1966). Clinopyroxenes of the latter two associations usually occur with coexisting orthopyroxene. To the writer's knowledge the co-occurrence of diopside and salite phenocrysts has not been reported other than in Jan Mayen rocks.

Chromiferous diopside has been reported (SCHARIZER 1884) from the relatively scarce olivine-rich nodules found within the lavas and tuffs of Jan Mayen (FITCH 1964, pers. comm. 1971). The chromiferous diopsides of this study and those reported from other Jan Mayen rocks (CARSTENS 1961, ROBERTS and HAWKINS 1965) probably represent portions of dissociated and mostly resorbed ultramafic nodules, and therefore may represent fragments of the upper mantle where the host basalts were generated (WHITE 1966). Problems with this interpretation include the lack of olivine ($\sim Fo_{90}$) and enstatite xenocrysts, which commonly coexist with diopside in nodules, and the lack of a reaction zone around the diopside grains, which is usually present where these grains are in contact with the host basalt (WHITE 1966). It is possible that during the time in the history of the magma that the salite phenocrysts formed, whatever enstatite was present completely melted, the olivine re-equilibrated with the magma (c.f. MOORE and EVANS 1967) yielding the observed phenocrysts of Fo_{79}, and the diopside xenocrysts were partly resorbed by, instead of reacting with, the magma. The distinct compositional differences between the salite phenocrysts and the titanaugite overgrowth (and groundmass crystals) apparently reflect widely differing physical and chemical environments.

Origin. – GREEN and RINGWOOD (1967) suggest that at 35–70 km depth, dry basaltic liquids segregating from a pyrolitic mantle will be of alkali olivine basalt type with about 20% partial melting, or olivine-rich tholeiite type with about 30% melting. Approximately 30% crystallization of aluminous enstatite from the olivine tholeiite could yield an alkali olivine magma. Separation at lower pressures of olivine and clinopyroxene has probably altered this primitive parental composition, chiefly resulting in a decrease in MgO and an increase in the alkalis. The absence of orthopyroxene xenocrysts, plus the existence of clinopyroxene, olivine and plagioclase phenocrysts (indicating that these three were near-liquidus phases) imply that the Jan Mayen basalts have undergone at least moderate differentiation.

Acknowledgements

The Norsk Polarinstitutt is thanked for the donation of the samples. B. BRUUN and W. L. GRIFFIN made parallel analyses which were averaged with the author's to give the results of Table 1. F. J. LANGMYHR kindly permitted use of the atomic absorption unit at the Kjemisk Institutt, Blindern. A fellowship from the G. Unger Vetlesen Foundation is gratefully acknowledged.

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Appendix 1

Clinopyroxene analyses. First sample no. refers to rock number, second to mineral grain, and letter to analytical point. A=average of 10 partial analyses of 5 grains; B=average of 12 partial analyses of 8 grains. Blank means not determined, dash means below detection, "x̄" is average for each group.

	Diopside phenocrysts											
	5–1a	5–1d	5–2b	5–2c	5–3a	5–3b	6–6a	6–6b	7–3j	7–3k	7–5b	x̄
SiO_2	52.0	52.6	51.7	52.5	51.9	52.3	51.7	52.2	52.7	52.3	52.4	52.2
TiO_2	0.5	0.5	0.8	0.7	0.6	0.7	0.6	0.7	0.5	0.7	0.7	0.6
Al_2O_3	2.0	2.0	2.8	2.6	2.7	2.5	2.6	3.3	2.5	2.5	2.8	2.6
FeO	3.5	3.3	4.3	4.1	3.8	4.0	4.2	4.3	3.7	4.0	3.7	3.9
MnO									0.1	0.1	0.1	0.1
MgO	17.9	19.3	17.2	18.0	17.7	17.3	17.5	16.6	17.7	17.4	17.4	17.6
CaO	22.1	22.1	22.4	22.0	22.2	22.2	22.4	22.3	22.1	22.2	22.1	22.2
Cr_2O_3									0.2	0.2	0.4	0.3
Sum	98.0	99.8	99.2	99.9	98.8	99.0	99.0	99.4	99.5	99.4	99.6	99.5

	Salite phenocrysts								Groundmass titanaugites			
	6–9	6–11a	6–11b	6–11c	6–12c	7–4e	A	x̄	6–9	6–13	7–8	x̄
SiO_2	48.5	48.6	49.0	50.5	49.5	49.4	49.3	49.3	47.4	46.2	44.7	46.1
TiO_2	1.8	1.7	1.7	1.8	1.9	1.6	1.7	1.7	2.5	2.6	3.2	2.8
Al_2O_3	5.5	5.3	5.3	3.7	4.2	4.7	4.9	4.8	5.8	5.5	6.2	5.8
FeO	7.5	6.8	6.7	8.5	7.4	7.4	7.7	7.4	9.5	8.7	8.2	8.8
MnO						0.2	0.2	0.2			0.2	0.2
MgO	14.1	14.3	14.1	13.3	14.6	14.4	13.5	14.0	12.3	14.8	14.1	13.7
CaO	21.6	21.9	21.8	22.0	22.6	21.6	21.8	21.9	21.1	21.4	22.3	21.6
Cr_2O_3						—		—			—	—
Sum	99.0	98.6	98.6	99.8	100.2	99.3	99.1	99.3	98.6	99.2	98.9	99.0

	Titanaugite rims								
	5–1b	5–1c	5–3d	7–3b	7–4a	7–4b	7–8b	B	x̄
SiO_2	45.1	45.7	45.0	43.4	46.6	46.3	45.9	45.8	45.5
TiO_2	3.1	2.9	3.0	3.5	3.0	3.4	3.0	3.2	3.1
Al_2O_3	7.4	6.9	6.5	7.8	6.4	7.2	7.6	7.1	7.1
FeO	8.9	9.2	7.8	8.7	9.3	8.0	8.6	8.7	8.6
MnO				0.2	0.2	0.2	0.2	0.2	0.2
MgO	12.0	12.6	13.4	12.5	11.8	12.7	12.3	12.3	12.4
CaO	22.0	22.0	22.4	21.9	21.4	21.2	21.6	21.7	21.8
Cr_2O_3				—	—	—	—		—
Sum	98.5	99.3	98.1	98.0	98.7	99.0	99.2	99.0	98.7

Appendix 2

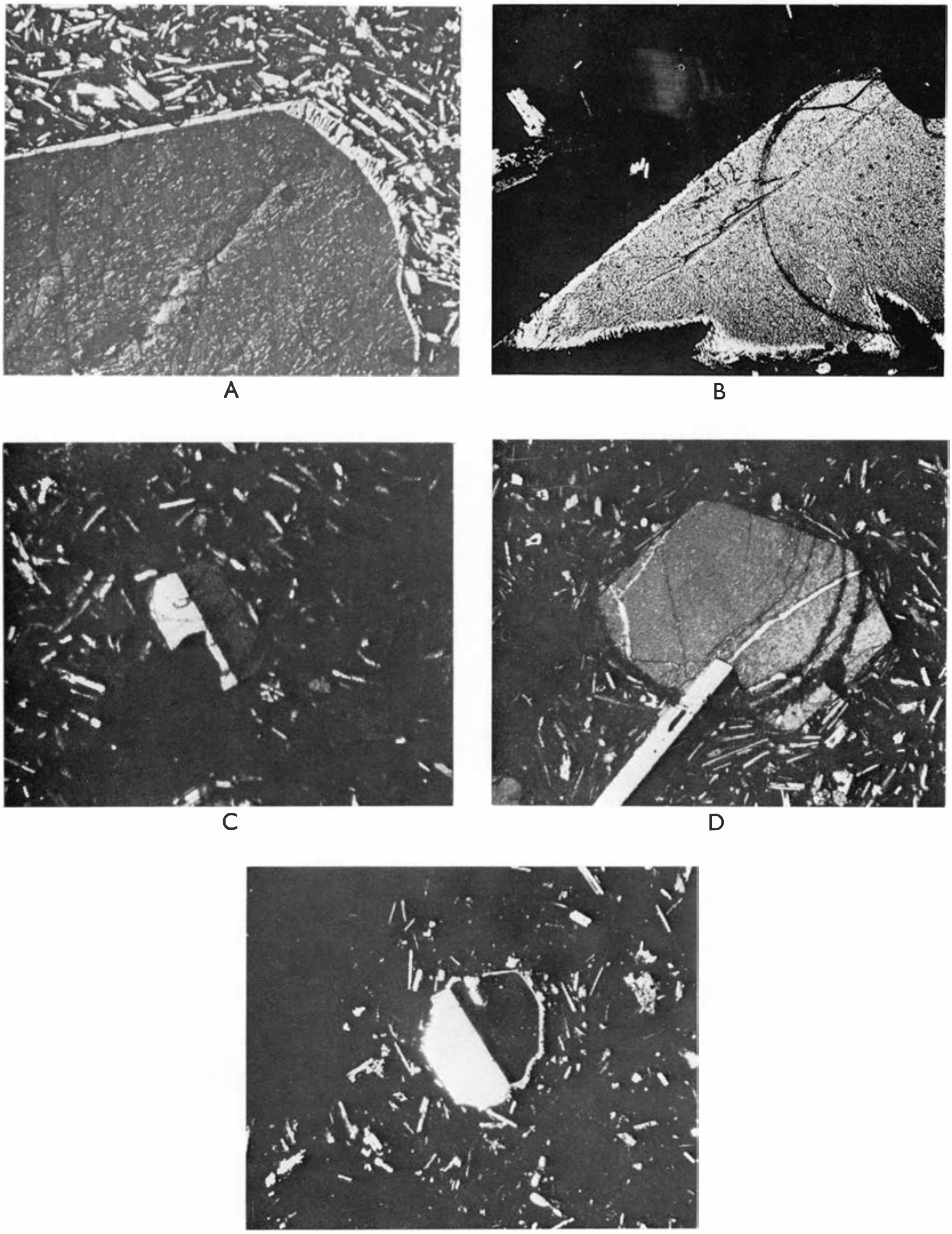
Partial analyses and Fo content of olivines

	FeO	MnO	MgO	Fo
6–10a	16.1	nd	42.3	82
6–10b	19.4	nd	38.5	78
6–10c	20.1	nd	38.1	77
7–8a	19.3	0.32	37.5	77
7–8b	19.6	0.33	37.5	77
7–8c	19.8	0.35	37.4	77
7–10a	18.0	0.30	38.9	79
7–10c	17.4	0.28	40.0	80
7–10d	16.8	0.27	41.1	81
$\bar{x}$	18.5	0.31	39.0	79

Appendix 3

Partial analyses of opaque minerals

	TiO_2	MgO
6–1	23.1	3.6
6–2	22.2	3.7
6–3	22.6	3.6
6–10	23.0	3.4
7–7	20.8	4.1
$\bar{x}$	22.4	3.7
7–1d	4.4	8.0
7–1e	3.8	5.7
7–1f	2.2	5.0
7–7	6.5	4.7
7–7	4.0	6.3
$\bar{x}$	4.2	5.9
6–9	0.9	0.5
6–9	1.0	0.5
$\bar{x}$	0.9	0.5



A. Diopside phenocryst with late-stage rim of titanaugite.

B. Diopside phenocrysts showing broken nature. Ring is identification mark for microprobe analyses.

C. Twinned salite phenocryst.

D. Euhedral olivine phenocryst partly enclosing plagioclase lath.

E. Twinned bytownite phenocryst with labradorite rim.

Note. Photomicrographs taken under crossed nicols. Long dimension represents 2 mm.

Distribution of the Svalbard reindeer (*Rangifer tarandus platyrhynchus*) in 1969-70

(Распространение свальбардского северного оленя (*Rangifer tarandus platyrhynchus*) в 1969-70)

BY

MAGNAR NORDERHAUG

Contents

Abstract

During the 1960's a continued restoration of the Svalbard reindeer population was observed. In this paper new details on the present (1969-70) distribution of the herd in different parts of the archipelago are given. A further expansion was observed in 5–6 different areas. A full return to its former population is possible in the coming years. Data from 1969–70 are given in Fig. 1. In Fig. 2 the known distribution of the Svalbard reindeer in 1970 is summarized.

Аннотация

За 1960-е годы наблюдалось непрерывное восстновление оленьей популяции Свальбарда. В данной статье приводятся новые детали по настоящему (1969-70) распространению оленьего стада в разных частях архипелага. Дальнейшее расширение ареала северного оленя заметилось в 5-6 разных областях. За следующие годы будет возможным полное возвращение оленей на прежние пастбища. Данные 1969-70 гг. приводятся на рис. 1. На рис. 2 подводятся итоги известного распространения свальбардского оленя в 1970 г.

Acknowledgements

I wish to express my gratitude to J. ANGARD and A. GUDDING for their field-work in NW Spitsbergen during spring 1970, and to J. MICHAELSEN, assistant biologist at Norsk Polarinstitutt's summer expedition 1970, who worked in the eastern parts of Svalbard. Furthermore, I would like to thank B. HELLE and O. I. RUUD for supplying other valuable information to this paper.

Introduction

In two papers (NORDERHAUG 1969 and 1970a) the distribution of the Svalbard reindeer (*Rangifer tarandus platyrhynchus*) during the 1960's have been summarized from different parts of the Svalbard archipelago.

A general increasing trend, both in population size and geographical distribution has been observed. This indicates a continuing re-establishment of this herd, which was nearly extirpated by hunting in the 1920's.

From different parts of Svalbard the distribution of reindeer was still unsufficiently known at the end of the 1960's. For this reason new field surveys have been performed in 1970 and supplemented with some additional data from 1969.

(Place-names used in this paper refer to Norsk Polarinstitutt's Svalbard maps 1:500 000.)

Material

1) During spring 1970 a field party (consisting of J. ANGARD and A. GUDDING) was sent out by Norsk Polarinstitutt to survey the distribution of reindeer in the northern part of Spitsbergen. The area between Smeerenburgfjorden and eastwards to Gråhuken was investigated, partly by airplane and partly by use of dog teams.

2) During Norsk Polarinstitutt's summer expedition a survey, partly from helicopter, was conducted in the area between Bockfjorden and the eastern coast of Wijdefjorden, and in the southern part of Hinlopenstretet from Barentsøya to Wilhelmøya.

3) From visits by the governor's ship «Nordsyssel» summer 1970, data on reindeer distribution were supplied from Bünsow Land, Dickson Land, and the NW corner of Spitsbergen.

4) From a French expedition visiting Svalbard in the summer 1969 further data on the present distribution in the Liefdefjorden/Woodfjorden area were made available (VOISIN 1970).

5) Information collected from different sources supplied new data on areas where reindeer at present (1970) not occur.

Results

Based on the present material (1969–70) the following new information was obtained (Fig. 1):

Albert I Land – Ny Friesland. – From the western part there are five observations of smaller herds (2–12 animals) in addition to numerous track observations from the area west of Raudfjorden and down to Blessingberget in Smeerenburgfjorden. One observation is from Norskøyane (5 animals, Indre Norskøya, 8 July 1970). In the southern part of the area tracks were observed to the bottom of Woodfjorddalen (1969). In Andrée Land there are nine sight records from 1969–

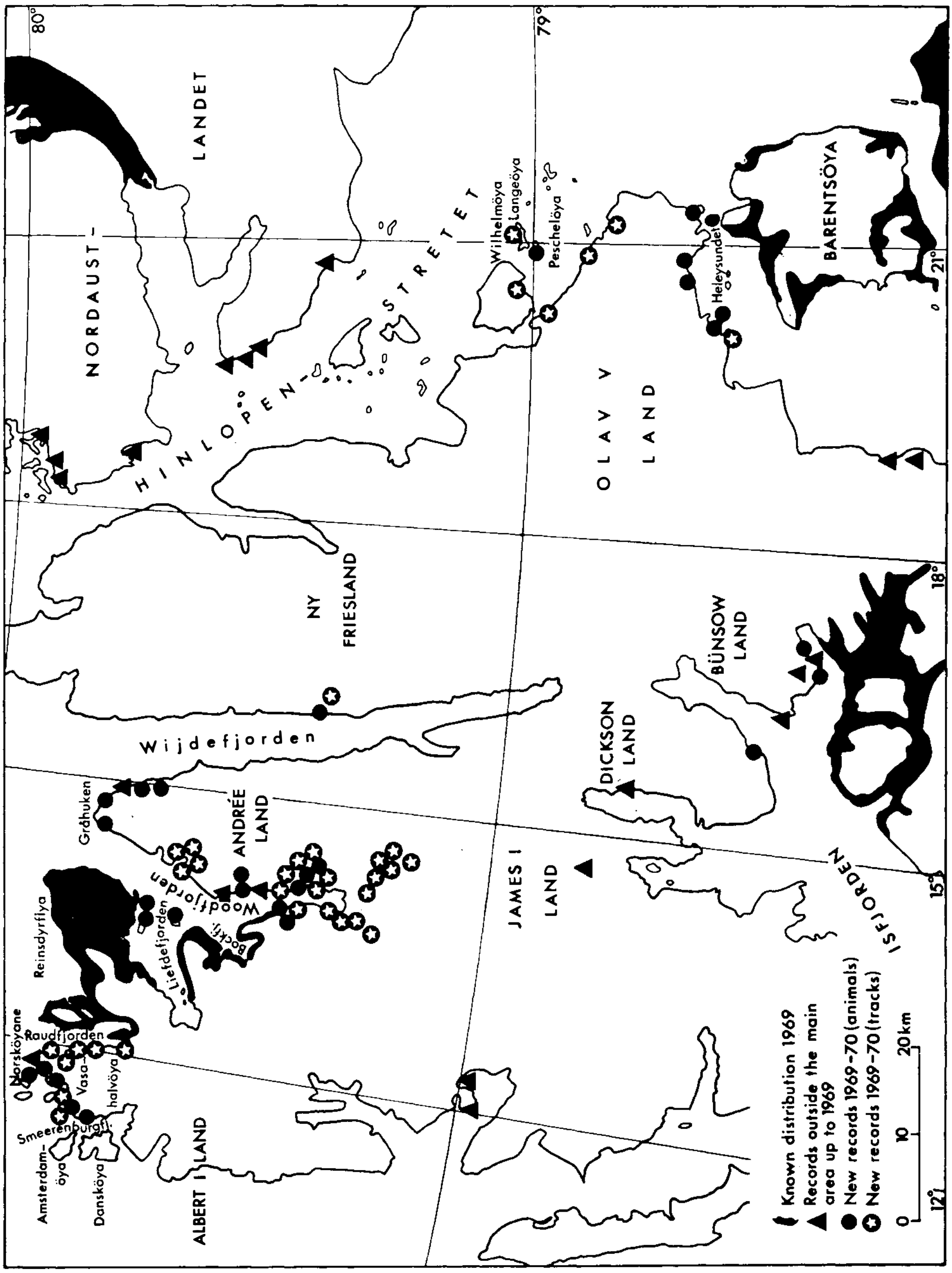


Fig. 1. *Occurrence of the Svalbard reindeer in the northern parts of the archipelago.*
Наличие свяльбардского оленя в северных районах архипелага.

70 (1–7 animals including calves) and ten observations of tracks south of Vogtdalen, east of Gråhuken. On 1 August 1970 tracks were seen near Daghøgda (Ny Friesland) and later (5 August) one individual was observed there. This is the first known record from this area in recent time.

Dickson Land – Bünsow Land. – In Bünsow Land 5 animals (in two groups) were seen 26 June 1970. Furthermore, 3 animals were recorded south of Skansbukta (Dickson Land) the same day.

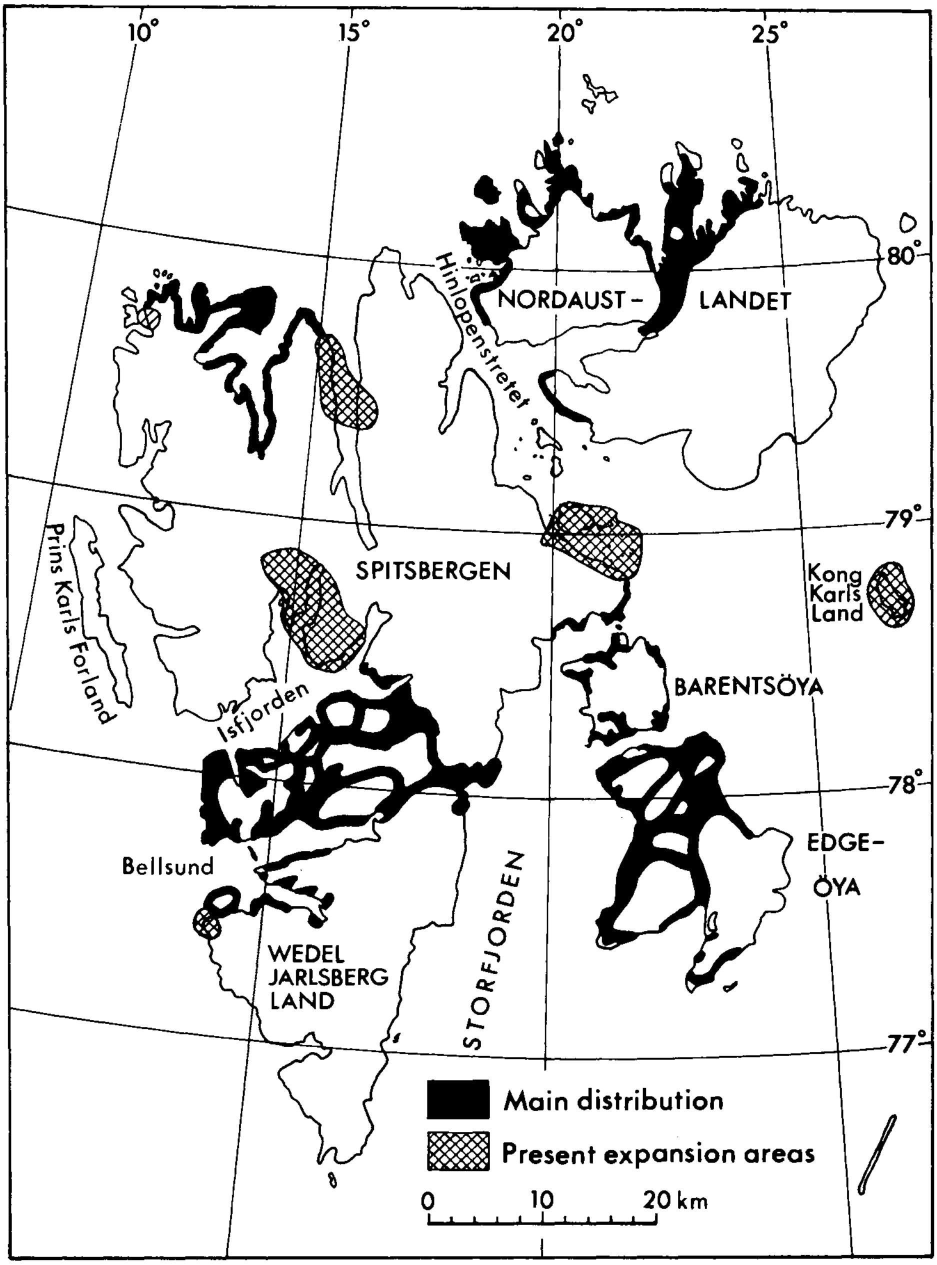


Fig. 2. *Known distribution of the Svalbard reindeer in 1970.*
Известное распространение свальбардского оленя в 1970 г.

Olav V Land – Hinlopenstretet. – The area from Wilhelmøya and southwards to Diabastangen was investigated 19–25 August 1970. On the main land tracks were found northwards to Beckerfjellet, and a herd of 34 animals (including 6 calves) occupied the area on the northern coast of Heleysundet. On the islands in the southern part of Hinlopenstretet tracks were found on Wilhelmøya and Langeøya. On Pescheløya 6 animals were recorded 23 August.

Wedel Jarlsberg Land. – According to information from O. I. RUUD, tracks have been seen south of Storvika during the winter 1969–70 (Fig. 2).

Discussion

From the present records it appears that the reindeer expansion in Svalbard continues in 5–6 different areas.

In the north-west tracks were previously (1966) observed westwards to Arneliusneset on Vasahalvøya (NORDERHAUG 1969). Records from 1970 indicate an expansion about 25 km southwards along Smeerenburgfjorden. A continued expansion in this area may well lead to re-establishment on Amsterdamøya and Danskøya. According to LØNØ (1959), reindeer have not been observed on these islands since 1828. The records from Andrée Land support earlier impression (1962–65) of re-establishment on this peninsula. Furthermore, the records from Ny Friesland (August 1970) indicate a further expansion towards the east. From Ny Friesland different field groups had negative reports in 1953–67 (NORDERHAUG 1969). This eastwards expansion from Reinsdyrflya is relatively slow. The first record from Andrée Land (crossing of Woodfjorden) was reported in 1962 (HEINTZ 1963), and from this range expansion into Ny Friesland (crossing of Wijdefjorden) must have taken about eight years according to the present records.

The area north of Isfjorden, Bünsow Land, is now probably permanently occupied. In Dickson Land and James I Land the situation is still uncertain, but smaller groups may now and then occupy this area.

From the southern part of Spitsbergen reindeer in the area south of Bellsund have now been found down to Storvika. A further southwards expansion in this area is possible.

When Edgeøya and Barentsøya were surveyed in 1969 (NORDERHAUG 1970a), it was not possible to investigate the area north of Heleysundet (Olav V Land). However, the present records from 1970 clearly show that Heleysundet, with its strong currents, is no significant barrier for the reindeer. When immigration started in Olav V Land is not known; however, movements into the islands in the southern part of Hinlopenstretet may have taken place in recent years, probably after 1966 when Wilhelmøya was visited and no signs of reindeer were found (NORDERHAUG 1969). A connection may now exist between the herds in Nordaustlandet in the north and Barentsøya/Olav V Land in the south over the islands in Hinlopenstretet. The known distribution in 1970 is summarized in Fig. 2 (where also present expansion areas are indicated). It should also be noted that there are signs of immigration to Kong Karls Land in the extreme east. For the first time in this century tracks were observed there in 1954 (or 1955) (LØNØ 1969). In 1967 one individual was seen on Svenskøya (NORDERHAUG 1969) and in 1969 tracks of two or more animals were found on the same island (NORDERHAUG 1970b).

It is evident that the expansion of the Svalbard reindeer, observed during the

1960's, still continues. Within the coming years the herd will probably have returned to the main part of its former ranges. Both the geographical distribution and the population dynamic of this unique reindeer are accordingly well worth further studies.

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Old Red Sandstone palaeomagnetism of central Spitsbergen and the Upper Devonian (Svalbardian) phase of deformation[1]

BY

KARSTEN M. STORETVEDT[2]

Contents

Abstract

In an attempt to provide more information about the late- or post-Caledonian tectonic processes in the Arctic and to study ancient geomagnetic field properties, a palaeomagnetic survey has been carried out on late Lower Devonian strata of central Spitsbergen. Thermal demagnetization studies and measurements of saturation magnetization versus temperature suggest that the Upper Devonian phase of diastrophism lead to an extensive modification of the original magnetic record. Cation deficient spinels (non-stoichiometric titanomagnetites) appear to have been produced through a reduction of primary haematite causing superimposed magnetization of thermo-chemical origin. The data suggest that during the Upper Devonian graben formation the border zones experienced a higher temperature increase than the central area. The resulting secondary magnetism seems to be oppositely directed to the original component causing in general a deviating net magnetization. As the Curie (or transformation) temperature of the secondary minerals may (at least in part) be as high as the Curie temperatures of the primary phases, the experimental efforts of determining single remanence components have failed. However, the demagnetization trends tend to suggest a magnetization axis corresponding to the Old Red Sandstone field relative to southern Norway. At present there is no evidence of any significant rotation of central Spitsbergen which might have resulted from the extensive strike-slip fault movements along the North Atlantic orogen and/or along the de Geer fracture zone. The experimental indications of a normal polarity field in Lower Devonian time and a reversed field in the Upper Devonian fit into a Devonian polarity/time sequence as previously postulated.

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Introduction

Several outlines of the geology of the Svalbard archipelago have been published; recent accounts being given by ORWIN (1940), FREBOLD (1951), HARLAND (1961) and SOKOLOV et al. (1968). The whole of Svalbard is considered to have been involved in the North Atlantic geosyncline, forming the basis of the Caledonides of Europe and of the Appalachians. This geosyncline was subjected to a major regional metamorphism at about Silurian time. As in other areas within the North Atlantic geosyncline, this mid-Palaeozoic phase of diastrophism was followed by Old Red sedimentation which in Svalbard continued to the end of the Middle Devonian. The Upper Devonian of Svalbard, which represents a gap in the sedimentary record, corresponds in time to the Svalbardian crustal movements (VOGT 1936). This late Caledonian deformation was essentially responsible for the formation of the great central graben of Spitsbergen within which the major part of the present Old Red succession is confined (Fig. 1). There is evidence that during the Svalbardian period the North Atlantic orogenic system was subjected to extensive sinistral strike-slip faulting (HARLAND 1965, 1969). In the opinion of HARLAND (1969) "the principal tectonic event in the Arctic region in late Devonian time translated Europe several hundred kilometres north with respect to North America and Greenland". Of further potential importance in the present context is the post-Palaeocene dextral strike-slip movements along the so-called de Geer fracture zone off the western coast of Spitsbergen, in part held responsible for the opening of the North Atlantic-Arctic basin.

On this background a palaeomagnetic study of the Old Red Sandstone of Spitsbergen involve interesting geodynamic problems in addition to geomagnetic aspects. The results presented here are based on the Lower Devonian strata of Dicksonfjorden and Ekmanfjorden (cf. Fig. 1) belonging to the Wood Bay Series (HOLTEDAHL 1914). The true thickness of sediments in the Old Red Sandstone graben of Spitsbergen is not known, but if maximum thicknesses are added, the total would amount to 7000–8000 metres. The common rock types are red siltstones and sandstones.

Laboratory experiments

Thermal demagnetization

A total of 62 cylindrical specimens (cut from 30 different samples) have been subjected to progressive thermal demagnetization in air. The remanence measurements were done on an astatic magnetometer after having cooled the specimens in zero field to room temperature. The typical NRM intensity (J_n) range of these specimens varies between $3 \cdot 10^{-6}$ emu/cm^3 and $7 \cdot 10^{-7}$ emu/cm^3 with a mean value around $1 \cdot 10^{-6}$ emu/cm^3.

The J_n–T curves reveal that the most important blocking temperature range is above 600°C, indicating that the relevant magnetic phases are in a high state of oxidation. However, at 620°C or 630°C the J_n was often very weak, on the limit of reliable measurement with our most sensitive magnetometer ($\sim 3 \cdot 10^{-7}$ emu/cm^3),

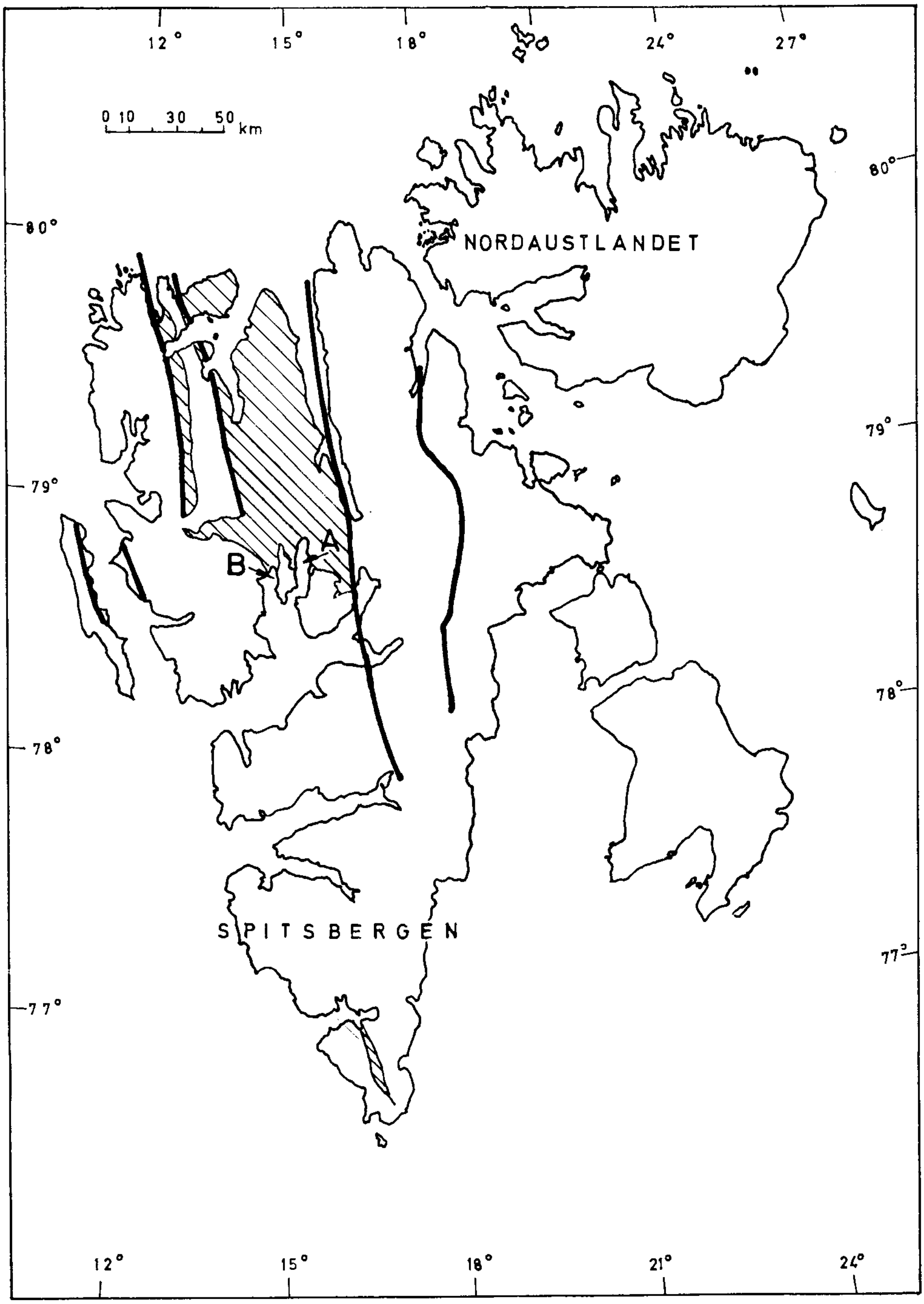

Fig. 1. *Sketch map of the Svalbard archipelago showing the outline of the Old Red Sandstone (shaded) in addition to major fault zones. (After* HARLAND *1969). Dicksonfjorden and Ekmanfjorden are marked by A and B, respectively. The indicated magnetization axis is that corresponding to data from southern Norway and the Orkney islands.*

so that in many cases a further study of the important high temperature region could not be achieved. Nevertheless, the high temperature data obtained fit in general into a fairly well defined directional pattern so there are good reasons for believing that they are negligibly affected by spurious components.

Nearly all NRM directions define a broad planar distribution with a NE–SW axis. In this distribution there is no preference for any particular magnetization direction and practically no specimens retain their NRM direction over the whole range of temperatures studied. In only 20 of the specimens tested is it possible to define a stable bulk magnetization direction, i.e. a direction which characterizes a specimen over the major range of temperatures, say below 600°C. These bulk magnetization directions are shown in Fig. 2 together with the postulated Devonian magnetization axis for Spitsbergen as based on results from southern Norway (STORETVEDT 1970a) and from the Orkney islands (STORETVEDT & PETERSEN 1971). As revealed by the demagnetization results (see below), the planar distribution of Fig. 2 is explained by the existence of antiparallel magnetization components of varying relative importance but of nearly identical thermal stability.

The directional behaviour during progressive demagnetization differs according to the situation of the sampling sites within the Devonian graben. Thus, in samples from Dicksonfjorden, which are centrally situated within the graben, the remanence directions nearly exclusivly move towards normal polarity at high temperatures, while samples from Ekmanfjorden, at the western graben boundary, exhibit both polarities at high temperatures but with a slight preference for reverse directions. Figs. 3 and 4 give characteristic examples of direction changes as a function of temperature. The general tendency of the natural remanence to split up and to attain at high temperature practically antiparallel directions clearly indicate a composite build-up of the fossil magnetization. The prime difficulty of estimating

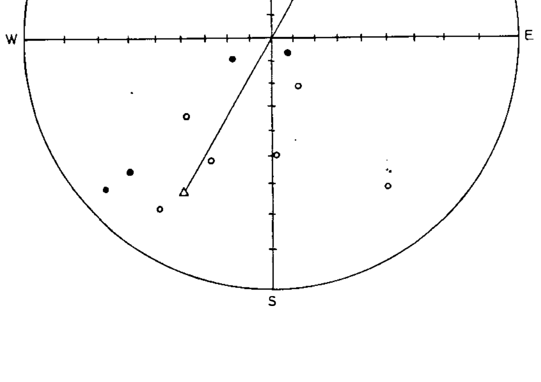

Fig. 2. *Directions of stable bulk magnetization in specimens from central Spitsbergen.*

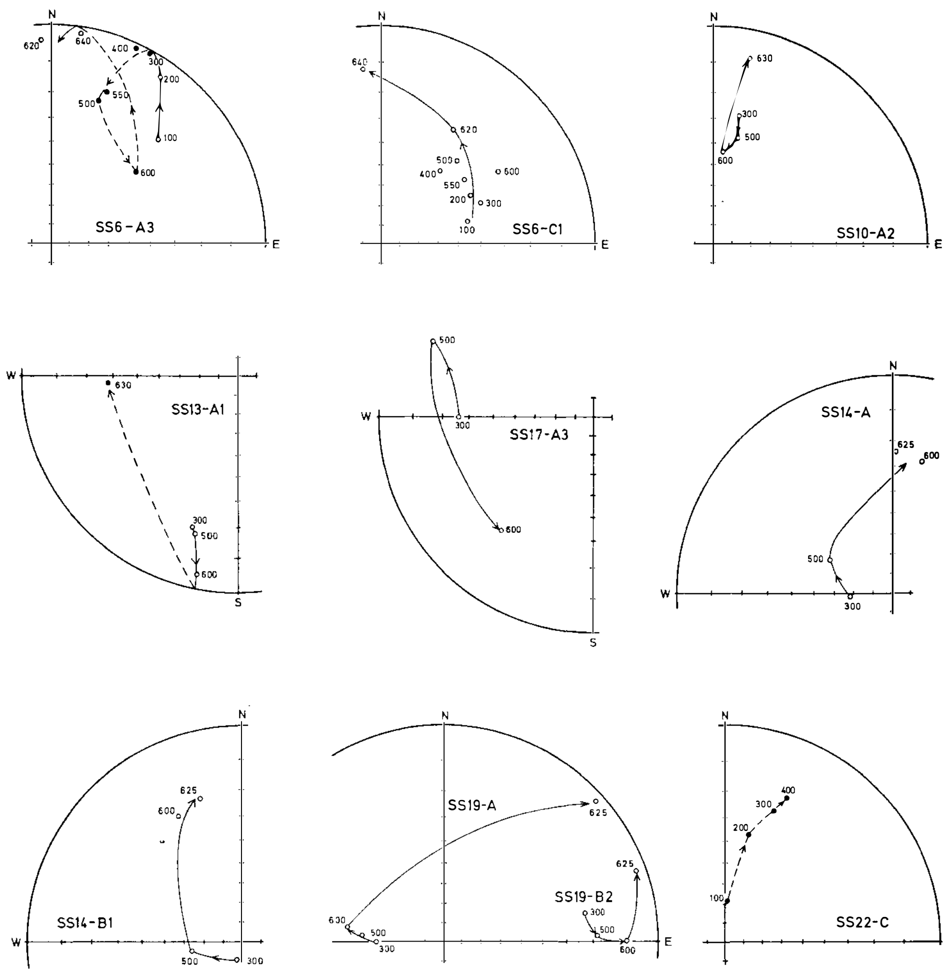

Fig. 3. *Examples of remanence directions versus temperature for separate specimens. Sample numbers below 43 refer to the Dicksonfjorden area while higher numbers refer to the Ekmanfjorden area. Single remanence components are not successfully estimated and therefore the tectonic corrections (small) have not been applied.*

single remanence components is that the J_n often reaches the lower limit of reliable measurement before the movement of the magnetic vector has come to a stop. Furthermore, random moments become significant after heat treatment at 650°C. There is no doubt, however, that the demagnetization trends tend to define two roughly opposite directions of shallow inclination. The directional behaviour of a number of specimens suggests the postulated geomagnetic axis for the Devonian (cf. Fig. 2) as the relevant palaeomagnetic field, while other specimens tend to define high temperature directions at some variance with this axis. Considering normally directed high temperature magnetization (the Dicksonfjorden area), there are some tendencies to stabilize in directions striking nearly due north and with negative inclinations, i.e. deviations of 35 degrees of arc or more from the

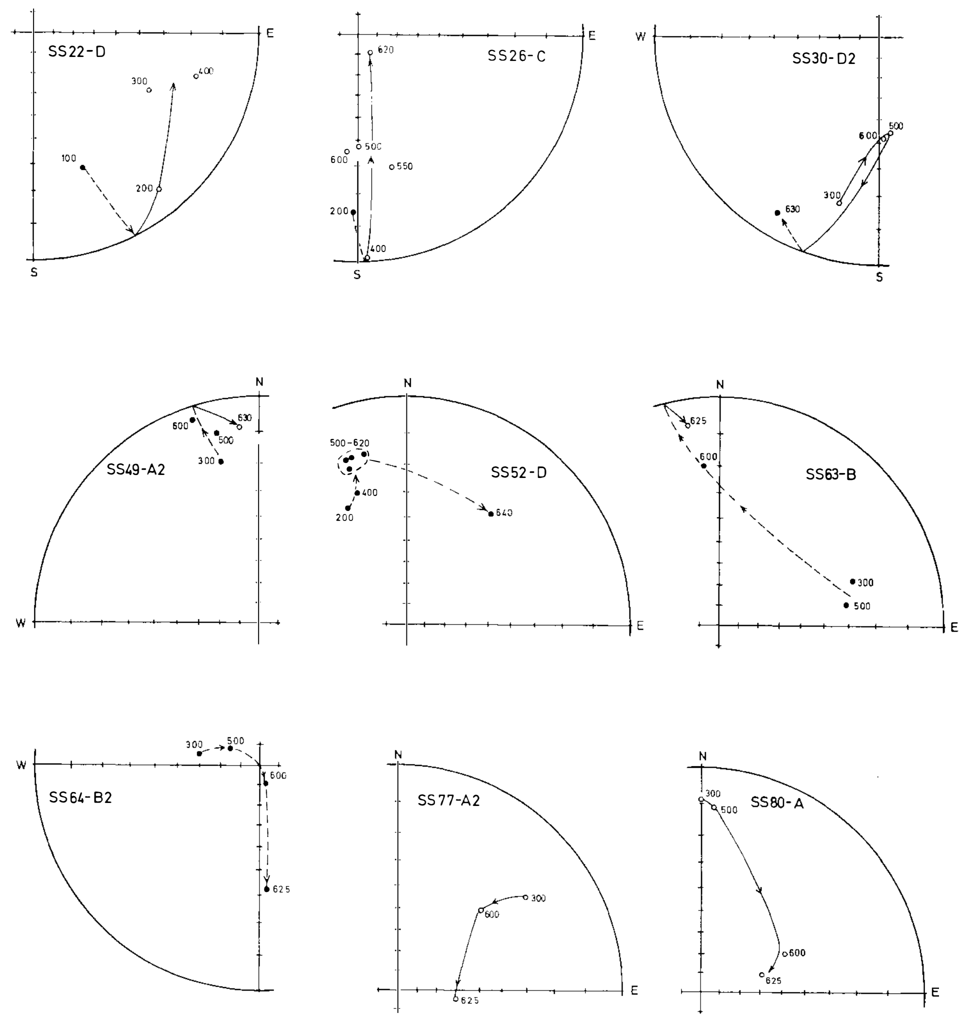

Fig. 4. *Text as to Fig. 3.*

postulated Devonian dipole field direction. However, as these "deviating" directions lie along a great circle through the two field directions suggested, there are good reasons for supposing that again one is dealing with composite magnetizations, i.e. the deviating directions are the resultant of superimposed normal and reversed components (with a predominance of normal magnetization) having nearly identical thermal stability at high temperatures. This means that the reverse magnetization, which appears to have its greatest importance along the western graben boundary, is also sufficiently well developed in central areas to destroy a successful experimental estimation of the normal magnetization component. The same problem may occur when attempts are made to determine the reversed component. In all, the Old Red Sandstone of central Spitsbergen exhibit the standard remagnetization problems (STORETVEDT 1970b). Though the present data do not justify calculation of a palaeomagnetic mean direction, there is strong experimental evidence that the fossil magnetization recorded was brought about by magnetization processes within the postulated Devonian field.

Saturation magnetization versus temperature

The saturation magnetization, J_S, as a function of temperature has been measured with a translation balance in an applied field of 8000 Oe. The heatings, up to 700°C, were carried out in air. The J_S—T curves suggest a certain magneto-mineralogical distinction between the two areas considered.

The Ekmanfjorden specimens. – In the specimens tested, large irreversible changes in general take place during heating. These changes are first of all recognized by a systematic lowering of the Curie temperature (T_c), the observed maximum reduction being 170°C. The T_c-range obtained on heating varies from 350°C to approximately 675°C, but with most Curie temperatures below 600°C.

The Dicksonfjorden specimens. – The T_c-range appears to be more strongly concentrated at higher temperatures (600°C–700°C) and the T_c-reduction after heat treatment is less pronounced.

The general characteristics of all specimens studied are that the cooling curve lies below the heating curve and that on cooling a new phase with $T_c \leq 200$°C appear. It seems evident, therefore, that metastable magnetic minerals are of importance in these red beds. Probably one is concerned with Fe-Ti cation deficient spinels inverting on heating into an intergrowth of haematite (α Fe_2O_3) and spinel phases with low T_c (probably Ti-rich). The weakly magnetic α Fe_2O_3 is hardly observed in the J_S—T curves (probably due to the small amount present). The inversion temperature of the supposed non-stoichiometric titanomagnetites may be very close to the T_c of haematite (in particular in the Dicksonfjorden samples), i.e. the high temperature remanence may represent a composite magnetization of high thermal stability. Representative examples of J_S—T curves are shown in Fig. 5.

The magnetization history

Based on thin section studies of red rocks from the Wood Bay Series, FRIEND (1961) suggests that these rocks were derived "from an area of lateritic weathering and a post-depositional continuation, if not of lateritic conditions, at least of oxidizing conditions". It seems not unrealistic to suppose therefore that at a comparatively short time after deposition the oxidation processes of the Fe-Ti oxides had reached completion. At this stage the fossil magnetization was probably composed of two different kinds of remanence; a DRM carried by deposited ferric oxide grains plus a CRM having partly originated during post-depositional oxidation of detrital Fe-Ti oxides and partly from ferric iron oxide precipitates derived from percolating solutions. Furthermore, a steady depression of the crust must have taken place in order to receive a continuous sedimentary sequence of several kilometres. Such a depression must have resulted in a general consolidation

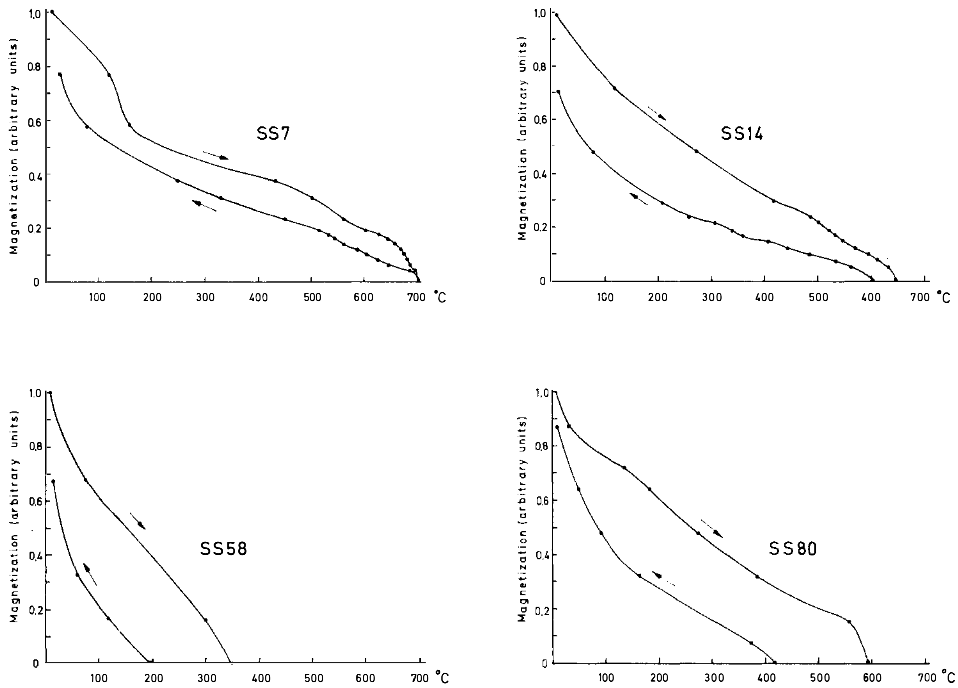

Fig. 5. *Examples of saturation magnetization versus temperature. Sample Nos. 7 and 14 are from the Dicksonfjorden area while Nos. 58 and 80 are Ekmanfjorden material.*

of the sediments whereby the remagnetization potential of penetrating solutions should be greatly reduced. Another point of greatest importance is the effect of temperature increase during burial. As the red beds considered belongs approximately to the middle of the Old Red succession of Spitsbergen, a minimum temperature elevation (adopting a normal geothermal gradient) should be about 100°C. Such elevated temperatures may have operated over times of the order of 10^6 years and therefore the process of acquiring viscous magnetization (VRM) is expected to have been enhanced. For this reason it seems not unlikely that the "primary" DRM/CRM magnetization became partly replaced by moderate temperature VRM during the time of diagenesis.

Our present knowledge of the Devonian geomagnetic field suggests a normal polarity throughout the Lower Devonian, the transition into a reversed polarity field occurring sometimes in the middle Devonian (STORETVEDT 1970b, STORETVEDT & PETERSEN 1971). As the geomagnetic dipole axis relative to Europe seems to have been firmly trapped throughout Old Red Sandstone time (STORETVEDT 1967, 1970b), there are reasons for supposing that the magnetizations acquired in the early history of the considered red beds (including diagenesis) were all aligned in the same geomagnetic dipole field. For convenience, this supposed normally directed net magnetization, thought to have been introduced by different magnetization processes within the Lower Devonian and possibly also in the early Middle Devonian, is in the following termed primary magnetization.

The intensive phase of crustal deformation in Spitsbergen during Upper Devonian times is likely to have provided the necessary agencies for a new period of remagnetization. As the geomagnetic field in the Upper Devonian appears to have been reversed, a partial remagnetization might easily cause intermediate remanence directions of high stability. The observed smeared distribution in a plane containing the postulated ORS field for Spitsbergen (cf. Fig. 2) indicate that such an Upper Devonian remagnetization phase in fact took place. Supposing a certain temperature increase as the sole remagnetization agency in Upper Devonian times, the high temperature direction of a resultant composite magnetization (in practise the only single remanence component which can be determined) should be of normal polarity and corresponding to the primary magnetization direction. On the other hand, if a sufficiently strong chemical or thermochemical activity took place, the high temperature component would equally well represent the direction of the Upper Devonian field. Considering the available results, it is an interesting feature that the great majority of high temperature directions from central areas of the graben (Dicksonfjorden) display the Lower Devonian polarity (normal) while reversed high temperature magnetizations are more strongly developed along the western graben boundary (Ekmanfjorden). The straight forward interpretation of this observation seems to be that the Upper Devonian deformation mainly caused a moderate temperature increase in central areas of the graben while the border zones also became subjected to pronounced chemical changes. Provided the actual polarity sequence was as assumed, the high temperature directions exhibited by some of the Dicksonfjorden samples (cf. for instance specimen SS 17–A3 of Fig. 3 and the deviating results of normal polarity discussed in the previous chapter) suggest that a certain thermo-chemical process of magnetic importance took place in central areas as well. As suggested by the J_s–T curves of the Dicksonfjorden samples, the secondary mineral phase has Curie (or transformation) temperatures up to 700°C, i.e. a thermal stability at least as high as that of any primary haematite, which implies that the high stability region of the remanence is likely to consist of two superimposed antiparallel components. When the chemical alteration is more advanced (as in Ekmanfjorden), the magnetic fraction with $T_c > 600°C$ is progressively reduced. On present information the metastable magnetic minerals are probably cation deficient spinels developed from haematite under variable reducing conditions. The reason why this reduction process has reached a much further stage at the graben boundary than in the central area may be due to a temperature difference: in addition to an assumed general temperature elevation (probably of the order of 100°C) owing to the downward displacement, the border zones of the graben may have been subjected to somewhat higher temperatures caused by heat generation from faulting and folding processes. This explanation is supported by some preliminary ore mineral studies from Old Red Sandstone inclusions in a post-Devonian intrusion of northern Spitsbergen (HALVORSEN, pers. comm.). These inclusions must at least have been reheated to several hundred degrees centigrad and the original ferric iron oxides appear to have been extensively replaced by titanomagnetites, i. e. a further reduction stage than that recorded by the considered red beds. Also, FRIEND (1961) has suggested that in the Wood Bay Series post-depositional reduction of ferric iron grains has taken place locally. It seems likely to suppose that a certain reduction took place already during the original diagenesis, but with a major development during the Svalbardian orogeny.

Conclusions

The palaeogeophysics conclusions drawn from this study may be summarized as follows:

a) The Lower Old Red Sandstone of central Spitsbergen underwent pronounced thermochemical changes of the magnetics during the Upper Devonian orogeny. The important process in the present context appears to have been a reduction of ferric iron oxides, forming non-stoichiometric titanomagnetites. There are indications that the reaction rate of this process was temperature dependent, involving that the formation of the Upper Devonian graben of Spitsbergen resulted in a somewhat greater temperature elevation along the border zones than in the central area.

b) In central areas of the Spitsbergen graben the suggested Upper Devonian reduction process was of minor importance whereby a greater fraction of the original magnetic components remained unchanged. The high temperature magnetization of this area, which is thought to be essentially associated with the original magnetic phases, is nearly exclusively of normal polarity. On the other hand, in samples where the secondary (Upper Devonian) chemical changes are more strongly developed there is a preference for reversed high temperature magnetization. This indicate that a normal geomagnetic polarity in the Lower Devonian was followed by a reverse polarity in Upper Devonian times, i.e. in agreement with the Devonian polarity/time sequence as previously suggested (STORETVEDT 1970a, STORETVEDT & PETERSEN 1971).

c) Owing to the Upper Devonian magnetization overprint the resultant fossil magnetization is composite (even at high temperatures) and no sufficiently reliable directional estimate of either the normal or the reversed component has been achieved. There appears to be strong evidence, however, that the magnetization axis corresponding to that obtained for southern Norway is the relevant one. This suggests a Devonian pole position relative to Spitsbergen at about 160°E, 20°N in the present grid system.

d) The build-up of the fossil magnetization in the Old Red strata of central Spitsbergen seems to be fully explained by magnetization processes within the Devonian. Therefore any post-Devonian thermal/chemical processes (for instance caused by the extensive magmatic activity at Spitsbergen in Jurassic time) was apparently of minor importance in this area. Furthermore, there is no evidence at present that the Upper Devonian and Tertiary strike-slip movements in the Svalbard region have resulted in any rotation of the archipelago.

Acknowledgements

This work would not have been possible without the extensive support and co-operation given by Norsk Polarinstitutt. The field work was carried out by Mr. E. HALVORSEN, Mr. T. STORETVEDT and Mr. O. THUNE, to whom I am greatly indebted. Financial assistance for the Spitsbergen project has been provided by the Norwegian Research Council for Science and the Humanities.

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A palaeomagnetic study of two volcanic formations from northern Spitsbergen

BY

ERIK HALVORSEN[1]

Contents

Abstract

A palaeomagnetic investigation of the Sverrefjellet volcano suggests that the fossil magnetization was imposed in Quaternary times (less then 700 000 years ago), thus not in contradiction with a postglacial origin as previously proposed. On the other hand, the calculated pole position, based on the Halvdanpiggen volcanic material, is in fairly good agreement with results from Permo-Carboniferous rocks elsewhere in Europe. It is suggested that the emplacement of this latter volcanic rock was simultanously with the relatively strong earth-movements that occurred in Spitsbergen in Permo-Carboniferous times.

Introduction

This paper gives palaeomagnetic results obtained from the Sverrefjellet volcano and from the Halvdanpiggen volcanic neck in Spitsbergen (Fig. 1). The Sverrefjellet volcano is assumed to be of postglacial age (HOEL and HOLTEDAHL 1911, HOEL 1914), while the Halvdanpiggen neck has been thought to be of Tertiary or Lower Quaternary origin, mainly because of a petrological similarity with the Sverrefjellet volcano (GOLDSCHMIDT 1911).

The only geological descriptions available are given by HOEL and HOLTEDAHL (1911), HOEL (1914), and GJELSVIK (1963). The rocks are trachy-dolerites and consist mainly of titano-augite, plagioclase, olivine, magnetite and glass. They also contain nodules made up of olivine and smaller amounts of diopside, enstatite, and spinel. The occurrence of such ultrabasic nodules in extrusive volcanic rocks

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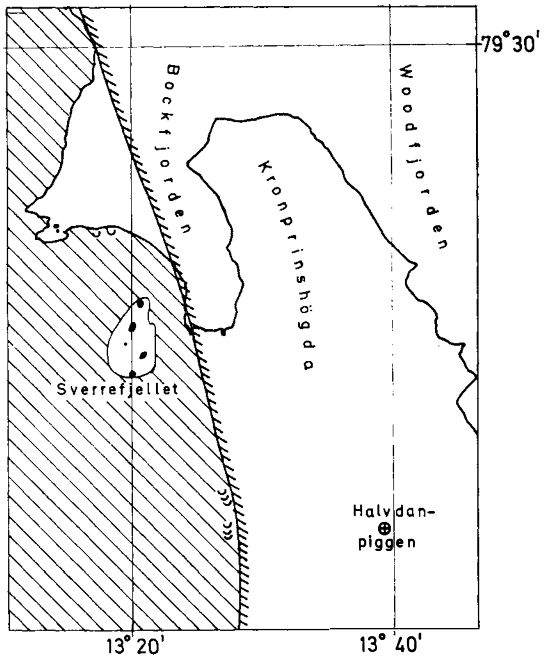

Fig. 1. *Geological sketch map. Hatched: Pre-Downtonian Hecla Hoek rocks. White: Devonian sandstone.*

indicates the connection with deep layers of the earth's crust, possibly down to the Mohorovicic discontinuity (GJELSVIK 1963).

The Sverrefjellet volcano contains inclusions of gneiss and marble. From the geological sketch map (Fig. 1) it is seen that the volcano is situated in the pre-Downtonian "Hecla-Hoek" series. The inclusions originate from these older rocks. To a large extent the volcano is covered by debris, making studies of structure and stratigraphy nearly impossible. The lavas are penetrated by fractures, probably caused by rapid cooling. It has been suggested (GJELSVIK 1963) that the solidification of the lavas took place under shallow water or subglacial conditions. The lavas are homogeneous in composition.

The Halvdanpiggen volcanic neck (dimension 170 m × 250 m) occurs in a Devonian sequence of sandstones and siltstones. In addition to inclusions of metamorphic rocks and ultrabasic nodules, the Halvdanpiggen neck also contains inclusions of Devonian sandstone. The latter inclusions are mainly found in the border zones. The minerals titano-augite and plagioclase, as well as the inclusions, often define a well developed fluidal texture.

Experiments

The measurements of direction and intensity of the natural remanent magnetization (NRM) were done with a spinner magnetometer (JELÍNEK 1966) in the Institute of Applied Geophysics, Brno, Czechoslovakia. A few additional measurements were carried out on an astatic magnetometer at the Department of Geophysics, University of Bergen. When the same specimen was measured in Brno and Bergen, the results were identical within a few degrees. For testing the stability of the NRM, the alternating field demagnetization technique was applied; 26 samples from 17 different sites (12 sites from Sverrefjellet and 5 sites from Halvdanpiggen) have been studied.

Results

The intensity of the NRM varies between about $11 \cdot 10^{-3}$ emu/cm^3 and $1 \cdot 10^{-3}$ emu/cm^3 with a mean value of $5.7 \cdot 10^{-3}$ emu/cm^3. The NRM intensities of the inclusions proved to be of the same order of magnitude as that of the igneous samples. Ore microscope studies have shown that the magnetic minerals in all types of samples were mainly titanomagnetite (REIJL, pers. com.), though the amount of this mineral in the inclusions is lower than that of the igneous material.

The alternating field demagnetization results suggest that the NRM contain only one single component of magnetization. Typical intensity decay curves are plotted in Fig. 2. Sample No. 49 is from the Sverrefjellet volcano while the other samples represent different rock types from the Halvdanpiggen neck (No. 57 is a sandstone inclusion, No. 71 an igneous sample, and No. 53 a mixture of these two types of rock). The intensity behaviour on demagnetization does not reveal any systematic difference in the magnetic hardness of the rock types involved.

Nearly all samples investigated showed a wide spectrum of coersive forces up to several hundred Oersteds. These values are quite high and the explanation of this can be at least twofold. Because of the rapid cooling of the Sverrefjellet lava flows, the growth of the magnetic minerals will be limited, resulting in a quite large amount of minerals with small grain sizes. Since the coersive force increases

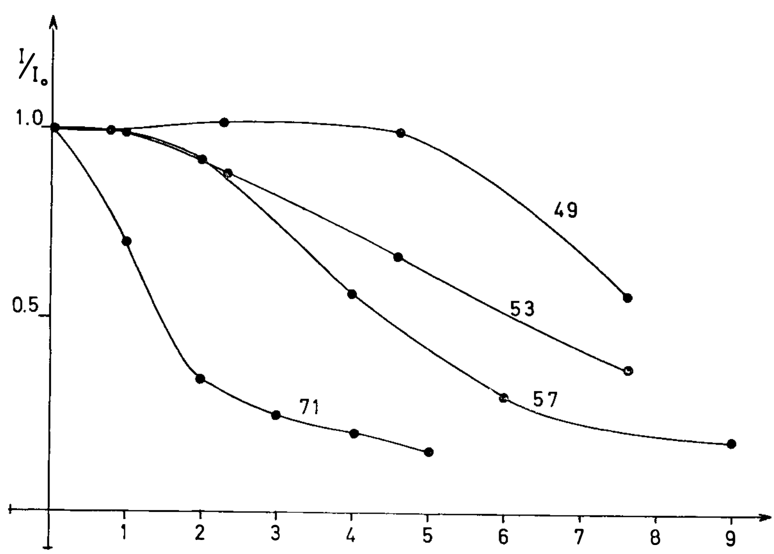

Fig. 2. *Typical intensity decay curves. Divisions on horisontal axis are in hundreds of Oersted.*

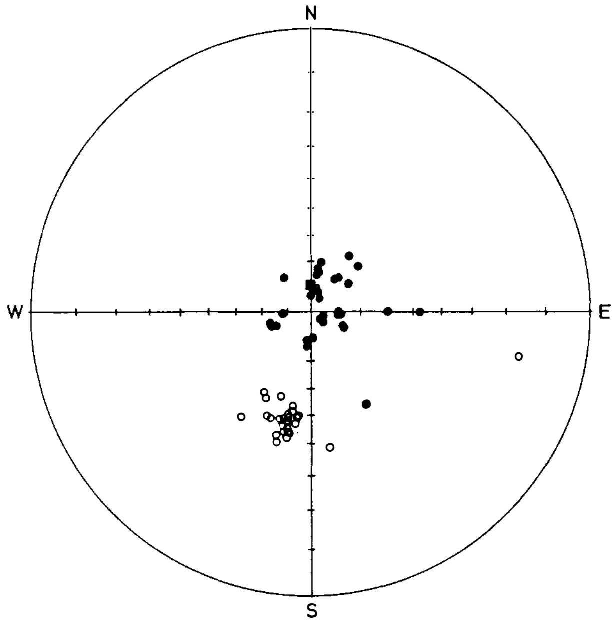

Fig. 3. *Directions of natural remanent magnetization. Filled square: Present axial dipole field.*

with decreasing grain size, this can explain the high coersivities found in this volcano. This explanation may also be valid for the Halvdanpiggen neck because only material from the chilled contact is involved. For the sandstone inclusions however, there must be another explanation. The titanomagnetites found in these rocks must be of secondary origin and probably formed by reduction of ferric iron oxides (STORETVEDT 1971). In a recent investigation it was found that different inclusions had the same direction of maximum, intermediate, and minimum susceptibility (HALVORSEN 1971c). This implies that the magnetic minerals have been formed after solidification of the neck.

The secondary formation of titanomagnetite most probably took place at high temperatures as a subsequent high temperature (deuteric) exolution-oxidation of the newly formed titanomagnetite took place. This latter subdivision of the grains will result in an increase of the coersive force. Ore microscopy shows the formation of exsolved lamellaes, though these in general may be on a submicroscopic scale thus making direct observation impossible. The problem of the formation of the secondary titanomagnetites in the inclusions will be the subject of another paper (HALVORSEN 1971e).

The results of the measurements of the direction of NRM are shown in Fig. 3. It is seen that the directions of magnetization are distributed in two clustered groups. The Sverrefjellet material has normal polarity with steep positiv inclinations indicating a high latitude of formation. In this group the scatter is relatively large. One of the reasons for this may be a large secular variation scatter of high latitudes, but the scatter may also reflect tectonic disturbances on a local scale during the entire phase of magmatic activity.

The other group of magnetization directions represents the Halvdanpiggen neck. The magnetization of this formation differs from that of the Sverrefjellet volcano in several ways. First of all the recorded polarity is opposite to that of the present geomagnetic field and the overall inclination is more shallow. The scatter of directions from the different samples are small, indicating that all samples have acquired their magnetization either at approximately the same time or that the magnetization time span was sufficient to average out secular variation at least to a certain extent. The magnetization direction of the inclusions agrees with that of the ignous material.

Discuss on and conclusion

The results of the study of the Sverrefjellet volcano indicate that the magnetization was acquired when the lavas originally cooled. The mean direction calculated from the measurements of NRM gives a declination of 025° and an inclination of +83° (down). This direction of magnetization corresponds to a relative pole position at 84°N, 120°E. When compared with other palaeomagnetic pole positions for Europe, this would correspond to a fairly recent age; the magnetization was probably acquired in Bruhnes normal polarity epoch (<700 000 years). Thus, the result is not in contradiction with the conclusion reached by HOEL (1914), suggesting a postglacial age of the Sverrefjellet igneous event.

The Halvdanpiggen neck gives a mean magnetization direction of 189° in declination and –48° (up) in inclination. This result gives a pole position at 40°N, 180°E, which is in good agreement with results recently obtained on Permo-Carboniferous rocks of Europe (STORETVEDT and GIDSKEHAUG 1969; HALVORSEN 1970, 1971d). Therefore, it appears likely that the emplacement of the Halvdanpiggen volcanic neck took place in Permo-Carboniferous times probably connected with the relatively strong earth-movements that occurred in Spitsbergen at that time (ORVIN 1940). Also, a radiometric age determination of monchiquite (lamprophyre) dikes outcropping near the Billefjorden fault zone gives a middle Carboniferous age (GAYER et al. 1966).

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Diurnal variations of the surface wind over the Antarctic ice shelf

BY
VIDAR HISDAL

Contents

Abstract

For the three Antarctic ice shelf stations considered (Norway St., Maudheim, and Halley Bay) it is shown that from spring to autumn a systematic diurnal variation of the mean vector wind at the surface exists. Different factors that may be responsible for this variation are discussed. The results seem to agree well with the assumption that in areas far from the ice front the main cause is the larger net gain of momentum in the lowest layers during the middle of the day, while closer to the ice front there is an additional effect of the varying contrast between the air temperature over the sea and over the ice shelf.

Introduction

For several Antarctic stations it has been found that, during the period from spring to autumn, there is a systematic diurnal change of the surface wind speed. Some stations have a maximum mean wind speed in the late night or early morning (e. g. Mawson (ANARE Reports 1954–) and Port Martin (LE QUINIO 1956)). For other stations the maximum occurs during the middle of the day (e. g. Cape Evans (SIMPSON 1919) and Davis (ANARE Reports 1957–)).

The morning maximum is typical for stations that are influenced by katabatic winds, which reach their greatest intensity about the time when the temperature over the ice slopes is lowest.

The noon maximum, on the other hand, may presumably be explained in the same way as the corresponding feature of the wind variation in lower latitudes, as the result of a maximal influence of the higher, faster moving layers at the time of the day when the turbulent exchange is strongest, and (or) of a maximal temperature contrast between neighbouring surfaces, with different thermal properties (usually a land- and sea-breeze effect).

Not all Antarctic stations, however, exhibit a distinct or unambiguous diurnal wind variation. This may be due to the masking influence of irregular (sampling) fluctuations, especially in cases where the observation period is short, or to the circumstance that two (or more) factors influencing the diurnal march neutralize each other.

It is the aim of the present paper to discuss, on the basis of observations from Antarctic stations, factors that may be responsible for a diurnal change of wind speed as well as wind direction. In order to simplify the problem in some measure, we have chosen stations situated on extensive ice shelves, where orographic influences, if any, should be insignificant. Adequate data were available for three stations of this kind, viz. Norway St. (70°30′S, 02°32′W, period: Apr. 1957–Dec. 1959), Maudheim (71°03′S, 10°56′W, period: Apr. 1950–Jan. 1952), and Halley Bay (75°31′S, 26°37′W, period: Jan. 1957– Dec. 1958). For the two former stations data were available at Norsk Polarinstitutt in Oslo, while for the latter station data were obtained from MacDowall et al. (1964) and Limbert (1965). The surface wind considered here is recorded by instruments at or near the 10 m level.

Regarding the course of the ice front and the location of the stations in relation to this "floating coast line", reference is made to the maps, Figs. 1 to 3. The distance from Norway St. to the ice front is about 30 km, while for the two other stations the corresponding distances are only about one tenth of this.

Observational results

For the three stations considered the main bulk of the wind observations is concentrated in comparatively few, adjacent direction sectors. At all stations easterly winds are predominant, with a secondary frequency maximum for southerly, or south-westerly winds. It seems justified to assume, therefore, that the mean vector wind for the individual observation hours will give a sufficiently realistic picture of the diurnal wind variation. It might in this connection have been of interest to study separately groups of days with winds within relatively narrow sectors. However, we here meet with special difficulties. Not only would this mean a severe reduction of the observation material, and accordingly large sampling fluctuations, but also we would be in danger of introducing systematic diurnal variations due exclusively to the persistence tendency of the wind (cf. Hisdal 1958, pp. 112–113).

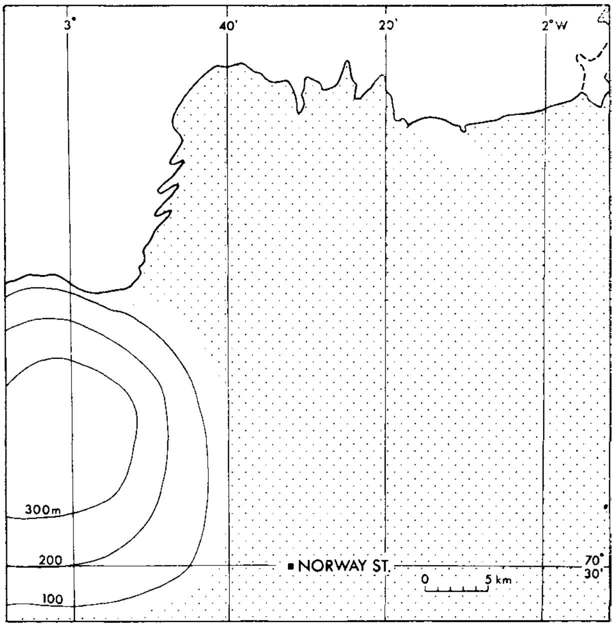

Fig. 1. *Sketch-map of the ice front near Norway St.*

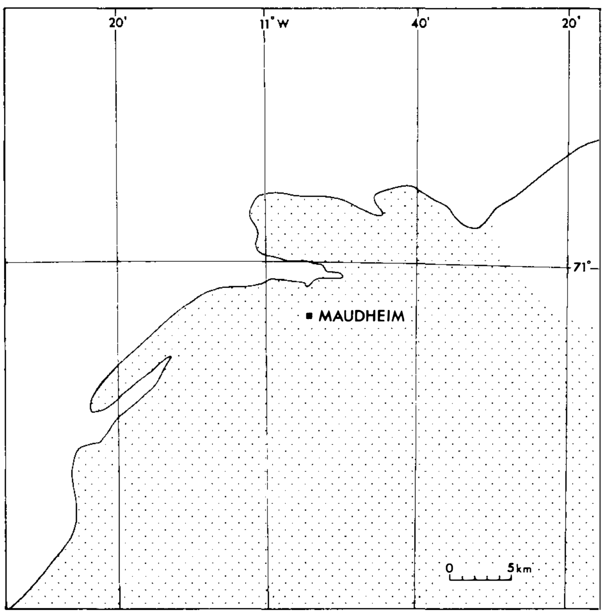

Fig. 2. *Sketch-map of the ice front near Maudheim.*

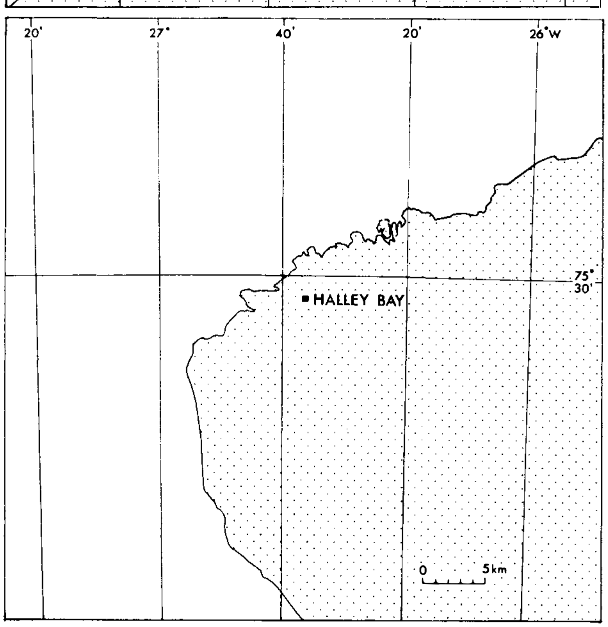

Fig. 3. *Sketch-map of the ice front near Halley Bay.*

In Fig. 4 are shown, for each station, mean vector winds for two seasons, which we here for the sake of convenience call the summer and winter season, and also the end points of the corresponding mean vectors for the individual observation hours, while Fig. 5 represents, for the summer season, the deviation of these latter mean vectors from their mutual mean. For the sake of simplicity these difference vectors are in the following sometimes referred to as "the diurnal wind". It appears that the length of the seasons is not the same for the three stations. For Halley Bay and Maudheim the mean vector winds were computed already for the combination of months specified in Fig. 4. Regarding Norway Station, data for the individual months were available. As a systematic diurnal variation was clearly in evidence only for the months October–February, it was natural to define that period as the "summer season" for this station.

We note from Fig. 4 that for all stations the diurnal variation is greater and more systematic in summer than in winter. During the former season the end-points of the difference vectors given in Fig. 5 turn quite nicely in a anti-clockwise direction as the day proceeds, their magnitude varying between about 25 and 75 cm/sec. Comparing with the course of the ice fronts (Figs. 1 to 3) we furthermore see that there is a tendency of the vectors to be on-shore during daytime, off-shore during the night. In the case of Maudheim this fact has been pointed out previously, in a general analysis of the surface wind (HISDAL 1958).

Discussion

In the following we consider different factors that may be supposed to contribute to the observed diurnal wind variation:

Sampling fluctuations

We first mention the obvious fact that the observed diurnal march of the wind is to some extent "haphazard". The amount of data is modest considering the small systematic change we try to trace here and the considerably greater wind changes connected with variations in the large scale pressure pattern. However, the much larger and more systematic diurnal course for the summer season than for the winter season strongly suggests that the "haphazard" element cannot be dominating.

Orographic and katabatic effects

Due to the site of the stations these effects are, as previously mentioned, supposed to be negligible.

Diurnal pressure oscillations

This phenomenon involves a diurnal change, however small, of the wind, and we shall describe briefly some results of an attempt to trace such effects. At a certain time of the year a pressure oscillation of this kind is supposed to give a small additional wind that is dependent on the time of the day only, and not on

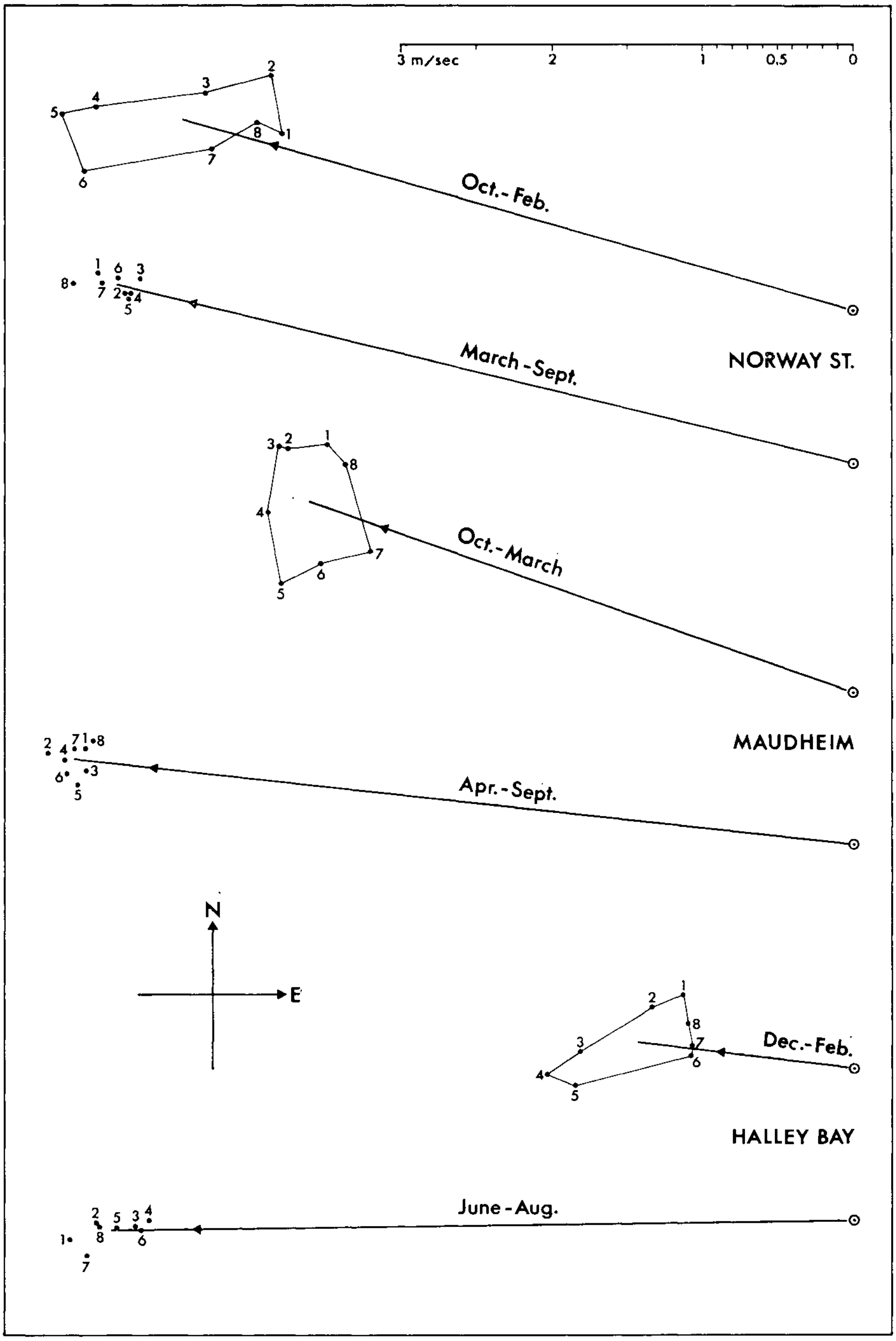

Fig. 4. *Seasonal mean vector winds and the end points of the corresponding mean vectors for the individual observation hours.*

The numbers 1, 2, 3,... refer to the observation hours 23.8^h, 02.8^h, 05.8^h,... LMT in the case of Norway St., 23.3^h, 02.3^h, 05.3^h, ... LMT in the case of Maudheim, and 22.2^h, 01.2^h, 04.2^h, ... LMT in the case of Halley Bay (cf. Fig. 5).

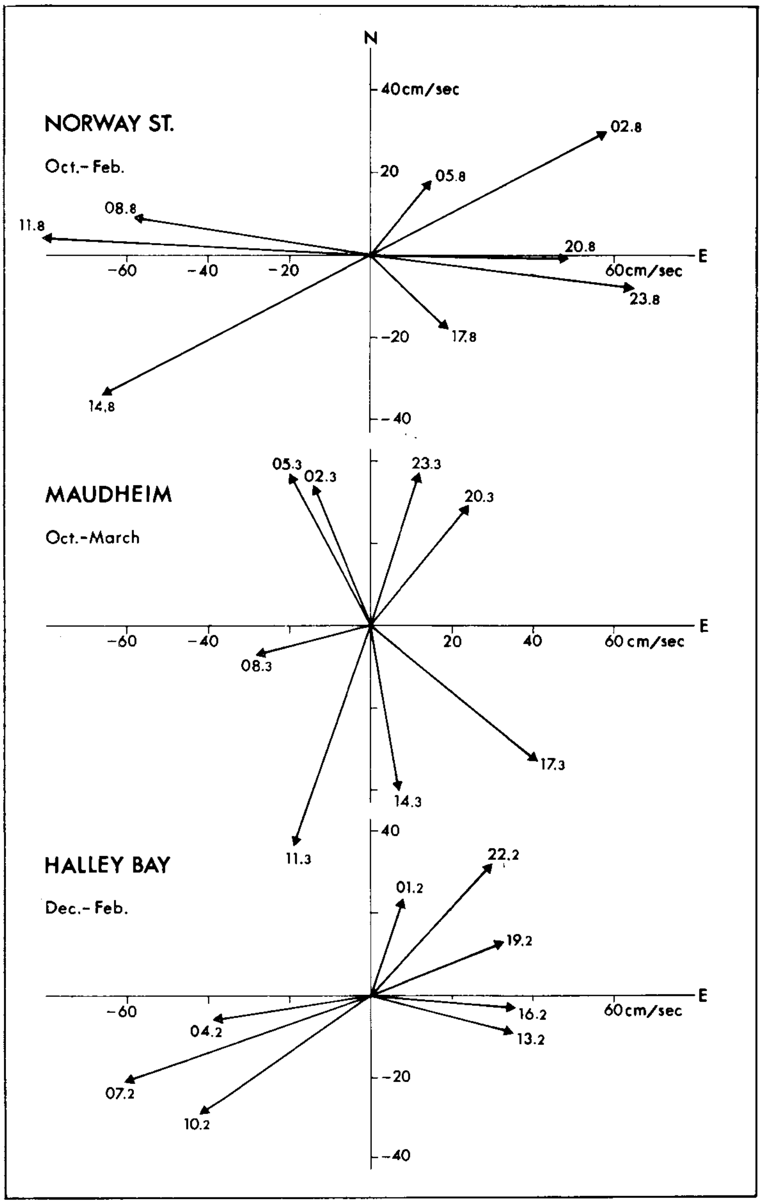

Fig. 5. *Deviation of the mean vector winds for the individual observation hours from their mutual mean.*

the direction of the main wind. Consequently, the hourly vector mean winds should be applicable as a basis of our investigation. The amplitudes and phases referred to in the following are found by means of an harmonic analysis of three-hourly mean values of the air pressure and of the vector components of the diurnal wind for the individual stations and seasons considered.

For all stations the calculated amplitude of the 24-hourly pressure wave (order of magnitude 0.1 mb) is greater for the winter than for the summer season, which in itself indicates that this phenomenon cannot have any great influence on the diurnal wind. This is further verified by the fact that there is no clear evidence of a connection between the phases of this pressure variation on the one hand, and the phases of the corresponding variation of the east- and north-components of the diurnal wind on the other. This applies both to the summer and winter season.

As is well known, the 12-hourly pressure oscillation is of a far more systematic character than the 24-hourly oscillation. For the region considered the amplitudes seem to be of the same order of magnitude for both oscillations, but are much more constant in the case of the semi-diurnal wave. It is further a well-established fact that the seasonal variation of the phase of the 12-hourly wave is very moderate and, furthermore, that the geographical variation of the phase as well as the amplitude shows certain regular features. Due to this regularity it is possible to derive an approximate expression for the variation with latitude and longitude of the amplitude and phase of this pressure oscillation. This has been made by SIMPSON (1918) and others. Introducing SIMPSON's expression in a perturbation equation STOLOV (1955) has, after some simplifying assumptions, calculated the corresponding, periodic variation of the surface wind. If the time (LMT) of the first daily maxima of the east- and north-component of STOLOV's "tidal winds" for the stations considered here are denoted t(E) and t(N) respectively, we find that the maximum of the semidiurnal harmonic constituent of the observed diurnal wind in 4 out of 6 cases occurs in the interval t(E)$\pm$2 hours as far as the east-component is concerned, and, also, in 4 out of 6 cases in the interval t(N)$\pm$2 hours as far as the north-component is concerned. The *a priori* probability that this result is purely accidental, is not very great (1%). However, taking into account the fact that the time intervals ($\pm$2 hours) are chosen *a posteriori*, by studying a graphical representation of the different components in an harmonic dial, the conclusive value of our result is considerably reduced. It should however encourage further investigations on this point, preferably by means of longer observation series. The magnitude of STOLOV's tidal wind in the considered area, about 50 cm/sec, is some five to ten times greater than the values found for the 12-hourly wind variation when analysing the observed data. This may to some extent be due to the simplifying assumptions introduced when computing the tidal wind field (i.a. frictionless atmosphere) and the fact that SIMPSON's expression generally gives much too large values of the amplitude in high latitudes (HISDAL et al. 1956). A recalculation of the "tidal wind" should be of interest, on the basis of an expressionfor the semidiurnal pressure oscillation that is in better agreement with the observed facts in high latitudes.

Concerning the 8-hourly period, there are some indications of a connection between the phase of the east-component of the wind and that of the tertidiurnal pressure oscillation. For the summer season the time-difference between the maxima of these two variations ranges from –1.3 to +1.6 hours. For the winter season the corresponding differences are contained in the interval –0.7 to +0.4 hours. Regarding the north-component of the wind there seems to be no such connection. The computed amplitude of the wind for the 8-hourly period is very small, generally well below 10 cm sec^{-1}.

On the basis of the above considerations it seems safe to conclude that compared with the observed diurnal wind change in the summer season, the influences on the wind of the 24-, 12- or 8-hourly pressure oscillations are slight, and that for the stations (or latitudes) in question a greater observation material is necessary to obtain conclusive information as to these influences. It is not unlikely that in particular the influence of the 12-hourly pressure oscillation is partly responsible for the observed irregularities in the dominating 24-hourly wind variation.

Diurnal variations of friction and of the surface geostrophic wind

The two last effects to be considered, viz. a diurnal change of (1) the eddy viscosity and of (2) the horizontal temperature-pressure field, are difficult to separate, especially since they may give rise to a diurnal course of the wind of much the same form. We will here confine ourselves to some tentative considerations.

The frequently observed noon maximum of the surface wind speed was explained by ESPY (1841) and KÖPPEN (1883) as due to maximal vertical mixing during the middle of the day. This theory was later revised by WAGNER (1936), KLEINSCHMIDT (1948) and others. Although the details of the connection between a changing eddy flux of momentum and the wind are still not fully understood, the observational basis is fairly well established. Thus it is generally found that the end point of the wind vector, because of this effect, describes in the course of the day a closed curve resembling more or less an ellipse, whose major axis cuts the curve near the points representing the time of maximum and minimum surface air temperature (or strictly, the time of minimum and maximum stability of the surface layer).

Studying Fig. 4 we find that Norway St. is the only station revealing a diurnal march that may be considered as typical of a "frictional wind". This agrees well with the fact that Norway St. is the only one of the three stations that has a well-defined noon maximum of the mean scalar wind speed and, furthermore, that this station is situated relatively far from the ice front, and thus from the region where the influence of a diurnal change of the "land"-sea temperature contrast should be most strongly in evidence.

Assuming tentatively that the diurnal wind at Norway St. is primarily a frictional phenomenon, we will, by means of simple theoretical considerations, estimate some parameters characterizing the frictional force.

The equation for horizontal, steady motion may be put in the form:

$$s\,\mathbf{F} = 2\Omega \sin\varphi \; \mathbf{k} \times (\mathbf{v}_G - \mathbf{v})$$

where s and $\mathbf{F}$ is the specific volume and frictional force respectively, $\Omega \sin\varphi$ is the vertical component of the earth's angular velocity at latitude φ, $\mathbf{k}$ is the vertical unit vector, and $(\mathbf{v}_G - \mathbf{v})$ is the geostrophic departure at the surface (anemometer level). We assume this equation to apply for average conditions around the times of the day when the diurnal turn of the wind changes direction (quasi-stationary conditions).

The geostrophic wind is the only unknown quantity on the right side of the equation above. On the basis of certain assumptions, LETTAU (1967) resolved the wind shear between the surface and 1,000 m at Little America into a frictional and a thermal component. He found that the latter component was roughly parallel to the ice front during summer time, and that it was of the same order of magnitude as the frictional component. Unfortunately, a similar analysis is hardly practicable in our case, particularly since the major part of the wind data from Norway St. is concentrated in a few, neighbouring direction sectors. It is reasonable to assume, however, that the thermal wind in the surface layer is appreciably smaller at Norway St. than at Little America, which was situated much closer to the ice front. In addition the temperature gradient "ice shelf-ocean" is likely to be larger in the latter area. For Norway St. we have supposed the conditions in the lowest layers to be quasi-barotropic, so that the wind at a certain level above the ground may be considered as a sufficient approximation to the surface geostrophic wind.

During most of the year a transition from an anticlockwise to a clockwise turn with height of the mean vector wind is found near or somewhat above the 850 mb level. A comparison of the mean vector wind at this level and at the surface is shown in Table 1. In view of the small surface roughness of an Antarctic ice shelf, the angular differences may seem too great to be interpreted as a frictional turning of the wind. However, the result agrees fairly well with that obtained by LETTAU (op. cit.) for the frictional turning of the wind from the surface to the 1,000 m level at Little America, viz. 17° to 28° in summer, 23° to 36° in winter, depending on wind direction. For the angular difference between the actual surface wind and the 1,000 m wind he found an average value of 24° for the summer season, and 28° for the winter season. Thus, as far as the turn of the wind in the lowest 1,000 m over Little America is concerned, the thermal wind seems to be of no great importance. The ratios of the magnitudes of the wind vectors for Little

Table 1

Vector mean winds at the surface (**v**) *and at the 850 mb level* (**v**') *for Norway St.*

t is the release time of the radiosonde in hours LMT
n is the number of days with two radiosonde ascents

t	n	Surface		850 mb level		Directional differences	|**v**|/|**v**'|
		|**v**| m/sec	Direction	|**v**'| m/sec	Direction		
			October—February				
11.6	326	9.59	107.4°	14.13	81.0°	26.4°	0.68
23.6	326	6.49	111.3°	12.58	81.7°	29.6°	0.52
Total	652	8.03	109.0°	13.36	81.3°	27.7°	0.60
			April—August*				
11.6	313	8.49	107.1°	14.18	72.5°	34.6°	0.60
23.6	313	8.28	108.0°	13.88	75.6°	32.4°	0.60
Total	626	8.38	107.6°	14.03	74.1°	33.5°	0.60

* These mean vectors were computed already in another connection, and the "winter" season differs somewhat from that used previously when studying the surface wind. For the present considerations, however, this is of minor importance.

America are not given. For a continental station like Byrd St. the frictional turn of the wind for approximately the same height interval is found to range from 30° to 39°, according to the strength of the surface inversion. Simultaneously the ratio of the observed surface wind and the geostrophic wind decreased from 0.46 to 0.34 (SCHWERDTFEGER and MAHRT 1969). The large frictional shear is attributed to the great stability of the surface layers over the Antarctic snow fields.

When comparing mean vector winds, as in Table 1, the largest wind speeds, which here occur in the easterly sector, will obviously have the largest influence on the results. As a check we have therefore for the period October–February considered the relation between the individual observations of the surface wind and the corresponding mean wind of the layer passed by the radiosonde during the time interval 2 to 4 minutes after release. This mean wind is assumed to be representative of the level reached 3 minutes after release. In about 75% of the cases this level is found in the height interval 1,000 m ± 100 m, with a mean height very close to 1,000 m.

The direction difference between the 3 min.-wind and the surface wind has an unimodal frequency distribution, with about 70% of the cases in the interval 0°–60°, as shown in Fig. 6. We have estimated the mode by finding the position of the vertex of the parabola passing through the midpoints of the tops of three 10° wide rectangles in the histogram, the central rectangle being that representing the greatest frequency. This mode equals 23.7°, which is 4° less than the angular difference found when comparing the mean vectors in Table 1. The mean of the individual ratios of the surface wind and the 3 min.-wind equals 0.60 which is the same as the corresponding ratio in Table 1. When one takes into account the fact that the average height of the 3 min.-level lies about 160 m lower than that of the 850 mb level, and that the wind tends to turn anticlockwise at these heights, the agreement between the two sets of values seems satisfactory. The result does not indicate, therefore, that in our case the estimates obtained on the basis of the mean vector winds are subject to any marked bias.

It may be mentioned that a study of easterly and southerly winds separately

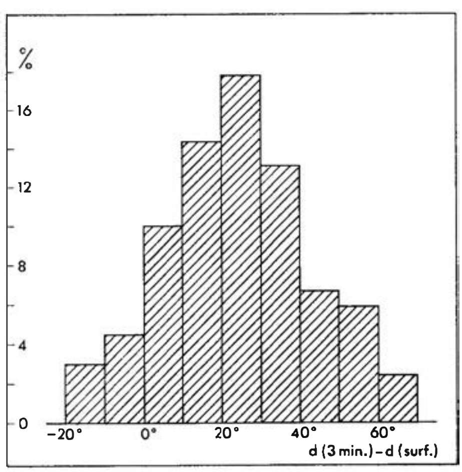

Fig. 6. *Percentage frequency distribution for Norway St. of the direction differences between the "3-min. wind" and the surface wind (Oct.-Feb.).*

gave no indications of a westerly thermal wind, that should be more pronounced for the easterly than for the southerly winds, as found by LETTAU (1967) for Little America.

Applying the results obtained by HESSELBERG and SVERDRUP (1915, SVERDRUP 1916), we put the magnitude of the frictional force proportional to the wind speed:

$$s\,|\mathbf{F}| = b|\mathbf{v}|$$

F being directed backwards to the left of **v** (southern hemisphere), forming an angle β with $-\mathbf{v}$. From the equation of motion given above we then get the following expressions for the balance of forces along **v**:

$$-2\Omega \sin \varphi\, |\mathbf{v}_G| \sin \alpha = b\,|\mathbf{v}| \cos \beta$$

and normal to **v**:

$$2\Omega \sin \varphi\, (|\mathbf{v}| - |\mathbf{v}_G| \cos \alpha) = b\, |\mathbf{v}| \sin \beta$$

where the latitude (φ) is given negative sign in the southern hemisphere. By division:

$$\mathrm{tg}\, \beta = \frac{\cos \alpha - \dfrac{|\mathbf{v}|}{|\mathbf{v}_G|}}{\sin \alpha}$$

We now assume that the values given in Table 1 may be used as estimates of the relation between the mean surface wind and the surface geostrophic wind, and that the latter wind does not show any appreciable diurnal variation. Introducing furthermore for the surface wind the mean vectors at 03^h and 15^h GMT (see Fig. 4), which show the greatest angular difference (11.8°), we obtain:

$$\beta = 27.9° \text{ and } b = 1.59 \cdot 10^{-4}\ \mathrm{sec}^{-1} \text{ at } 03^h,$$
$$\beta = 33.9° \text{ and } b = 0.90 \cdot 10^{-4}\ \mathrm{sec}^{-1} \text{ at } 15^h.$$

The frictional forces at anemometer level become:

$$s\ |\mathbf{F}| = b\,|\mathbf{v}| = 6.6 \cdot 10^{-2}\ \mathrm{dyn\ g}^{-1} \text{ at } 03^h,$$
$$s\ |\mathbf{F}| = 4.7 \cdot 10^{-2}\ \mathrm{dyn\ g}^{-1} \text{ at } 15^h.$$

Thus, according to these estimates the ratio between the frictional forces at 03^h and 15^h equals 1.42.

VINJE (1971) estimated the ratio between the frictional forces for the same anemometer level, and for the same hours and months as those considered here, but using an entirely different method. Fitting a power law to the wind profile observed in an approximately 30 m high tower at Norway St., he found on the basis of the relationship between the eddy viscosity parameters that the ratio was equal to 1.40, i.e. practically the same value as that obtained above. The results thus support each other. In view of the many factors of uncertainty involved, however, the fact that the values are nearly exactly equal in the two cases, is in all probability merely a coincidence.

It may be of interest also to compare our values of β and b with those found by BAUR and PHILIPPS (1938) for the Atlantic Ocean on the basis of surface weather maps (March):

$$\beta_S = 50^\circ,\ b_S = 0.65 \cdot 10^{-4}\ \text{sec}^{-1}.$$

By averaging the values found previously by HESSELBERG and SVERDRUP, they arrived at the following values for land areas:

$$\beta_L = 29^\circ,\ b_L = 1.9 \cdot 10^{-4}\ \text{sec}^{-1}.$$

We see that the values of β for Norway St. is fairly close to the mean value for land areas. The b values, on the other hand, are intermediate between the means for sea and land areas, the value found for 15^h being most close to the mean representing the sea surface. In view of the small roughness of the surface of the ice shelf one might perhaps have expected the b values for Norway St. to be small compared with the means given by BAUR and PHILIPPS. This feature may however be accounted for by the high stability that usually exists in the lowest layers over the ice shelf, which may involve a comparatively rapid vertical change of the stress vector. Obviously, the assumption frequently made, that the eddy stress is constant near the ground, does not apply in the present case.

Accepting the view that the diurnal wind at Norway St. is mainly due to frictional effects, we have to suppose these effects to produce similar wind variations at the two other stations as well, but here more strongly masked by changes caused by the diurnal course of the temperature contrast between the air over the sea and over the snow fields. It is tempting to try to estimate the part played by the latter influence by assuming that the variations caused by the changing frictional force are of the same form at all three stations. This is of cource to be considered as a rather broad assumption, as it implies, among other things, that the diurnal changes of the stability conditions are the same, which is hardly likely to be true. The different lengths of the "summer" seasons mean an additional complicating factor in this connection.

The frictional part of the wind variation is obtained by a certain adjustment of the observed diurnal course at Norway St. A moderate smoothing of the observed angular speed of the frictional vector is obtained by fitting a sine function to the observed values. Furthermore, the end points of the frictional vector are supposed to describe an ellipse in the course of the day. The axes of the ellipse and their orientation are determined by minimizing the following quantities: (1) the angular distance between the observed frictional vector and the corresponding vector turning with the smoothed angular speed, and (2) the distance along the latter vector from the vector end point to the ellipse. The fitting of the sine function as well as the ellipse is based on the method of least squares. In Fig. 7 (uppermost diagram) are entered the observed as well as the adjusted frictional vector. The adjusted vector is indicated by the end points on the ellipse only.

In accordance with the assumption that the diurnal change of the frictional effect is nearly the same at the three stations, we may suppose the axes of the ellipse to form the same angles with the total mean vector wind at all stations, the

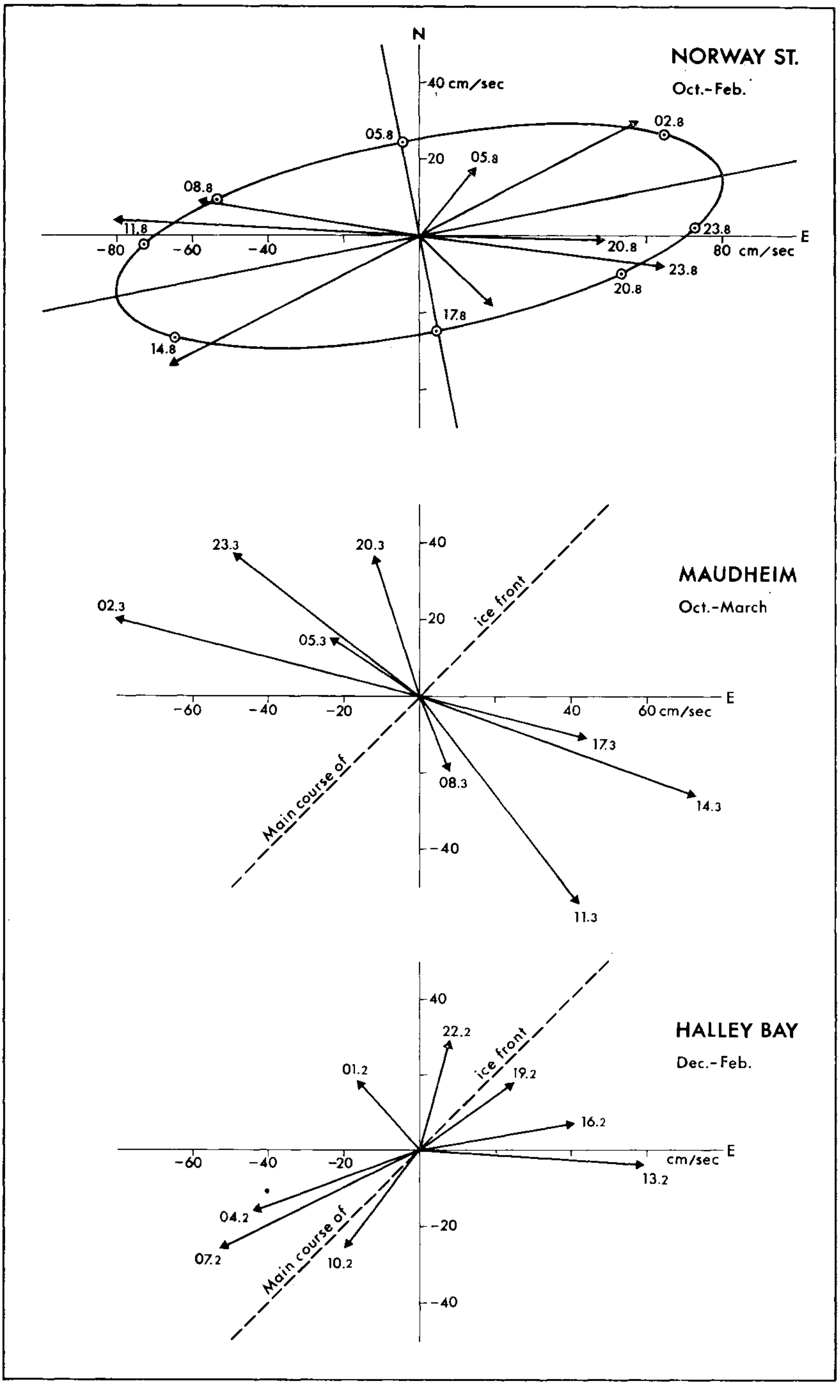

Fig. 7. *Uppermost diagram*: *Assumed frictional wind vectors for Norway St. Both observed and adjusted vectors. The adjusted vectors are indicated by their end points on the ellipse only. Lower part of the figure*: *The diurnal wind at Maudheim and Halley Bay after a tentative correction for the frictional effect.*

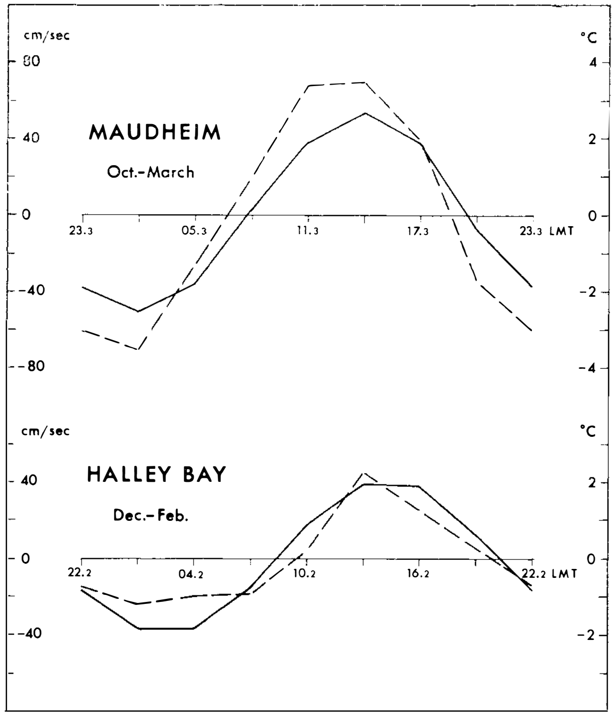

Fig. 8. *Solid lines: Diurnal variation of the on-shore component of the wind vectors in Fig. 7 (lower part).*
Broken lines: Diurnal variation of the surface air temperature ("screen temperature").

length of the axes being proportional to the magnitude of this mean vector. The frictional vector for the different observation hours at Maudheim and Halley Bay is then easily found, and may be subtracted from the observed diurnal wind. The result is shown in Fig. 7 (lower part). Comparing this diagram with Fig. 5 we see that the new diurnal wind vectors are turned in an anticlockwise direction with respect to the observed ones, especially so for Maudheim. The magnitudes of the vectors are, as a whole, not very much altered. As indicated in the diagram, the main direction of the coastline (i.e. ice front) most close to the stations is roughly SW-NE both at Maudheim and at Halley Bay. It appears that the vectors point off-shore during the night and on-shore during the day, the directions at the time of maximum and minimum temperature (cf. Fig. 8) being to the left of the normal to the coastline. The diurnal variation of the vector component perpendicular to the main direction of the ice front is in fact quite similar to that of the air temperature at the two stations, as illustrated by Fig. 8. These features correspond well to the characteristics found when studying the land- and sea-breeze phenomenon in lower latitudes.

Comparison with a linear sea-breeze model (DEFANT 1950) gave some general, qualitative conformities. However, a further discussion on this point does not seem worth while, as a fair agreement between theory and observation cannot be expected in the present case. This is due not only to the relatively primitive model applied and the very broad assumptions leading to the difference vectors in Fig. 7, but also to the irregular course of the coastline. It goes without saying that in the areas considered we do not imagine a land- and sea-breeze circulation that is reversed from day to night. The phenomenon may rather be compared to a small scale winter monsoonal system, where the appertaining isobaric-isosteric solenoidal field is subject to a weakening during daytime and a reinforcement during the night, the direction of the circulation being unaltered.

Concluding remarks

In the vicinity of the ice front the diurnal change of the surface wind over the Antarctic ice shelf may reasonably be supposed to be a combined effect of the diurnal variation of (1) the vertical exchange of momentum and of (2) the contrast between the air temperature over the sea and over the ice shelf. The results presented here seem to agree well with this supposition.

It is hoped that the present discussion will help to stimulate interest in further investigations of the problem, based on more exhaustive observations, preferably also of the conditions at higher levels in the planetary boundary layer. Sufficient information should be available about the diurnal change of the eddy viscosity characteristics to allow a theoretical estimation of the corresponding variation of the frictional wind.

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Late Caledonian (Haakonian) movements in northern Spitsbergen

BY

David G. Gee[1]

Contents

Abstract

The evidence for the age of late-Caledonian deformation in Spitsbergen is briefly reviewed. New data on late-orogenic movements in north-west Spitsbergen are presented and it is concluded that the main phase deformation, the Ny Friesland orogeny, should be treated separately from two subsequent episodes of late-Caledonian deformation, the Haakonian and Svalbardian movements. The Ny Friesland orogeny is thought to have culminated in the late Ordovician or early Silurian, the Haakonian deformation in the late Silurian and the Svalbardian deformation in the late Devonian.

Introduction

It has long been accepted that the late Pre-Cambrian and Lower Palaeozoic Hecla Hoek successions of Svalbard, composing the northernmost part of the North Atlantic Caledonides, were subjected to orogenic deformation in the late Silurian. Devonian sediments, largely of Old Red Sandstone facies, overlying this orogenic complex were folded and faulted prior to the Carboniferous and this deformation has been treated as a separate late phase of the Caledonian

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orogeny. The main tectogenic event, with folding and metamorphism of the Hecla Hoek sequence has been referred to as the Ny Friesland orogeny (HARLAND 1959), whilst the late Devonian deformation has been called Svalbardian (VOGT 1928).

During the last ten years various new lines of evidence have appeared which bear on the question of the time of Caledonian deformation in Spitsbergen. Fossil collections from the uppermost part of the Hecla Hoek have proved to be of post-Canadian (probably Champlainian) age (VALLANCE and FORTEY 1968). A substantial post-orogenic conglomerate and sandstone succession of uncertain age, the Siktefjellet Group, has been recognised to separate the metamorphosed Hecla Hoek from the unconformably overlying Gedinnian sediments (GEE and MOODY-STUART, 1966). Isotopic age-determinations from the Hecla Hoek Complex (GAYER et al. 1966) have given evidence of pre-Silurian metamorphic phenomena within the Hecla Hoek. These and other evidences are reviewed below where it is concluded that it is important to treat the Ny Friesland folding (probably late Ordovician or early Silurian) as a phenomenon separate from two subsequent late-Caledonian periods of crustal movements, the Haakonian (late Silurian) and Svalbardian (late Devonian).

Stratigraphic outline

HECLA HOEK

The Hecla Hoek succession provides the most northerly evidence available of deposition within the North Atlantic geosyncline (HALRAND 1967). A sequence some 19 km thick has been recognised within the area of Ny Friesland, where HARLAND and WILSON (1956) introduced a threefold subdivision, the Upper, Middle, and Lower, which was subsequently revised (HARLAND et al. 1966). The Upper Hecla Hoek, c. 2 km thick, includes tillites and shales of Varangian age overlain by carbonates and subordinate shale which range into the Middle Ordovician. The tillites overlie Middle Hecla Hoek dolomites and limestones which are underlain by a clastic unit, together c. 6 km thick. Below the Middle Hecla Hoek there is a marked increase in the metamorphic grade but this has not prevented the recognition of a substantial (c. 11 km) succession of clastic, volcanic, and carbonate rocks. Whereas in Ny Friesland the available data favours a more or less continuous depositional sequence, in other areas the successions are interrupted and pre-Caledonian orogeny has been suggested, influencing the lower part of the succession (e.g. GEE, in FLOOD et al. 1969).

OLD RED SANDSTONE

Fossiliferous Upper Ordovician and Silurian strata are not known from Spitsbergen and the oldest fossiliferous post-orogenic sediments overlying the Hecla Hoek Complex are of Gedinninan age and are exposed only in north-west Spitsbergen. The basal conglomerates of this sequence, the Red Bay Group (FRIEND et al. 1966) rests partly on the Hecla Hoek rocks and partly on a sequence of sandstones and conglomerates some 1500–2000 m thick, the Siktefjellet Group. GEE and MOODY-STUART (op. cit.) described this group to be folded and thrust prior to deposition of the Gedinnian strata. The age of the Siktefjellet Group must be younger than Champlainian and older than (or lowermost) Gedinnian, and a late Silurian deposition is probable.

The Red Bay Group, a sequence starting with a coarse limestone-boulder conglomerate and passing upwards into red and green sandstones, is Gedinnian in age and reaches a thickness of c. 2000 m. It is almost entirely restricted to the Raudfjorden graben, only the uppermost units being recognised (FØYN and HEINTZ 1943) below the Siegenian of the main Devonian graben (FRIEND 1961). Within the latter, the Wood Bay Formation, c. 3000 m, is dominated by fluviatile red siltstones and these are overlain by c. 1000 m of marine, dark shales (Grey Hoek Formation). The latter pass upwards into c. 500 m of grey shales and lighter sandstones, the Wijde Bay Formation, which range into the Middle Devonian (Givetian). Conglomerates appear in the uppermost part of the Devonian succession which is overlain with marked unconformity by Tournaisian strata.

Caledonian deformation

The stratigraphic outline indicates a threefold division of Caledonian deformation. The main orogenic folding was followed by uplift and erosion prior to Siktefjellet Group deposition. The deformation subsequent to the latter was separated from the later post-Givetian folding and faulting by a period of relative stability during the Lower and Middle Devonian.

MAIN PHASE (NY FRIESLAND) OROGENY

The whole Hecla Hoek succession was folded at some time between the Champlainian and the Gedinnian. For the purposes of this paper, a Caledonian model is assumed that includes the polyphase metamorphism and folding of the lower parts of the Hecla Hoek succession within this post-Champlainian fold episode. Elsewhere (GEE, in preparation) the evidence of pre-Cambrian deformation of the Lower Hecla Hoek is analysed. It is probable (but by no means certain) that this polyphase folding about c. N-S axes and associated metamorphism were approximately synchronous throughout Spitsbergen and Nordaustlandet. HARLAND (1969) commented "The tectonic and metamorphic facies are so similar in both east and west that it is tempting to correlate in time the main phase of tectogenesis throughout Spitsbergen". This conclusion is supported by the similar patterns of deformation, metamorphism and migmatisation reported by GEE and HJELLE (1966) from north-west Spitsbergen and FLOOD et al. (1969) from Nordaustlandet. Detailed structural/metamorphic analyses of areas in Ny Friesland (GAYER 1969) and north Haakon VII Land (GEE, 1966b) likewise are so comparable that a more or less synchronous development is probable.

Whereas both in north-west Spitsbergen (Albert I Land) and Nordaustlandet migmatisation of the Lower Hecla Hoek is extensive, in Ny Friesland and North

Haakon VII Land it is subordinate. The upper amphibolite facies rocks crystallize kyanite and Lower Hecla Hoek basic rocks in the latter area recrystallized in eclogite facies (GEE 1966a). These metamorphic phenomena suggest overburden pressures of at least 15 km of rock, probably more, a conclusion in accord with a model of a compressed Hecla Hoek pile, the stratigraphic overburden alone being in the order of c. 12 km (Upper, Middle, and upper part of Lower Hecla Hoek).

An attempt was made to date the time of this main phase of Caledonian metamorphism by isotopic age-determination methods (GAYER et al. 1966). With the exception of eight determinations in the range from c. 530–630 m.y. and some substantially older (K/Ar) omphacite ages, the majority of the Caledonian metamorphic specimens yielded ages from 450–350 m.y. These were interpreted as indicative of a main Caledonian tectogenic event at c. 425 $\pm$ 10 m.y. with a late Caledonian ? migmatisation and plutonism at c. 390–400 $\pm$ 20 m.y. However, in view of the development in recent years of the "cooling hypothesis" (HARPER 1964, 1967) and its application to the Scottish Caledonides, it seems more probable that it is the older age-determinations that approach the age of regional metamorphism whilst the younger Caledonian ages reflect later cooling of the complex. Ages of 430–450 m.y. occur in all the main metamorphic terraines of northern Spitsbergen and Nordaustlandet and suggest that, if the ages from 530–630 m.y. be neglected, the main phase metamorphic event occurred at c. 440–450 m.y. This would imply late Ordovician orogenesis (following the Geological Society Phanerozoic Time-Scale, 1964).

LATE PHASE (HAAKONIAN) MOVEMENTS

The most clearly defined data on these late Caledonian movements are found in the area of north Haakon VII Land where post-orogenic conglomerates and sandstones were folded and thrust prior to Gedinnian deposition. The Siktefjellet conglomerates rest directly on eclogite facies Hecla Hoek basement, requiring that in the order of at least 15 km of rock overburden was eroded prior to this post-orogenic deposition. Rates of uplift of the Caledonian orogenic belt and the time necessary to remove the overburden from this high grade complex are uncertain. Consideration of Alpine and Andean fold belts suggest (RUTLAND et al. 1965) uplift at an average rate of somewhat less than 500 metres/m.y. Downwarping of the Old Red Sandstone basins, which might be expected to have kept pace with Caledonian uplift, occurred at c. 200–400 metres/m.y. (FRIEND, 1969). Using these figures, the Siktefjellet Group deposition would have commenced c. 50 $\pm$ 20 m.y. after the main orogenic phase, a figure compatible with the interpretation of the isotopic age-determinations according to the cooling hypothesis, and requiring that the Siktefjellet Group should be of late Silurian age. Taking into account the Champlainian age of the youngest Hecla Hoek, it is probable that the main Haakonian movements occurred some 40 $\pm$ 10 m.y. after the Ny Friesland orogeny.

A wide variety of tectonic phenomena are thought to be related to the Haakonian movements, phenomena that both precede and succeed the post-Siktefjellet Group pre-Red Bay Group deformation. These are described below.

Pre-Siktefjellet Group joint drags and inferred strike-slip faulting

The Hecla Hoek Complex of north Haakon VII Land has been subject to extensive retrogressive metamorphism and cataclastic deformation. Much of this is manifest as reverse faulting, one example, the Richardvatnet thrust being shown on Fig. 1. This fracturing of the metamorphosed complex occurred in response to a stress orientation similar to that required for the preceding main phase folding and metamorphism and for this reason it is included with the latter, being considered a late-stage tightening of the main phase structure, probably associated with early uplift of the crystalline block. In marked contrast to these early structures, which formed in response to E-W compression, are the joint drags, a small scale fold phenomenon developed (particularly in the pelitic rocks) throughout the area from Biskayerhuken to Liefdefjorden. Their geometry requires a radical change in stress orientation and it is this change which is considered to initiate Haakonian deformation.

The joint drags have axes lying consistently in a WNW-striking vertical plane, the orientation being remarkable for its regularity throughout north Haakon VII Land. They occur as minor folds, having straight limbs and angular hinges, their axes varying in plunge with the orientation of the folded surface. Their geometry requires consistent dextral movement within the WNW-striking vertical axial planes. In marked contrast to the ubiquity of these WNW-oriented structures is the very rare development of conjugate folds showing sinistral movement on N-striking vertical planes. Apparently the joint drags developed in response to c. NW-SE compression.

The paucity of joint drags showing sinistral movement on N-striking high angle surfaces suggests that this movement was probably accommodated by N-S fracturing of the crystalline complex. In Scotland, KNILL (1961) inferred from development of dextral joint drags and the lack of associated conjugate folds that the accommodating sinistral movement occurred on major faults forming part of the Great Glen system, where this sense of movement had been previously demonstrated (KENNEDY 1947). Major fractures, trending c. NNW, occur in north-west Spitsbergen and include the Raudfjorden, Hannabreen–Rabotdalen, and Breibogen faults. All three show some characteristics of strike-slip faults and all show approximately dip-slip movement in relation to the post-Hecla Hoek sediments. Thus the Hannabreen–Rabotdalen fault is high angle and downthrows Red Bay Conglomerates westwards in the north (Rabotdalen) and eastwards in the south (Hannabreen to Bockfjorden). In Hannabreen substantial easterly downthrow of the Siktefjellet Group occurred prior to Red Bay Conglomerate deposition and this was followed by renewed movement in the same sense during or after the Gedinnian. The Breibogen fault downthrows Siegenian red beds eastwards in the north, whilst its southern extension in Ekmanfjorden shows post-Carboniferous westerly downthrow. Recent volcanism (GJELSVIK 1963) is located in the vicinity of this faultline. The high angle orientation, length, and longevity of these faults makes it probable that they represent major crustal fractures. This evidence, taken in relation to the joint drag phenomena, suggests

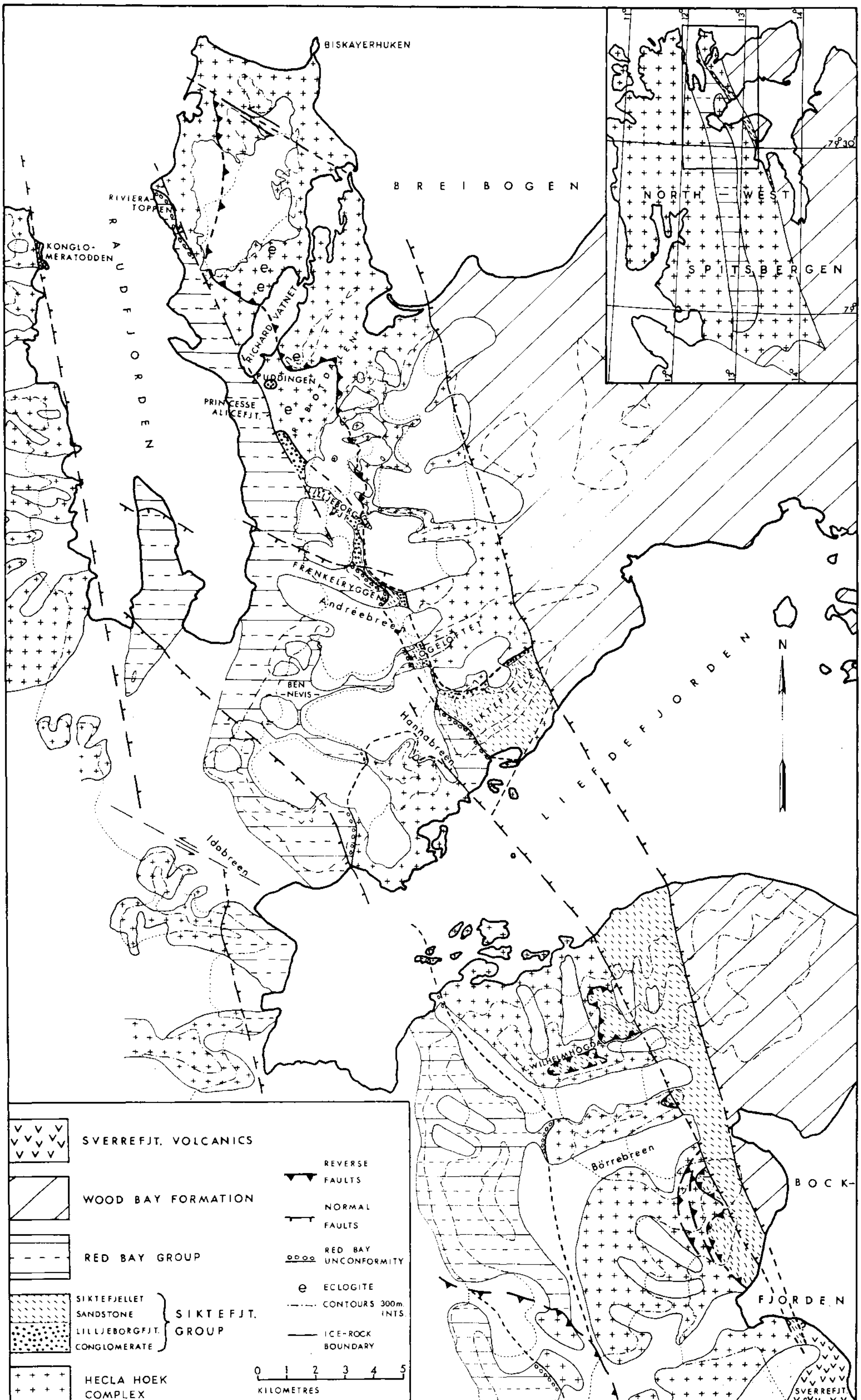

Fig. 1. *Geological map of north Haakon VII Land.*

that these fundamental faults originated as transcurrent phenomena prior to Siktefjellet Group deposition and that by the time these post-orogenic sediments had been deposited strike-slip movements were ceasing and giving way to dip-slip movement.

Post-Siktefjellet Group pre-Red Bay Group structures

The Siktefjellet Group is arched (major Siktefjellet anticline) and minor folded about NE-SW axes (GEE and MOODY-STUART, op. cit.). This geometry suggests that the NW-SE compression responsible for the development of the pre-Siktefjellet Group joint drags and inferred strike-slip faulting persisted after the deposition of these sediments, perhaps separated from the earlier NW-SE compression by a less active period during which deposition of the c. 1400 m of Siktefjellet sandstones took place. The Siktefjellet Group was also subject to normal(?) faulting (in Hannabreen and along the south side of Siktefjellet) prior to Red Bay Group deposition and the subordinate thrusting of the unit reported by MOODY-STUART south of Liefdefjorden may also have occurred prior to the deposition of these Gedinnian sediments.

Post-Red Bay Group movements of the Raudfjorden graben

After the main Haakonian movements described above, the area between Liefdefjorden and Biskayerhuken was temporarily stable (? peneplained) prior to the influx of the limestone-boulder conglomerates of the basal formation of the Red Bay Group. Cross-bedding in the overlying sandstones suggests derivation from the south (GEE and MOODY-STUART, op. cit.) and it is probable that Red Bay Group deposition in general was initiated in response to uplift to the south, the latter perhaps being related to the intrusion of the post-orogenic Horneman batholith (GEE and HJELLE 1966). The Red Bay Group occurs almost entirely within the Raudfjorden graben but this structure appears to be essentially a post-Gedinnian phenomenon, although an initiation of subsidence during Gedinnian deposition is not impossible. A variety of faults dislocate the Red Bay Group only to terminate against the Raudfjorden and Breibogen boundary faults and in view of the little disturbed nature of the Siegenian sediments east of the latter fault it is tempting to consider these and the arching of the Bockfjorden anticline as pre-Siegenian phenomena.

LATE PHASE (SVALBARDIAN) MOVEMENTS

In north-west Spitsbergen, the only unambiguous evidence of post-Siegenian movements is manifest in the Breibogen fault. MOODY-STUART has demonstrated that this fracture was active during Siegenian deposition. If the full Red Bay and Siktefjellet Groups were to be represented beneath the Wood Bay Formation, then a downthrow eastwards of at least 4 km would be necessary. At least after the Siegenian only normal movement occurred along this fundamental fault. This is in marked contrast to the evidence from the eastern side of the main Devonian graben where a similar fundamental fault with a greater vertical displacement has been inferred to show strike-slip movement after deposition of the youngest (Givetian) sediments (FRIEND, in HARLAND, 1969). It is this late Devonian faulting and associated folding that has been termed Svalbardian, being separated from the Haakonian by a relatively stable period during the Lower and Middle Devonian.

Summary of the orogenic sequence

On the basis of the foregoing discussion, the following Caledonian orogenic sequence is preferred for Spitsbergen (see Fig. 2).

1) The main Caledonian tectogenic event (Ny Friesland orogeny) culminated in the late Ordovician. This time of deformation is inferred from the isotopic age-determinations and is supported by estimates of the time interval prior to the Gedinnian required to remove some 15 km of overburden from the Hecla Hoek Complex of north Haakon VII Land. It is important to note that this evidence depends critically on the assumption that the regional metamorphism and associated folding of the Hecla Hoek was synchronous throughout Spitsbergen and that it was post-Champlainian. Should these orogenic phenomena prove, even in part, to be pre-Cambrian, this would clearly influence the estimate of the age of the Ny Friesland orogeny, probably placing it in the early Silurian.

2) Following Ny Friesland folding in response to E-W compression, there was an important reorientation of the stress systems, possibly associated with the initial fragmentation of this part of the North Atlantic Caledonides (HARLAND 1965). NW-SE compression, influencing the crystalline rocks prior to Siktefjellet Group deposition is referred to as early Haakonian and heralded the main Haakonian events involving folding and faulting of the Siktefjellet Group. The precise age of these movements will remain uncertain until the age of the Siktefjellet Group is better established. However, it seems very probable that the latter is late Silurian, implying that the Haakonian movements commenced in the Silurian and culminated in the latest Silurian. The subsequent deformation associated with deposition, arching, and faulting of the Red Bay Group is treated as late Haakonian in that it was more closely related in time to these movements than with the Svalbard deformation. It includes thrusting of the Hecla Hoek Complex over the Red Bay Conglomerates, transverse faulting of the Raudfjorden Graben and updoming of the Bockfjorden anticline, all these phenomena apparently being achieved prior to Siegenian deposition. Thus the western margin of the main Devonian graben in Spitsbergen probably was established with the late stages of Haakonian movements when the NW-SE compression had relaxed and the Breibogen fault was downthrowing gently eastwards.

3) Steady uplift of a southerly landmass providing material for deposition in the main Devonian graben persisted from the Siegenian to the Givetian (c. 30 m.y.) and provides record of a relatively tranquil period prior to Svalbardian deformation, the final episode in the Caledonian orogenic history of Spitsbergen.

This orogenic sequence shows marked differences from other parts of the fragmented Caledonides. It emphasises the lack of synchroneity of orogenic phenomena within the North Atlantic Caledonides despite superficial similarities

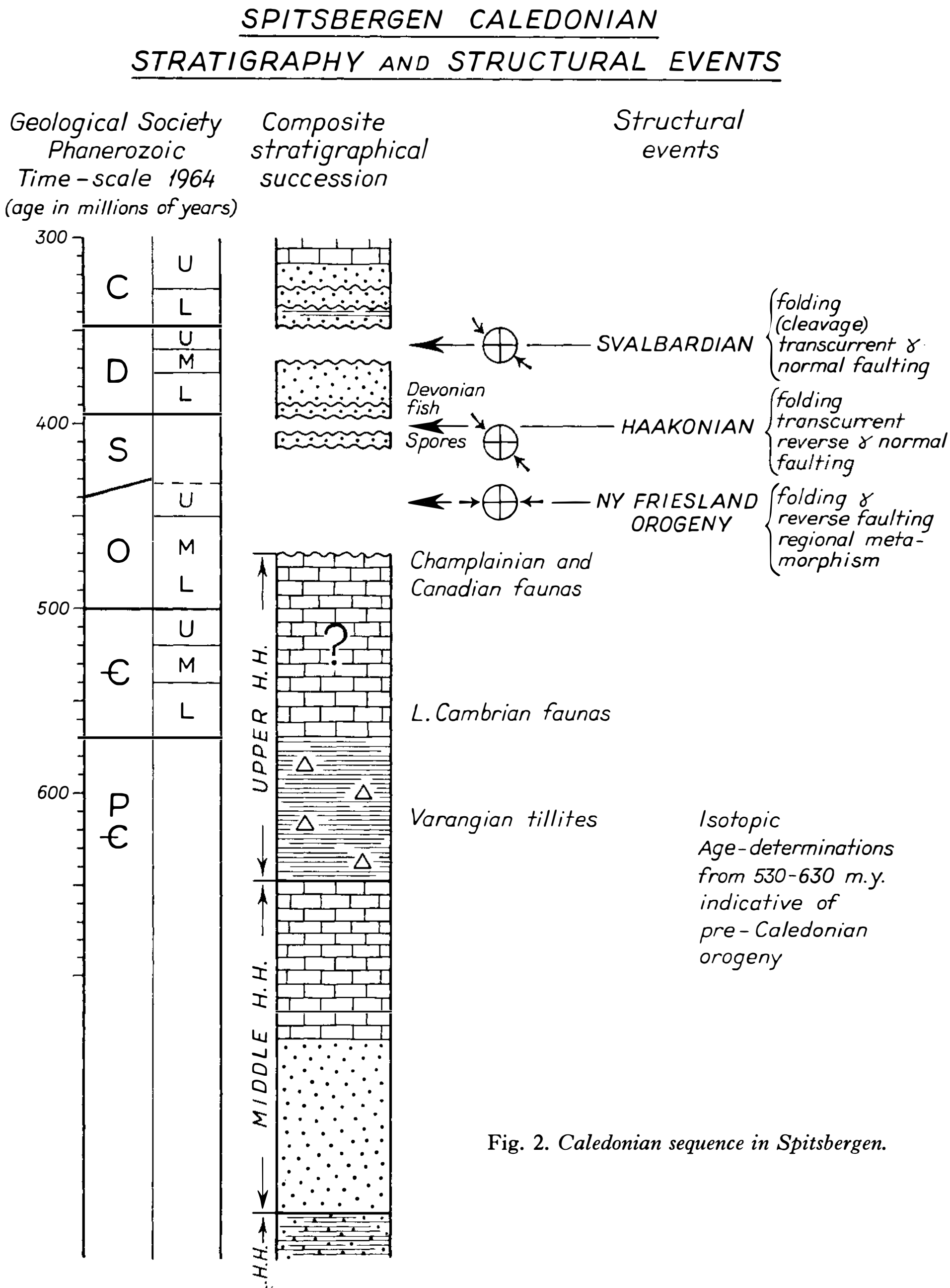

Fig. 2. *Caledonian sequence in Spitsbergen.*

and stresses the necessity to establish the nature of Caledonian movement in time with the greatest possible accuracy in order to reconstruct the relative movements and their sequence within the whole orogenic belt.

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Sedimentological observations on the Grey Hoek Formation of northern Andrée Land, Spitsbergen

BY

DAVID WORSLEY

Contents

Abstract

In this preliminary report the main sedimentological features of the Devonian Grey Hoek Formation are briefly described, and the results of an analysis of palaeocurrent trends are presented. It is suggested that the formation was deposited on the floodplain of a northerly flowing river complex, with brackish water lagoons and swamps between the meandering river channels.

Introduction

The Devonian succession of Spitsbergen ranges in age from Gedinnian to Givetian and attains a maximum thickness of c. 6,000 metres. The main outcrop area in the north of the island lies in a northerly trending graben which generally corresponds to the original depositional basin (Fig. 1). The grey shales and sandstones of the Grey Hoek Formation (Upper Emsian) dominate the geology of northern Andrée Land and contrast strongly with the red-bed development of the underlying Wood Bay Formation which outcrops to the south and west. Although the fauna and flora of this Devonian succession are relatively well known, sedimentological studies have concentrated on the Wood Bay Formation (BIRKENMAJER 1965, FRIEND 1965, and MOODY-STUART 1966), and knowledge of the Grey Hoek is limited to a brief description by FRIEND (1961).

The present work was carried out under the auspices of Norsk Polarinstitutt as

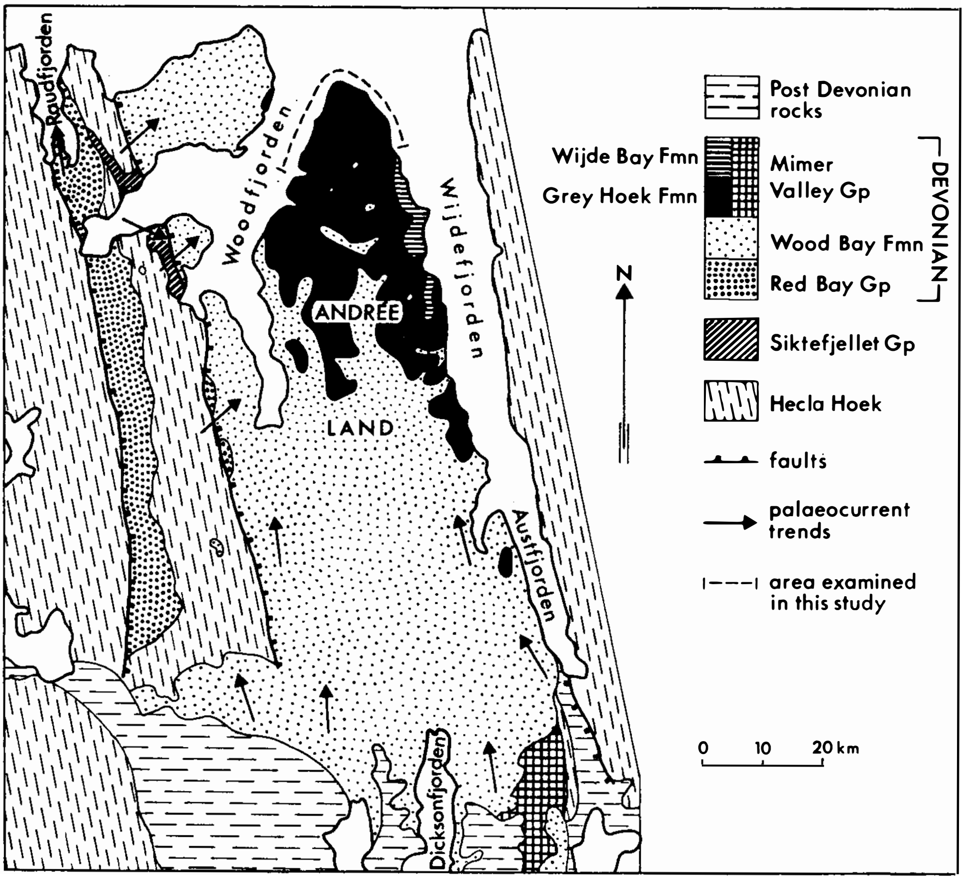

Fig. 1. *Geology of Andrée Land, with previously published palaeocurrent data added. Based on* FRIEND (*1961, 1967*), GEE & MOODY-STUART (*1966*), and ALLEN et al. (*1967*).

a preliminary to a more detailed study of both the Grey Hoek and overlying Widje Bay Formations. In this initial study I examined the coastline of Andrée Land between Mushamna in Woodfjorden and Vogtvatnet in Wijdefjorden. Because of intense folding and dislocation during the late Caledonian Svalbardian phase of deformation very few continuous sections of any great thickness were seen in this area, but abundant exposures provided a wealth of data on sedimentary structures and rock types. The orientations of approximately 900 directional structures were measured and plotted on a base map (1:100,000 issued by Norsk Polarinstitutt) with a superimposed 2 km square grid network. The preferred orientations of the different structures in each grid were then analysed by the vector mean method of CURRAY (1956), and major trends deduced from two-dimensional moving means computed by combining all measurements from each set of four adjacent quadrants. Computations were carried out with the CDC 3300 facilities of the University of Oslo and my own programs.

Sedimentology

The Grey Hoek Formation comprises dark grey to black sandy shales and siltstones with intercalated paler grey to green sandstones. Just as deformation obscures the total thickness of the formation (the accepted figure of 1,000 m being no more than a rough estimate), so too are the relative abundances of the different rock types uncertain, although the darker beds dominate the succession.

SHALES AND SILTSTONES

The most common rock types among these darker beds are poorly bedded sandy mudstones and muddy siltstones with few structures. However, more thinly bedded shales, mostly consisting of alternating laminae of shale and slightly paler siltstone, are also widespread. The silty laminae often have rippled tops, both symmetrical oscillation ripples and asymmetrical current ripples being most common. The ripple crests are straight to slightly sinuous, sometimes branching, with a mean wavelength of 4 cm and a ripple index of 10. Plant debris is often concentrated in ripple troughs, with plant stems oriented parallel to the ripple crests. Ripples tend to be locally concentrated on closely adjacent bedding planes, their crests showing a strong preferred orientation NNE–SSW over the whole area. Asymmetric current ripples give no clear sense of current direction, oscillatory rather than unidirectional currents apparently being responsible for their formation. Some linguoid ripples and more complex interference and rhomboid patterns are also occasionally seen.

Irregularly developed desiccation cracks are locally abundant in these thinly bedded silty shales, the cracks being filled by the more silty material. Although ripples and desiccation cracks were frequently observed on the same bedding planes, present results neither indicate nor negate the possibility of a significant association, as both structures also commonly occur alone. This is equally true of trace fossils (usually a small *Chondrites* type c. 2 cm in diameter), which again occur both in association with each of the above structures, and alone.

In well weathered sections small slump balls up to c. 15 cm in diameter are also seen in these laminated sediments; these structures often have eroded tops and in certain exposures several 'cycles' of slumping followed by erosion were observed. Other evidence of erosion within the shales is widespread, intraformational mudflake and silt pebble conglomerates being relatively common. Isolated irregular zones of pale green shale are also seen, usually showing a sharp and clearly erosive contact with the more typical dark shales.

Fossil assemblages (mainly molluscs) occur locally concentrated in thin bioclastic zones in the shales. The fossils are usually highly fragmented and have obviously been drifted from their life position, but occasionally bivalve assemblages (especially *Nucula* sp.) are seen preserved with both valves still articulated although opened, indicating very little transport. Plant debris is often oriented, with stems parallel to the general trend of ripple marks, even when the plants are not associated with rippled beds.

SANDSTONES

The paler intercalated sandstones show a highly variable development, but for ease of description three main types or 'end-members' are tentatively defined on the basis of bed thickness and form, grain size, and sedimentary structures:

1. Massive sandstones
2. Flaggy sandstone lenses
3. Thinly interbedded sandstones and shales.

1. Massive sandstones

These beds are generally 2 to 5 m thick, although at Gråhuken exceptional thicknesses of up to 15 m are seen (it is interesting that all sediment types in the locality which gives the formation its name show a much more sandy development than elsewhere). The bases of these sandstones are often clearly scoured surfaces, which although mainly undulating, are occasionally developed as broad shallow channels with depths of up to 60 cm (Fig. 2a). Lenses of mudflake conglomerate are especially common in the lowermost part of such sandstones, the mudflakes locally constituting the bulk of the rock. The matrix of the sandstone associated with the mudflakes is dominantly medium to coarse-grained and poorly sorted, but a general upwards decrease in grain size is common within each massive sandstone, the rock becoming more flaggy and better sorted with decreasing grain size. Both planar and trough cross-stratification are well developed in sets up to 30 cm thick throughout each bed, but are most striking in the more flaggy upper parts.

The upper development of each massive sandstone appears often to follow one of three patterns; there may be a gradual transition either into thinly bedded silty shales by a steady decrease in the sand grain size and increase in the proportion of shale intercalations, or into the flaggy sandstone lenses of type 2. Alternatively the top of the sandstone is sharply defined and overlain by a sequence of thinly interbedded sandstones and shales of type 3; in this case the uppermost part of the sandstone often shows slump structures and the upper surface is eroded (Fig. 2b). The few measurements of slump axes which were obtained indicate a highly varied direction of slumping relative to cross-stratification from bed to bed, the direction ranging from parallel to perpendicular to cross-stratification in different beds.

2. Flaggy sandstone lenses

These bodies are generally up to 1 m thick and can often be traced laterally for up to several tens of metres before dying out. They occur either as single isolated bodies or in complexes (Fig. 2c) where they may form an upper 'phase' of a massive sandstone. In these complexes, individual lenses are separated by shaly partings (the upper surfaces of which often show desiccation cracks), and may pass laterally into thinly interbedded sandstones and shales. The lenses occasionally have irregular scour markings on their bases, or, more rarely, swarms of flute casts fill the bases of very shallow scour channels. Although both trough and planar cross-stratification are usually well developed, flat bedding is also seen. Parting lineation is common in the latter case, and small scour crescents are often seen on lamination planes which show parting lineation. When lens complexes occur associated with massive sandstones, the top of the whole sequence is often slumped in a similar development to that seen when massive sandstones occur alone, again with a sharp transition to shales or thinly interbedded sandstones and shales above.

3. Thinly interbedded sandstones and shales

In many outcrops these thinly bedded sandstones appear to form the uppermost 'phase' of a sandstone unit; however, this relationship is highly variable and at some localities these beds also occur alone in thick sequences. In most sections the mean thickness of the sandstones is less than 10 cm, with thinner shale interbeds; the sandy beds often become progressively thinner upwards, the succession phasing gradually upwards into silty shales. In several cases where these thinly bedded sandstones occur above or below more massive sandstone units, a small but marked angular discordance is seen between the thin sandstones and the more massive units. This is also seen when these beds grade laterally into more massive sandstones (Fig. 2d).

The fine to very fine grained sandstones show an impressive variety of sedimentary structures. Sole structures include both irregular scour markings, cut-and-fill gutter like structures, and tool markings such as groove, striation and prod moulds. The undersurfaces between the erosional structures often carry imprints of desiccation cracks from the underlying shale, while whole bases are crowded with spectacular meandering and branching infilled burrows (Fig. 2e). Small-scale ripple-drift cross-lamination is common within the beds, with more rare convolute lamination and micrograded bedding. Top surfaces may be rippled or show poorly developed desiccation cracks; in one case a top surface with meandering trails also showed what appeared to be rain drop impressions.

Various kinds of slump structures are seen in these sandstones; often single beds are locally disrupted, forming slump balls with chaotic inner structures. In other cases several beds are affected, resulting in coherent slumps showing miniature overfold and thrust structures, with the individual beds retaining their internal structures relatively undisturbed (Fig. 2f). As with other slumped horizons no regional trend is apparent, although individual examples show a marked preferred orientation of slump axes.

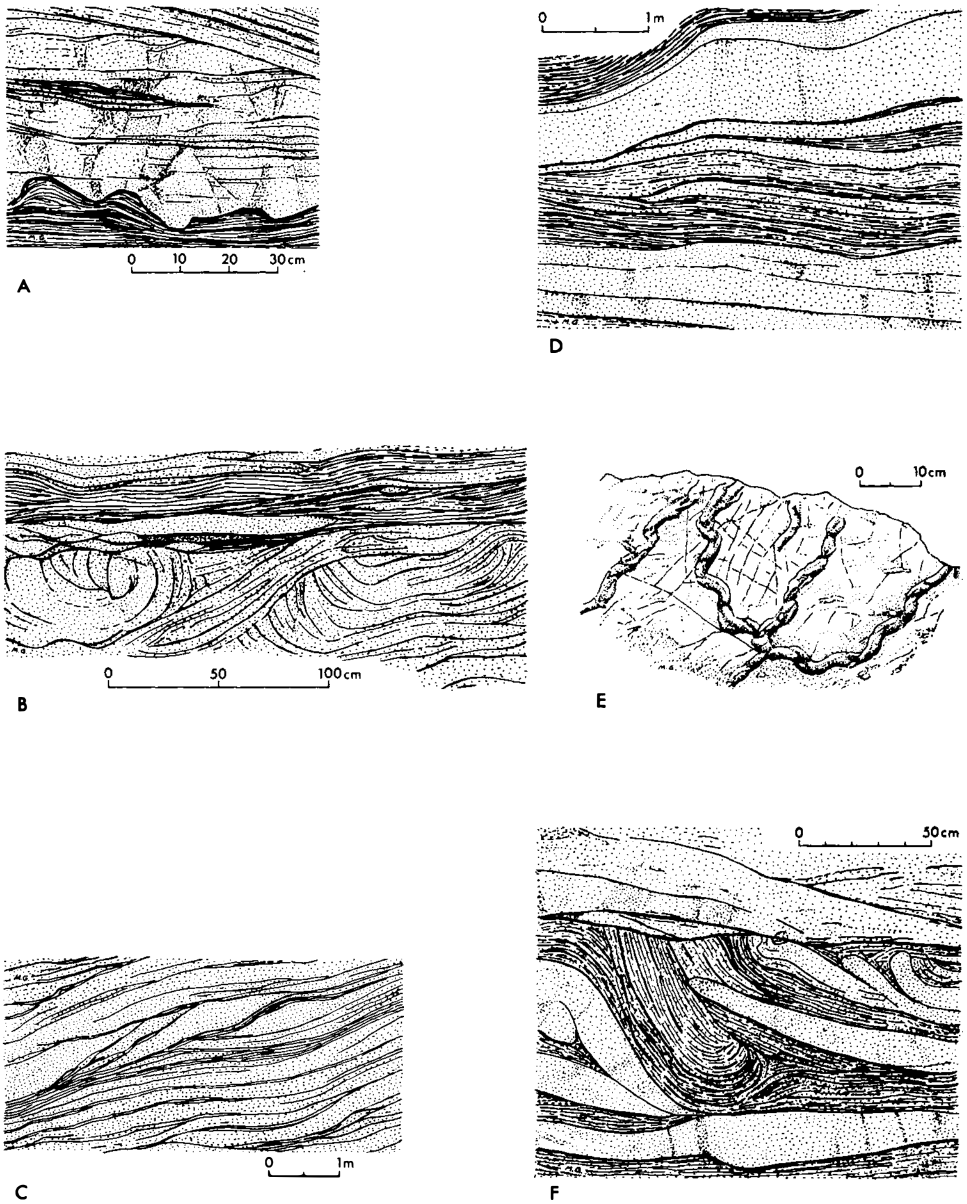

Fig. 2. *Selected sandstone structures: A – Scoured base of massive sandstone. B – Slumped and eroded upper phase of massive sandstone unit. C – Flaggy sandstone lenses. D – Angular discordance between thin and massive sandstone beds. E – Burrows on base of thin sandstone. F – Coherent slump in thin sandstones.*

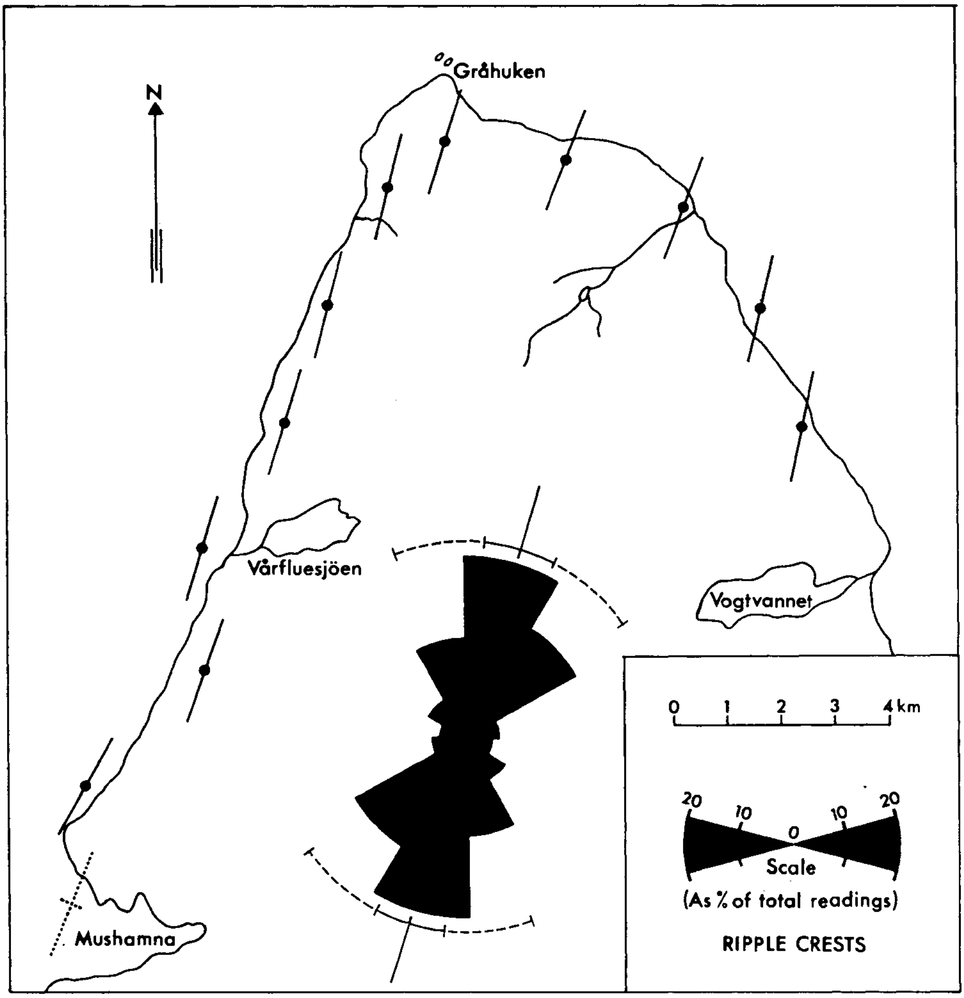

Fig. 3. *Preferred orientation of ripple crests, both for single grids (smoothed vector means, dotted lines indicating that the mean is not significant), and for the whole area (rose diagram, with vector mean, confidence limits, and standard deviation indicated).*

Palaeoccurents and depositional environment

Palaeocurrent trends indicated by the most common structures seen in the area are summarized in Figs. 3 and 4, while the important statistics of the combined measurements plotted in the rose diagrams are shown below.[1]

Structure type	Vector mean	Standard deviation	Confidence interval	Total observations
Ripple crests	19°	40°	4°	362
Cross-stratification	59°	93°	10°	307
Sole structures	19°	43°	11°	65

[1] All angles are expressed in centesimal degrees (i.e. 400° circle).

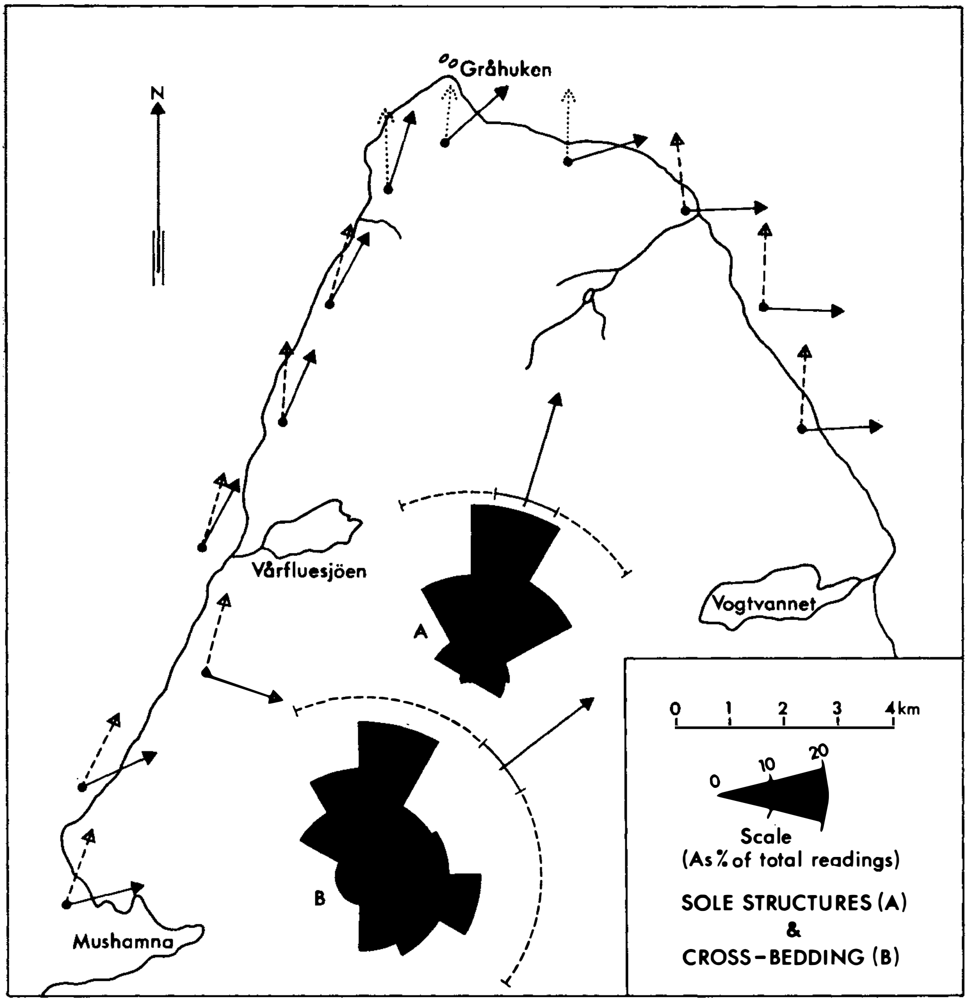

Fig. 4. *Preferred orientation of sole structures (broken arrows and rose diagram A) and cross-stratification (solid arrows and diagram B). Presentation as in Fig. 2.*

It is interesting that while sole structures suggest a clear northerly current trend over the whole area, cross-stratification is much more varied, with two overlapping components, one parallel to sole structures and one roughly perpendicular and directed eastwards. Fig. 4 shows that this latter trend is strongly developed between Mushamna and Vårfluesjøen in Woodfjorden and along the whole Wijdefjorden coast. Although ripple marks show the same low variation as sole structures, the ripple orientations indicate oscillating currents perpendicular to those responsible for the sole structures and more closely related to the eastwards directed component of the cross-stratification.

This complex current pattern shown by the different structures must be considered together with the possible environment of deposition of the formation before any conclusions can be made. FRIEND (1961) suggested deposition of the shales in bodies of slowly moving or standing water in a brackish marginally marine environment, with the sandstones representing periodic deposition in faster moving water. The present work indicates that these periodic sandstone invasions follow a distinct pattern of development, and the features observed suggest a fluvial origin for the sandstones. Thus the coarse and poorly sorted sandstones with mudflakes may represent flood channel deposits, while the finer and better sorted flaggy sandstones reflect subsequent deposition in the already established channels, perhaps as point bar or similar deposits. The observed pattern of cross-stratification may then result from deposition in a meandering river complex with a predominantly easterly migration pattern. In such a system, sand bodies deposited on the eastern side of a river channel would be preferentially destroyed by erosion during migration, resulting in the observed 'residual' easterly trend in cross-stratification relative to sole structures (cf. WILLIAMS 1966). It is not clear at present whether the variation in cross-stratification in different parts of the area is of stratigraphic or geographic significance, but further work may resolve this problem. The well-defined upper surfaces of the sandstones may result from sudden abandonment of existing channels, while sandstones showing a gradual transition into shaly siltstones reflect the more gradual silting-up of an established channel system.

In accordance with the above interpretation the thinly interbedded sandstones and shales would appear to represent overbank deposits formed immediately adjacent to the river channels. The angular discordance frequently observed between these and the massive sandstones is reminiscent of levee deposits which frequently show a depositional dip outwards from their associated channels. The dark shales and siltstones reflect the floodplain environment between this river system. As suggested by FRIEND (1961) the restricted molluscan faunas suggest a brackish water environment, but an intertidal origin appears unlikely if one considers the frequent desiccation cracks and (presumed) absence of any typically marine fossils. Observations suggest deposition on a broad coastal swamp with shallow lagoons, probably largely cut off from more typically marine conditions by barrier beaches.

The clear preferred orientation of ripples associated with these sediments is at variance with most other studies of ripple marks (e.g. see summary in POTTER & PETTIJOHN 1963, pp. 89–99) which show an alignment of ripple crests perpendicular to palaeoslope. The association of ripples with local concentrations of silty laminae indicates that they were formed during intermittent periods of unusual turbulence. The sometimes observed upward grading of sandstones into silty laminae may suggest that the latter represent overbank deposits further removed from the river channels than the thinly interbedded sandstones and shales. The ripples may then have been formed during flood periods, and represent the action of oscillatory currents set up by lateral spillage of water out of the channels. The parallel alignment of ripple crests to the lateral margins of the depositional trough may also suggest that these margins also played some role in this process. Although FRIEND (1965) usually found close agreement between the preferred orientation of ripples and other structures in the Wood Bay Formation, he noted occasional divergences and suggested a similar origin by 'over-bank deposition by divergent flood-streams'. However, if lateral spillage was the dominant factor in ripple formation in the Grey Hoek, a much more varied orientation of ripple crests should perhaps be expected. An alternative explanation, also suggested by FRIEND (pers. comm.) is that wind action may have been the controlling mechanism; this would then ease the difficulty of interpreting the variance between the ripple orientation and palaeoslope as indicated by other directional structures.

Thus, although these results from the Grey Hoek Formation show a general agreement with previous work on the palaeogeography of this area, the complex palaeocurrent pattern and abundance of sedimentary structures indicate that more comprehensive study will add substantially to our understanding of the depositional environments of the Devonian of Spitsbergen.

Acknowledgements

Dr. P. F. FRIEND suggested this study and has supplied me with much invaluable information and advice. I would also like to thank colleagues at Norsk Polarinstitutt and Drs. BIRKENMAJER and BRUTON for helpful discussion and criticism, MAGNE GALÅEN who drew the figures, Miss SIGNE ØVERLAND who typed the manuscript, and my field assistant NILS M. HANKEN.

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The thelodont *Sigurdia lata* n. g., n. sp. from the Lower Devonian at Sigurdfjellet, Spitsbergen

BY

NATASCHA HEINTZ[1]

Abstract

A description is given of the impression of the cephalo-thorax and anterior part of the post-pectoral body of *Sigurdia lata* n.g, n. sp. This thelodont, found in Lower Devonian beds at Sigurdfjellet, Spitsbergen, is the first specimen described from outside Scotland which shows the body form.

Introduction

In connection with curating the collections of Devonian agnathes in the Palaeontological Museum, Oslo, I found a piece of sandstone from Spitsbergen with an approximately 5 cm long impression of the anterior part of a thelodont. Thelodont scales have been reported several times from Spitsbergen (ØRVIG 1957, 1969a, b, c; SCHULTZE 1968), whereas complete specimens have not been previously described.

Over the years large amounts of thelodont scales have been described from Upper Ordovician, Silurian, and Devonian beds from many different localities around the world. However, as STETSON (1931) points out: "The Scottish Coelolepidae are the only ones known that give any clue whatever to the body form of this family." The new specimen from Spitsbergen can now be added to the Scottish forms.

Sigurdia n. g.

Thelodonti; Thelodontida

Derivatio nominis. – The name *Sigurdia* is derived from Sigurdfjellet, the locality where the type species was found.

Diagnostic characters. – Broad, flat thelodont with trapez-shaped cephalothorax. Lateral tip of the pectoral flaps rounded. Body behind the pectoral flaps very broad, tapering slowly posteriorly. Along the lateral side of the body, spines protrude at regular intervals.

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Remarks on the diagnostic characters. – The more detailed systematic division of the thelodonts is at present nearly totally based on the form and histological structure of the scales. However, GROSS (1967) points out in his revision of the systematic of Thelodontida that: "Die Aufstellung eines System auf Grund der Schuppen muss stets ein *Provisorium* sein, das erst der endgültigen Bestätigung oder der Korrektur durch Funde intakter Fische bedarf."

In the present specimen the scales are so poorly preserved that it is not possible to determine them either on the basis of their general morphology or of their histological structure. It is thus impossible to place our specimen generically according to GROSS' (1967) "Schuppensystem". When I introduce a new genus – *Sigurdia* – for the Sigurdfjellet thelodont, this is based on the following considerations:

The specimen from Spitsbergen gives a good outline of cephalo-thorax and the anterior part of the post-pectoral body. Its general shape, and particularly the broad post-pectoral body, is clearly different from the Scottish Thelodontida. A new genus for this form seems to be justifiable.

The thelodont scales so far described from Spitsbergen come from either older or younger beds. The poorly preserved scales on our specimen do not permit a comparison with the previously described forms. As *Sigurdia* occurs in a stratigraphic layer where no thelodont remains have been reported earlier, I find it reasonable to place our specimen in a new genus.

Sigurdia lata n.g., n. sp.

Derivatio nominis. – Lata is derived from the Latin *latus* that means broad, alluding to the broad post-pectoral body.

Holotype. – The impression of cephalo-thorax and the left half part of the anterior part of the post-pectoral body (Figs. 1 and 2). P.M.O. No. D 2973.

Locality. – 270 m a.s.l. on the south-east side of Sigurdfjellet in the innermost part of Woodfjorden, Spitsbergen. Collected by Mr. A. HOEL in 1912.

Geological occurrence. – The specimen occurs in a grey, slightly greenish, dense sandstone rich in mica. The sample is labelled "Red Bay Series" (HOLTEDAHL 1913, 1914). In 1912 A. HOEL established the presence of a contact between the older "Red Bay Series" (=Formation (FRIEND 1961)) on the southern side of Sigurdfjellet and the overlying "Wood Bay Series" (=Formation (FRIEND 1961)). This observation was confirmed in the field in 1939 by S. FØYN and A. HEINTZ, and in their paper (1943) they state: "The lowermost part of the Kapp Kjeldsen Division (lowermost Wood Bay Formation) consists of red sandstones resting conformably on the greyish-green sandstone." According to the fossil content of the greyish-green sandstone, there seems to be no doubt that these layers belong to the uppermost part of the Red Bay Group, the Ben Nevis Division. So far no thelodont remains have been reported in this division. The thelodont scales described from Spitsbergen occur either in older beds (Frænkelryggen Formation, ØRVIG 1969a) or in younger beds (Wood Bay Formation, ØRVIG 1957, 1969b; and Grey Hoek Formation, SCHULTZE 1968, ØRVIG 1969c).

Description. — The present specimen does not seem to be secondarily deformed and it is therefore useful to give some measurements (Fig. 2):

A. Anterior breadth	22 mm
B. Length antero-external angle to lateral corner of pectoral flap	26 »
C. Width of the body with pectoral flaps	46 »
D. Width of the post-pectoral body immediately behind the pectoral flaps	32 »
E. Length cephalo-thorax	33 »

The surface of the impression is covered by a thin, black carbon film. However, in places the badly preserved ventral side of the base of scales can be observed. This indicates that our specimen is seen from the inside of the body.

Antero-medianly a triangular-shaped dimple is preserved. In width it is about 1/3 of the total anterior breadth, and along the median line it is about as long as it is wide. Such antero-dorsal dimples have previously not been reported from complete thelodont specimens. I am inclined to interpret this dimple as the impression of the *nasal sacks*. The poor preservation of the squamation is presumably the reason why no traces of eyes can be seen. Both TRAQUAIR (1905) and STETSON (1931) mention and figure thelodonts from Scotland, where eyes are found as black spots close to the antero-external corners. The presence of eyes would be a strong indication of this being the dorsal side.

However, we cannot totally reject the possibility that the present specimen is the inside of the ventral squamation. The anterior dimple would in this case presumably be the impression of the mouth cavity. The lateral lines, described in the next paragraph, give, however, strong evidence for this being the dorsal side of the animal.

On the left half part of cephalo-thorax traces of two fine canals can be seen (Figs. 1 & 2). The lateral canal runs from the post-pectoral angle and nearly to the median line just posteriorly to the antero-dorsal dimple and is here called the *lateral oblique canal*. A median canal joins the lateral oblique canal at about 2/3 of its total length, measured from the post-pectoral angle. This canal is called the *posterior median canal* and it runs nearly straight posteriorly close to and on the left side of the median line.

The dimensions and location of these canals make it reasonable to assume that they are parts of the lateral line system. The canals have much the same shape and dimensions as the canals of the lateral lines that we find in the plates of Heterostraci.

No traces of lateral lines have so far been recorded in Thelodontida. However, GROSS (1968a) reports the presence of pore-holes in the scales of *Phlebolepis*. The pore-holes obviously served as openings for the lateral line system, and on the basis of the distribution of the scales with pore-holes, GROSS gave some indications of the location of the sensory canals in *Phlebolepis*. However, their distribution in *Phlebolepis* is still so poorly known that a safe comparison is not yet possible. The lateral line system in *S. lata* is so different from that of both the pteraspids

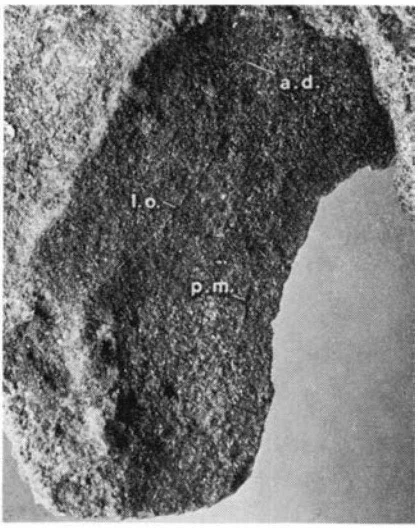

Fig. 1. *Sigurdia lata* n.g., n.sp. View of the inside of the dorsal squamation with the sensory canals (l.o. and p.m.) and the antero-dorsal dimple (a.d.). ×1.4.

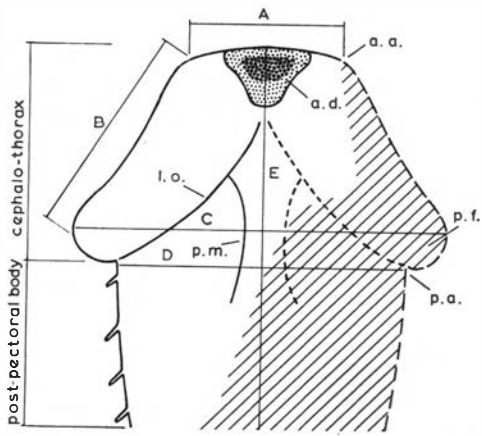

Fig. 2. Reconstruction of the front part of the dorsal side of *S. lata*. a.a. – antero-external angle, a.d. – antero-dorsal dimple, l.o. – lateral oblique canal, p.a. – post-pectoral angle, p.f. – pectoral flap, p.m. – postero-median canal. A, B, C, D and E measurements given on p. 114.

and cephalaspids that it is not possible to suggest to which of these two main groups of agnathes *S. lata* shows the closest resemblance.

The presence of a posterior median canal is another indication that our specimen shows the dorsal squamation. The lateral lines normally do not occur in the median part of the ventral side of the body, and particularly not when it is as flat as it presumably must have been in *S. lata*.

The body behind the pectoral flap, here named the post-pectoral body, is surprisingly broad, particularly compared with the complete specimens of thelodonts from Scotland (Stetson 1931; Traquair 1899a, 1899b, 1905). It tapers rather slowly posteriorly and this presumably means that *S. lata* had a comparatively long post-pectoral body. In *Thelodus* and *Logania*, where the body tapers rather quickly posteriorly, the length of this part of the animal is about twice the length of the cephalo-thorax. Taking the slowly tapering post-pectoral body of *S. lata* in consideration, the post-pectoral body is presumably at least three times the length of cephalo-thorax.

The spines along the lateral side of the post-pectoral body are about 4 mm long. Nothing of their structure is preserved, only very small parts of the impression of the outside of the spines and in one case the fillings of the pulp-cavity. Such distinct lateral spines have previously not been recorded from Thelodontida.

Remarks

Over the years the systematic position of Thelodonti have been much discussed. They are to-day considered to belong to Heterostraci, mainly on the basis of the histological structure of their scales. However, a closer relation to Anaspida has been suggested by WESTOLL (1945). RICHIE (1968) has found the branchial aperture in *Logania* and *Lanarkia* from Scotland, and he says: "The branchial apertures form a straight condensed row, probably eight in number, situated opposite and ventral to the lateral fin." This type of branchial aperture is clearly different from that found in Heterostraci.

This and some of the features described in the present paper, make it in my opinion more uncertain which group of Agnatha are most closely related to Thelodonti.

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Megaripples and phosphorite pebbles in the Rhaeto-Liassic beds south of Van Keulenfjorden, Spitsbergen

BY

KRZYSZTOF BIRKENMAJER[1]

Contents

Abstract

Megaripples and phosphorite pebbles are described from the uppermost part of the Kapp Toscana Formation (predominantly fresh-water Rhaeto-Liassic) at Tilasberget, Van Keulenfjorden (Spitsbergen), just below the marine Janusfjellet Formation (Callovian to Hauterivian). These two lithostratigraphic units are separated by a thin but very constant marker bed, the so-called phosphorite conglomerate (Brentskardhaugen Bed). The origin and stratigraphic position of this conglomerate are also discussed, with reference to the stratigraphical scheme for the Upper Triassic to Middle Jurassic-Lower Cretaceous sediments of Svalbard.

Relation of the Janusfjellet Formation to the Kapp Toscana Formation at Tilasberget

Sedimentological observations within the Rhaeto-Liassic clastic deposits at Tilasberget (Figs. 1, 2), south coast of Van Keulenfjorden (Spitsbergen) were carried out by the author in 1962 during a geological expedition to Torell Land sponsored by Norsk Polarinstitutt, Oslo. The rocks in question have been mapped

[1] Norsk Polarinstitutt, Oslo 3, Majorstua, Postboks 5054, Norway (on leave from the Polish Academy of Sciences, Geological Laboratory, Kraków, ul. Senacka 3, Poland).

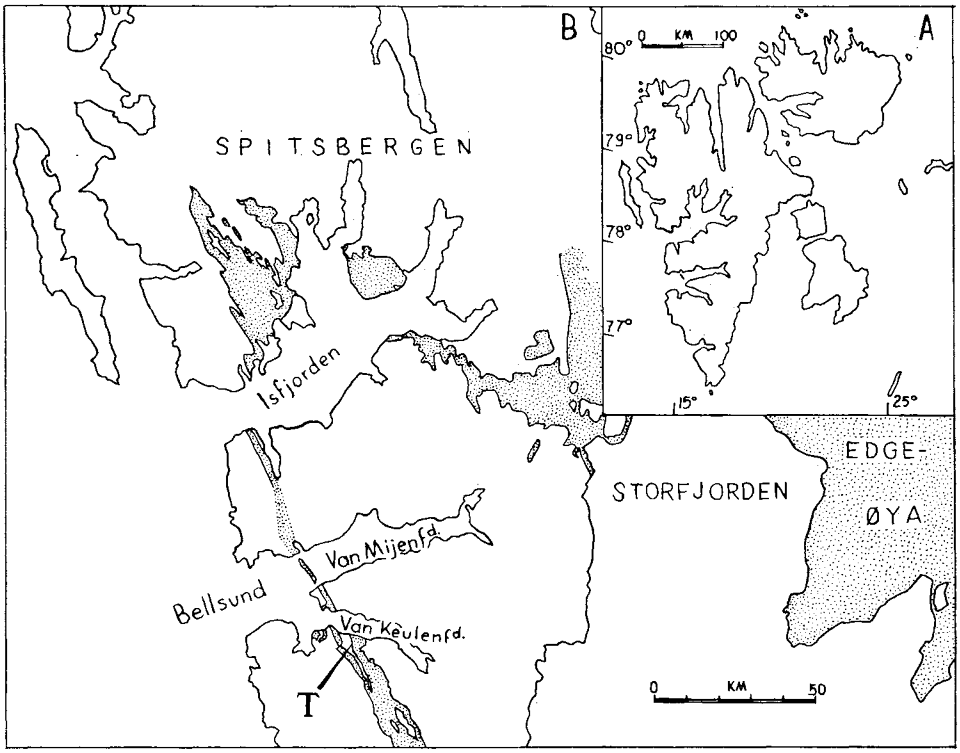

Fig. 1. *Position of Tilasberget (T) in Spitsbergen (B) and in Svalbard (A). Stippled – outcrops of Triassic rocks (after* BUCHAN *et al. 1965, Fig. 1, simplified).*

by RÓŻYCKI in 1934 (RÓŻYCKI 1959, Pls. V, VI) as the *Estheria* beds, and included in the Rhaetian-Lower Liassic stages (RÓŻYCKI 1959, p. 60 *et seq.*). They yielded (in Torell Land) *Estheria brodieana* JONES (=*E. minuta* var. *brodieana*), a phyllopod known to occur both in the Rhaetian beds of Scotland, England and Germany, and in the Lower Liassic beds of Poland. Since the determination of the flora from Bellsund by NATHORST (in 1910 and 1913) was based on comparison with the Scanian flora and that this has since been re-interpreted as a Rhaeto-Liassic flora, these beds could eventually range upwards into the Hettangian (RÓŻYCKI 1959, p. 66). The *Estheria* beds of RÓŻYCKI have been renamed the Kapp Toscana Formation by BUCHAN et al. (1965). In Torell Land these are predominantly fresh-water sandstones and shales, often with bonebed and clay-ironstone intercalations.

There follows the so-called phosphorite conglomerate (bed) or "Liassic" conglomerate which is a very thin but very constant marker horizon between the Kapp Toscana Formation (Rhaeto-Liassic) and the *Aucella* (*Buchia*) shales, especially in south and east Spitsbergen (see FREBOLD 1929a, b, 1930, 1951; BODYLEVSKIJ 1929; RÓŻYCKI 1936, 1959; BIRKENMAJER 1958, p. 195, 1960a, Table 2; PČELINA 1965a, b; KOPIK 1968). The conglomerate contains (in phosphorite pebbles) a mixed fauna, mostly ammonites, belemnites and pelecypods, as well as fragments of phosphoritized wood and reptilian bones. The ammonites indicate the presence of several zones: the Middle and Upper Toarcian (*Hildoceras bifrons* and *Haugia variabilis* zones, possibly also *Grammoceras striatulum* subzone), the Lower Aalenian (=lowest Bajocian: *Leioceras opalinum* zone) and, possibly, also the Lower Vesulian (=Upper Bajocian: *Parkinsonia parkinsoni* zone). This fauna is evidence of marine sedimentation in Svalbard during the Toarcian and Bajocian, preceding the sedimentation of the *Aucella* shales. However, the fossils occur entirely as secondary deposit in fragments (pebbles) of the original Toarcian to Bajocian phosphorite layer, at the base of the *Aucella* shales. The matrix of the conglomerate is derived mainly from the reworked Kapp Toscana Formation[1] and is mixed with the new sediment (limonitic sandstone, oolitic clay-ironstone etc.) typical for the *Aucella* shales, the lowermost part of which is dated as the basal Callovian (or uppermost Bathonian) on the *Kepplerites* fauna. This was the reason that BIRKENMAJER (1964, Fig. 2) included the phosphorite conglomerate to the Callovian.

The phosphorite conglomerate has been renamed by PARKER (1967) the Brentskardhaugen Bed, and placed in the topmost part of the Kapp Toscana Formation. Thus the Kapp Toscana Formation has appeared on stratigraphical schemes as representing the time span from the Rhaeto-Liassic to the Bajocian inclusively (see PARKER 1967, p. 491; HARLAND 1969, Table VI). However, there is a long break in sedimentation between the Kapp Toscana Formation (Rhaetian and Lower Liassic) and the Brentskardhaugen Bed (Callovian, with Toarcian and Bajocian faunas as secondary deposit) which corresponds to the Meso-Cimmerian uplift of the sea-bottom, followed by a new marine transgression during the Callovian. Analogous breaks in sedimentation at the end of the Middle Jurassic or a the beginning of the Upper Jurassic are well known from the Tethyan geosyncline area (e. g. the Carpathian Mountains – see BIRKENMAJER 1963) and the epicontinental Jurassic of the Middle Europe as well (see RÓŻYCKI 1953), and reflected synorogenic Meso-Cimmerian movements preceding the world-wide Callovian transgression. The Brentskardhaugen Bed (phosphorite conglomerate) could, therefore, be regarded as the proof of this Callovian transgression in Svalbard.

The *Aucella* shales are a thick sequence of predominantly dark (black) shales with subordinate clay-ironstone and sandstone intercalations, the latter being present mainly in its lowermost and uppermost parts. The shales differ very little throughout the whole sequence and, as a whole, they display the characteristics of a single formation. H. MAJOR has proposed the name Janusfjellet Formation for the *Aucella* shales appearing on his Adventdalen geological map (1:100 000) printed by Norsk Polarinstitutt in 1964 but not yet published. This term was also accepted by BUCHAN et al. (1965). PARKER (1967) changed the name of the Janusfjellet Formation to Subgroup, and subdivided it (in Sabine Land and Nordenskiöld Land) into the lower Agardhfjellet Formation (basal Callovian or uppermost Bathonian to Lower Volgian) and the upper Rurikfjellet Formation (Valan-

[1] RÓŻYCKI (1959, p. 68) has also found fragments of rocks from the Hecla Hoek Succession and from the younger Palaeozoic formations, and the present author has observed fragments of vein quartz such as is common in the Hecla Hoek Succession.

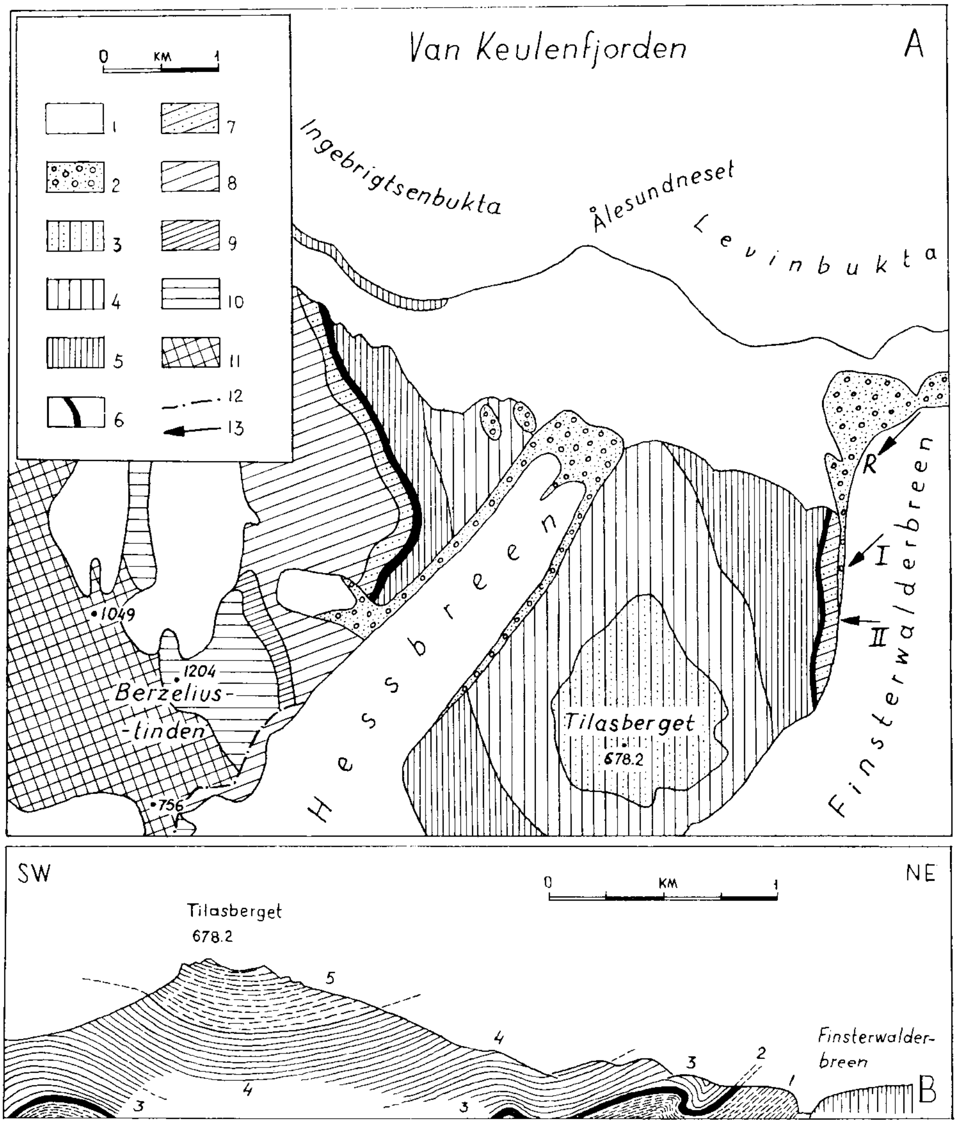

Fig. 2. *Geological map (A) and cross-section (B) of Tilasberget and its vicinity (after* RÓŻYCKI 1959 *Pls. V, VI, simplified, explanations modified).* 1 – *glaciers, outwash and terrace deposits;* 2 – *moraines;* 3 – *uppermost Valanginian to Aptian-Albian sediments;* 4 – *Volgian to Valanginian sediments (Janusfjellet Fm., Tirolarpasset Mb.);* 5 – *Callovian to Kimmeridgian (Janusfjellet Fm., Ingebrigtsenbukta Mb.);* 6 – *Callovian phosphorite conglomerate with Liassic-Bajocian fossils as secondary deposit (Janusfjellet Fm., Ingebrigtsenbukta Mb., Brentskardhaugen Bed);* 7 – *Upper Triassic to Lower Liassic sediments (Kapp Toscana Fm.);* 8 – *Middle to Lower Triassic sediments (Botneheia Fm. and Sticky Keep Fm.);* 9 – *Lower Triassic sediments (Vardebukta Fm.);* 10 – *Carboniferous and Permian sediments;* 11 – *Precambrian metamorphic complex (Hecla Hoek Succession);* 12 – *overthrust;* 13 – *position of geological cross-sections R (see Fig. 2B), I (see Fig. 3) and II (see Fig. 3). Dolerite sills not marked.*

ginian to Upper Hauterivian[1]), separated by a non-sequence and local unconformity, the break occurring between the Lower Volgian and the Valanginian.

In Torell Land the *Aucella* shales represent a nearly continuous sequence, possibly with only a minor break at the base of the Volgian (sandstones with pebbles at Jurakammen – "basal conglomerate of the Portlandian transgression" of RÓŻYCKI 1959, p. 74). The original H. MAJOR's designation of the sequence as the *formation* (and not subgroup) still holds here and, consequently, the ranks of the Agardhfjellet and the Rurikfjellet lithostratigraphic units of PARKER (*op. cit.*) should be lowered to *members*. RÓŻYCKI's (1959) subdivision of the *Aucella* shales (now: Janusfjellet Formation) into "series" (now: members): Ingebrigtsenbukta (Callovian–Kimmeridgian), Tirolarpasset (Volgian–Valanginian), and Ullaberget (Valanginian[2]) is very useful for a greater part of the area between Van Keulen-

[1] Recent finds of the ammonites *Simbirskites* and *Speetoniceras* from the top of the Rurikfjellet Formation (PČELINA 1965a, b; PARKER 1967, p. 502) have extended the formation's stratigraphic range upwards into the Upper Hauterivian.

[2] Valanginian to Hauterivian – see the preceding footnote.

Table 1

Proposed stratigraphic scheme for the Upper Triassic to Lower Cretaceous sediments of Spitsbergen. Modified from RÓŻYCKI (*1959*), BUCHAN *et al.* (*1965*), PARKER (*1967*), *and* HARLAND (*1969*). *Vertical hatching denotes major breaks in sedimentation.*

<table>
<tr><th></th><th></th><th>TORELL LAND</th><th>NORDENSKIÖLD LAND & SABINE LAND</th><th></th></tr>
<tr><td rowspan="3">Lower Cretaceous</td><td>Hauterivian</td><td rowspan="2">Ullaberget Mb.</td><td rowspan="2">Rurikfjellet Mb.</td><td rowspan="7">Janusfjellet Fm. (Aucella shales)</td></tr>
<tr><td>Valanginian</td></tr>
<tr><td>Berriasian</td><td rowspan="2">Tirolarpasset Mb.</td><td rowspan="2"></td></tr>
<tr><td rowspan="3">Upper Jurassic</td><td>Volgian</td></tr>
<tr><td>Kimmeridgian</td><td rowspan="2">Ingebrigtsenbukta Mb.</td><td rowspan="2">Agardhfjellet Mb.</td></tr>
<tr><td>Oxfordian</td></tr>
<tr><td rowspan="3">Middle Jurassic</td><td>Callovian</td><td colspan="2">Brentskardhaugen Bed</td></tr>
<tr><td>Bathonian</td><td colspan="3" rowspan="5">(Toarcian and Bajocian fossils as secondary deposit in the Brentskardhaugen Bed)</td></tr>
<tr><td>Bajocian</td></tr>
<tr><td rowspan="4">Lower Jurassic (Liassic)</td><td>Toarcian</td></tr>
<tr><td>Pliensbachian</td></tr>
<tr><td>Sinemurian</td></tr>
<tr><td>Hettangian</td><td colspan="2" rowspan="3">De Geerdalen Mb.</td><td rowspan="4">Kapp Toscana Fm.</td></tr>
<tr><td rowspan="3">Upper Triassic</td><td>Rhaetian</td></tr>
<tr><td>Norian</td></tr>
<tr><td>Carnian</td><td colspan="2">Tschermakfjellet Mb.</td></tr>
<tr><td rowspan="2">Middle Triassic</td><td>Ladinian</td><td colspan="3"></td></tr>
<tr><td></td><td colspan="3"></td></tr>
</table>

fjorden and Hornsund, and still farther south. These members can easily be mapped to a 1:50 000 scale and distinguished on cross-sections (see BIRKENMAJER 1960b, Fig. 3, 1964, Fig. 2). The author of the present paper considers RÓŻYCKI's scheme as valid for the western and southern parts of the Jurassic-Lower Cretaceous marine basin of Svalbard, while PARKER's scheme as representative for the north-eastern margin of this basin.

The modifications of the Rhaeto-Liassic to Lower Cretaceous stratigraphic scheme discussed above, and presented in Table 1, are supported also by observations in two geological cross-sections (I and II – see Figs. 2–4) across the eastern slope of Tilasberget, where the relation of the Janusfjellet Formation (with the basal Brentskardhaugen Bed) to the Kapp Toscana Formation can easily be studied. These are the exposures in two small erosional gullies where the sequence of strata is particularly well exposed, and some very interesting sedimentological features are visible.

TILASBERGET, EASTERN SLOPE, CROSS-SECTION I

(Fig. 2A: I, and Fig. 3)

Stratigraphy	Thickness in metres
Janusfjellet Fm.: Ingebrigtsenbukta Mb. (Callovian to Kimmeridgian)	
(8) Shales, black. Total thickness (according to RÓŻYCKI 1959, Pl. VI) about 160 m. Thickness in the cross-section	7.5
(7) *Brentskardhaugen Bed:* Conglomerate consisting of pebbles and angular fragments of black phosphorite 1–30 cm in diameter (usually 1–3 cm in diameter), subordinately with pebbles of white vein quartz 1–2 cm in diameter. Pebbles are cemented with a reddish ferruginous matrix. Phosphorite pebbles contain a poor pelecypod fauna	0.5–0.7
(Sedimentary hiatus)	
Kapp Toscana Fm. (Rhaeto-Liassic)	
(6) Sandstones, in the lower part grey or blackish, often quartzitic (then whitish), with subordinate black shale intercalations. Transist upwards into limonitic sandstones, and these into sandstones, quartzitic sandstones and quartzites, grey or whitish	5.5
(5) Shales, black, with intercalations of grey fine-grained sandstones	3.5
(4) Sandstones, grey, rusty if weathered	3.0
(3) Shales, green, purple and variegated, with thin intercalations of grey fine-grained sandstones	9.5
(2) Shales, arenaceous, and siltstones, grey, green, blackish, with thin intercalations of clay-ironstone	7.0
(1) Sandstones, micaceous, fine grained, often silty, finely laminated, grey, greenish, abounding in plant detritus and fragments of *Equisetites* and *Podozamites*. Sandstone surfaces often wavy, uneven. Subordinate greenish shale and clay-ironstone intercalations. Incomplete thickness	3.0

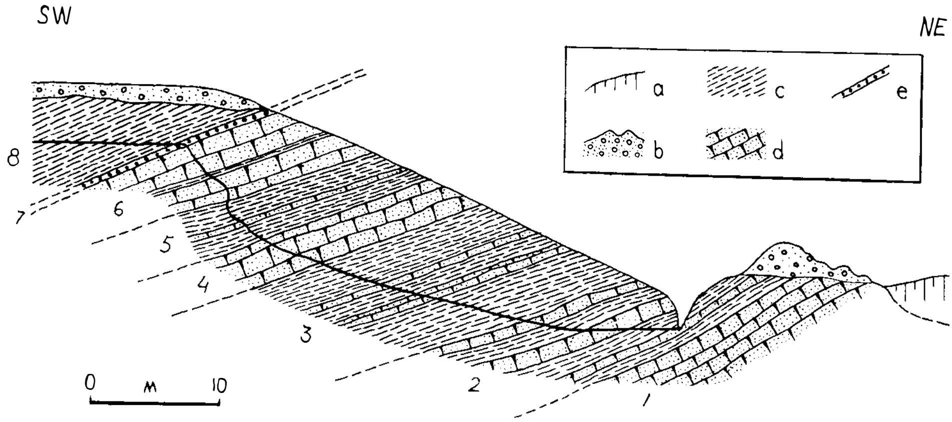

Fig. 3. *Geological cross-section I, eastern slope of Tilasberget (see Fig. 2A: I).* 1–8 – *for explanations see the text. a – glacier; b – moraine; c – shales, subordinately clay-ironstones; d – sandstones and siltstones, subordinately clay-ironstones; e – conglomerate.*

TILASBERGET, EASTERN SLOPE, CROSS-SECTION II

(Fig. 2A: II, and Fig. 4)

Stratigraphy — Thickness in metres

Janusfjellet Fm.: Ingebrigtsenbukta Mb. (Callovian to Kimmeridgian)

(4) Shales and paper shales, black, intercalated with layers of red-weathering clay-ironstones 0.5 to 20 cm thick, at intervals from 1 to 1.5 m. Incomplete thickness........ 18.0

(3) Sandstone, fissile, platy, rich in limonite, transisting upwards into arenaceous clay-ironstone, red or yellow. Black shale intercalations in the lower part.................. 5.0

(2) *Brentskardhaugen Bed:* Conglomerate consisting of black phosphorite pebbles and phosphoritized reptilian bones 0.3

(Sedimentary hiatus)

Kapp Toscana Fm. (Rhaeto-Liassic)

(1) Sandstones, quartzitic, fine-grained, grey or whitish, with megarippled top surfaces (see Figs. 5, 6A). About 0.5 m below the contact with the Brentskardhaugen Bed there occurs either a fine-grained quartz conglomerate with white rounded quartz pebbles 0.5 to 2 cm in diameter or a mixed quartz-phosphorite conglomerate with black, flattened phosphorite pebbles (1–20 cm in longest diameter and 1–4 cm in shortest diameter) which may vary in shape from irregular to ovoidal and spheroidal. Some phosphorite pebbles contain big *Unio* shells (up to 15 cm long) often with both valves connected. In addition, fragments of phosphoritized reptilian bones (black, with bluish or whitish strips), up to 40 cm long, may be found in the conglomerate. The conglomerate is maximum 3–4 cm thick, discontinuous, and fills depressions in the megarippled sandstones (see Fig. 4–6A). Incomplete thickness 6.0

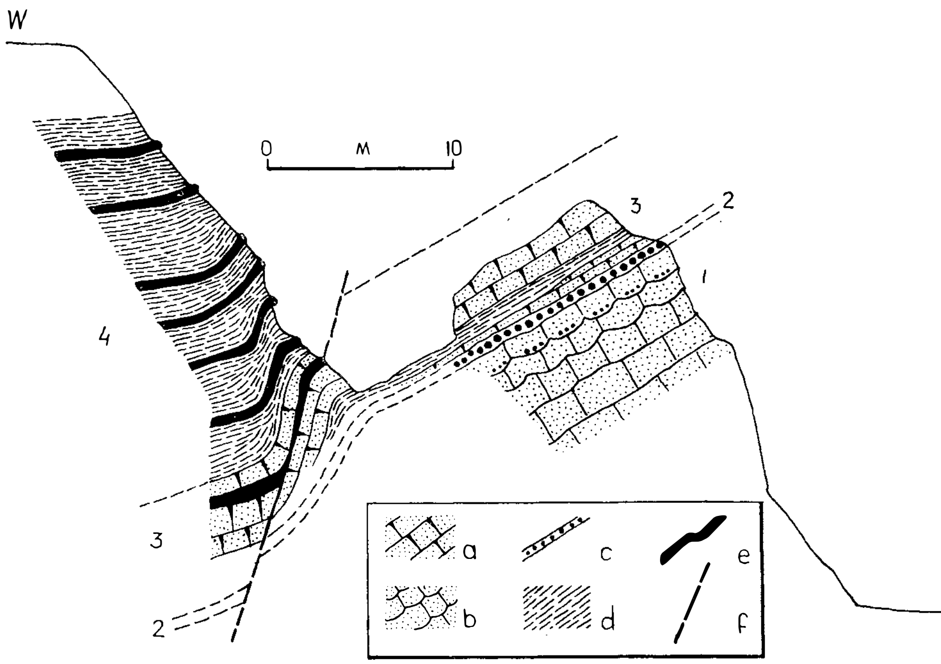

Fig. 4. *Geological cross-section II, eastern slope of Tilasberget (see Fig. 2A: II).* 1–4 *– for explanations see the text. a – sandstones; b – megarippled sandstones; c – conglomerates; d – shales; e – clay-ironstones; f – fault.*

Sedimentological observations in the Kapp Toscana Formation at Tilasberget

Megaripples

The top surfaces of quartzitic sandstone layers from the uppermost part of the Kapp Toscana Formation at Tilasberget show well developed megaripples. These sedimentary structures are rather uncommon in Spitsbergen, either in Rhaeto-Liassic or in other shallow-water unmetamorphosed sequences.

At cross-section II (Fig. 4), about 200 m a. s. l., these are asymmetric current megaripples well preserved on tops of several successive quartzitic sandstone layers. The ripple crests run parallel to each other NW–SE (azimuth 130°). The tilt of the ripple slopes with respect to the dip of the beds is the following: NE (lee) slopes – c. 25°, SW (stoss) slopes – c. 15°. The azimuth of the traction current responsible for the asymmetry of megaripples is 40°, i. e. towards north-east (Fig. 6B).

The ripple wave-lengths (λ) vary from 2–2.10 m to 0.7–1.0 m, and the ripple amplitudes (h) – from 0.4 to 0.2 m respectively. The wave index (λ/h) varies from 0.16 to 0.24 respectively.

Bigger quartz and phosphorite pebbles, as well as phosphoritized reptilian bones, occur in the ripple troughs just below the steeper (lee) slopes of ripple crests and are arranged parallel to them. At the bottom of the ripple troughs smaller pebbles and fragments are arranged in a haphazard way, and only larger and longer ones show again the same orientation parallel to the ripple axis (Figs. 5, 6A).

Slightly farther south of cross-section II there is a steep cliff which exposes the same megarippled sandstones, also with phosphorite pebbles in the ripple troughs. The azimuth of the ripple crests is here 120° and the direction of current (normal to the lee side of the ripples) – towards north-east (azimuth 30°). In a phosphorite pebble have been found imprints of small striated pelecypods resembling *Avicula*.

Phosphorite pebbles

The mode of occurrence of phosphorite pebbles and phosphoritized bones within the megarippled sandstones at Tilasberget indicates that these are fragments of an older layer (or layers) crushed and rounded by strong wave action responsible for the formation of megaripples. The original phosphoritic layer (or layers) could have been formed partly in a fresh-water environment, as indicated by the presence of big fresh-water pelecypods (*Unio*), partly in a marine environment as indicated by striated pelecypods resembling *Avicula*. A part of this primary phosphatic deposit could have represented a true bonebed, as shown by numerous phosphoritized reptilian bones.

It is a well known fact that the Rhaeto-Liassic beds in Svalbard often contain

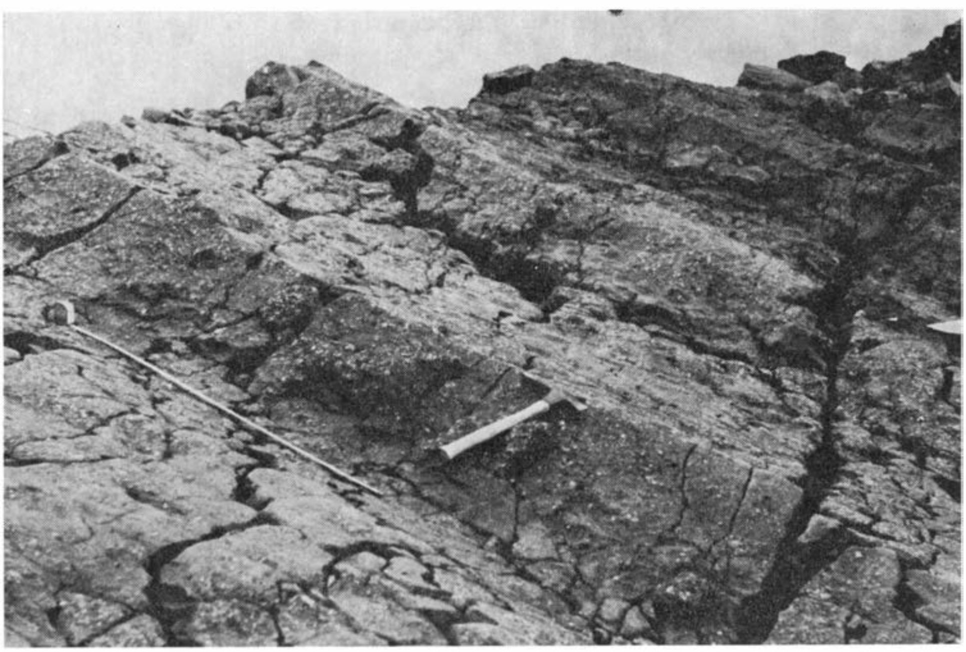

Fig. 5. *Megaripples in the Kapp Toscana Formation (Rhaeto-Liassic) at Tilasberget. Note accumulation of phosphorite pebbles along the steeper, lee slopes of the ripples (left sides of ripples on the photograph). Traction current direction from the right to the left (as indicated by the hammer). Scale (shown along the ripple trough) corresponds to one metre.*

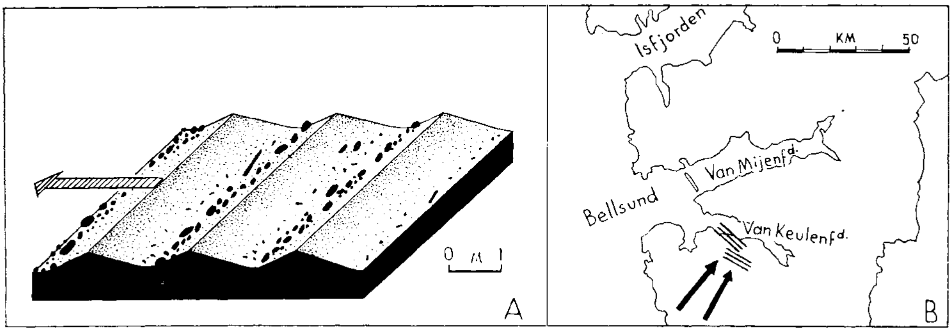

Fig. 6. *A. Model of megaripples from the Kapp Toscana Formation (Rhaeto-Liassic) at Tilasberget. Note orientation of phosphorite pebbles and phosphoritized bones as parallel to the ripple axis. Direction of traction current indicated by arrow.*

B. Orientation of megaripples in the Kapp Toscana Formation (Rhaeto-Liassic) at Tilasberget (parallel lines). Direction of winds responsible for the formation of megaripples indicated by arrows.

both bonebeds *in situ* and fragmentated, reworked bones in quartz conglomerate intercalations (pebble-lag concentrates), where their number may increase so as to form redeposited bonebeds. The above described phosphorite pebble-and-bone conglomerate falls into the latter category.

Sedimentary environment of the Kapp Toscana Formation at Tilasberget

The majority of the Rhaeto-Liassic clastics in Svalbard are shallow-water deposits, either formed in fresh-water lakes or in brackish lagoons with minor marine influence (see Różycki 1959, p. 64; Buchan et al. 1965, p. 25). In the case of Tilasberget, the presence of generally fine-grained sandstones (with transitions to siltstones) alternating with shales which often show purple or variegated colouration, and the lack of cross-bedding in sandstones, would also fit the lagoonal conditions of sedimentation. Sometimes the basin waters became highly agitated due to south-westerly winds, and the resulting oscillatory movement of water had reworked loose bottom sediment to form sand megaripples, and had crushed already consolidated phosphorite layer (or layers). The abrasion of phosphorite fragments by quartz grains had produced phosphorite pebbles. However, the duration of the winds and the resulting high turbulence of the waters was short-lived. Thus the sorting of phosphorite pebbles is poor: all size grades from 1 to 20 cm longest axis and all grades of roundness from irregular (angular) to spheroidal (well rounded).

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Cross-bedding and stromatolites in the Precambrian Höferpynten Dolomite Formation of Sørkapp Land, Spitsbergen

BY

KRZYSZTOF BIRKENMAJER[1]

Contents

Abstract

Cross-bedding and stromatolites are described from the Höferpynten Dolomite Formation (Precambrian) of Sørkapp Land, Spitsbergen. These sedimentary structures proved to be very useful criteria in defining the stratigraphic order in strongly folded rock-sequences of the Hecla Hoek Succession in southern Spitsbergen. The sedimentary environment of the Höferpynten Dolomite corresponds to a very shallow sea, even within the range of tides. Cyclic sedimentation, possibly related to sunspot cycle, influenced the growth and shapes of algal stromatolites. New lithostratigraphic division of the Höferpynten Dolomite Formation is proposed along with redefinitions of some other Precambrian and Lower Palaeozoic lithostratigraphic units for the area of southern Spitsbergen.

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Introduction

The north-western part of Sørkapp Land (Figs. 1 and 2) belongs to the western fold belt of Spitsbergen. The oldest rocks are here represented by strongly folded low-grade metamorphic formations (Precambrian) of the Hecla Hoek Succession, and are unconformably covered by Lower Carboniferous fresh-water deposits, with thin, possibly Devonian, remnants at the base (see MAJOR & WINSNES 1955; BIRKENMAJER 1959, 1960a, b, 1964; SIEDLECKI 1960; SIEDLECKI & TURNAU 1964). The strongly folded Hecla Hoek rocks and their slightly folded late Palaeozoic cover are cut by a pre-Triassic peneplain on which Lower Triassic and younger sediments occur farther south (MAJOR & WINSNES 1955, Fig. 1; BIRKENMAJER 1960b, Figs. 1 and 2, 1964, Figs. 10 and 11). All the rocks from the Precambrian to the Mesozoic inclusively are displaced by two NNW–SSE-trending faults probably of Tertiary age (Figs. 1 and 2).

The Hecla Hoek Succession of the area between Sigfredbogen and Gåshamna is represented by formations belonging to the Deilegga Group (Precambrian) and the Sofiebogen Group (late Precambrian). The Sofiebogen Group is further subdivided into the Slyngfjellet Conglomerate, Höferpynten Dolomite and Gåshamna Phyllite formations, as recognized here by MAJOR & WINSNES (1955) and BIRKENMAJER (1959, 1960a, b, 1964). The position of the Höferpynten Dolomite Formation within the lithostratigraphic scheme of the Hecla Hoek Succession in Sørkapp Land is shown in Table 1 which presents a modernized nomenclature of already known lithostratigraphic units (see also Appendix).

The Deilegga and Sofiebogen groups are tectonically reversed between Sofiebogen and Gåshamna, where they are parts of the western limb of a great Caledonian syncline, the core of which (farther east) being built of the Cambrian

Table 1

Position of the Höferpynten Dolomite Formation within the Hecla Hoek Succession of Sørkapp Land (broken lines denote major unconformities)

Sørkapp Land Group (Lower Ordovician)	(Canadian fossils)
Sofiekammen Group (Cambrian)	(mainly Lower Cambrian fossils)
Sofiebogen Group (Late Precambrian)	Gåshamna Phyllite Formation Höferpynten Dolomite Formation - - - - - - - - - - Slyngfjellet Conglomerate Formation
Deilegga Group (Precambrian)	

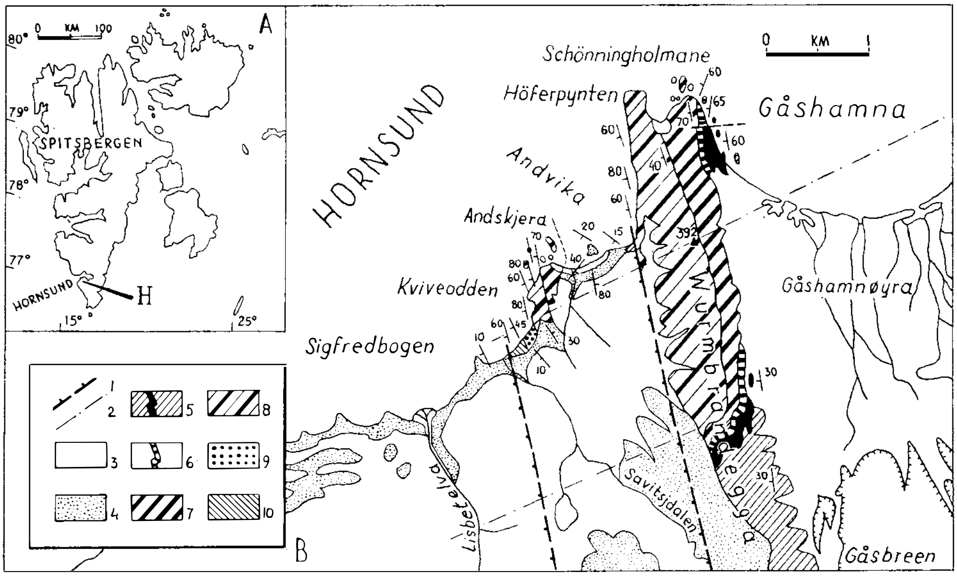

Fig. 1. A. *Position of Höferpynten* (*H*) *in Spitsbergen.*

B. *Geological map of the area between Sigfredbogen and Gåshamna, Sørkapp Land* (*after* BIRKENMAJER 1964, Fig. 10, *simplified*). 1 – *Tertiary faults*; 2 – *line of geological cross-section* (*see* Fig. 2); 3 – *Quaternary deposits, lakes and glaciers*; 4 – *Lower Carboniferous sediments*; 5 – *Gåshamna Phyllite Fm.* (*quartzitic horizons in black*); 6 – *Dunøyane Mb.*; 7 – *Wurmbrandegga Mb.*; 8 – *Andvika Mb. and Fannytoppen Mb.* (6–8 – *Höferpynten Dolomite Fm.*); 9 – *Slyngfjellet Conglomerate Fm.* (5–9 – *Sofiebogen Group, late Precambrian*); 10 – *Deilegga Group* (*Precambrian*).

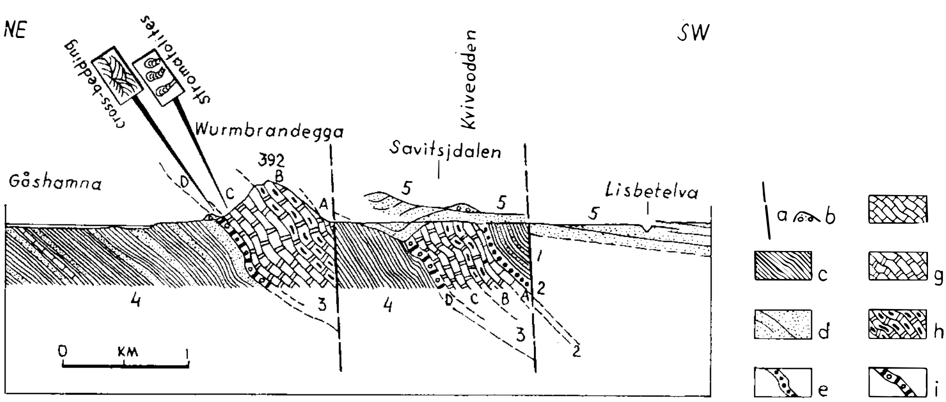

Fig. 2. *Geological cross-section between Lisbetelva and Gåshamna* (*after* BIRKENMAJER 1960b, Fig. 2; 1964, Fig. 11, *modified*). *Positions of the tectonically overturned cross-bedding and stromatolites indicated.* 1 – *Deilegga Group* (*Precambrian*); 2 – *Slyngfjellet Conglomerate Fm.*; 3 – *Höferpynten Dolomite Fm.* (*A – Fannytoppen Mb.*; *B – Andvika Mb.*; *C – Wurmbrandegga Mb.*; *D – Dunøyane Mb.*); 4 – *Gåshamna Phyllite Fm.* (2–4 – *Sofiebogen Group, late Precambrian*); 5 – *Lower Carboniferous sediments*; *a – Tertiary faults*; *b – moraines*; *c – phyllite and shale*; *d – sandstone and quartzite*; *e – conglomerate*; *f – limestone*; *g – dolomite*; *h – dolomite with cherts*; *i – oolitic dolomite.*

(Sofiekammen Group) and Ordovician (Sørkapp Land Group) sediments. The sediments of the Höferpynten Dolomite Formation show the presence of tectonically reversed sedimentary structures, cross-bedding and stromatolites, which provide a further proof for the stratigraphic order within the Precambrian of the area.

The field investigations in the north-western part of Sørkapp Land have been carried out by the present author in 1958, during the Polish Spitsbergen Expeditions (1957–1960), and in 1970, during another expedition sponsored by Norsk Polarinstitutt, Oslo.

Hecla Hoek Succession between Sigfredbogen and Gåshamna

DEILEGGA GROUP

The rocks of the Deilegga Group have been found only at Sigfredbogen (BIRKENMAJER 1959). These are yellowish and green quartz-phyllites and chloritic phyllites with thin light-coloured (greyish, yellowish, pinkish) quartzite intercalations, similar to those occurring in the upper division of the Deilegga Group north of Hornsund (see BIRKENMAJER 1958, p. 146). The incomplete thickness of the Deilegga Group at Sigfredbogen amounts to about 300 m.

SOFIEBOGEN GROUP

The Sofiebogen Group is represented by three formations, of which the Slyngfjellet Conglomerate is the oldest, the Höferpynten Dolomite is the middle, and the Gåshamna Phyllite is the youngest.

1. Slyngfjellet Conglomerate Formation

The Slyngfjellet Conglomerate Formation is exposed only at Sigfredbogen, where it consists of highly deformed (lenticular) yellow or reddish quartzite pebbles and boulders 2–20 cm in diameter. The matrix of the conglomerate consists of equally deformed quartz-phyllite. The general colouration of the conglomerate is yellowish or reddish. The conglomerate is only c. 10 m thick compared to about 500 m in the area north of Hornsund (see BIRKENMAJER 1958, p. 146, 1960c, p. 67). At Sigfredbogen there is no transition from the conglomerate either to the underlying Deilegga Group or to the overlying Höferpynten Dolomite Formation, and the conglomerate represents here the lower member of the Slyngfjellet Conglomerate Formation (see BIRKENMAJER 1959, p. 131).

2. Höferpynten Dolomite Formation

The Höferpynten Dolomite Formation is here subdivided into four members (Fig. 3), roughly following the subdivision into four horizons as proposed by BIRKENMAJER (1958, 1959). The lowermost division is here termed the ***Fannytoppen Member***. At Fannytoppen, north of Hornsund, it consists mainly of phyllitic and

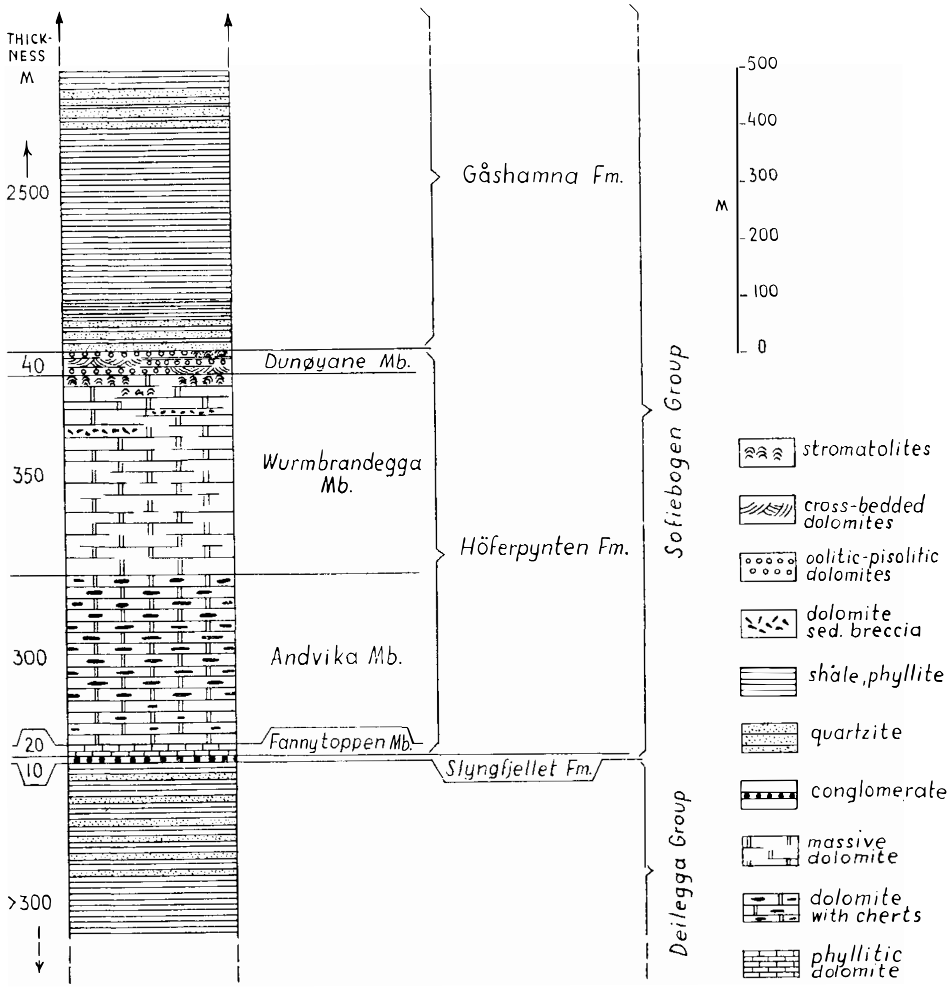

Fig. 3. *Lithostratigraphic column and subdivision of the Höferpynten Dolomite Formation at Höferpynten.*

laminated limestones, red, grey and yellow, 80 m thick, with laminated slates in the upper part (BIRKENMAJER 1959, p. 146, 1960c, p. 67: "lowermost part of the Höferpynten Series"). At Höferpynten, in the western part of Andvika (close to tectonic contact with the Gåshamna Phyllite) this is a 20 m thick complex of grey, greenish or yellowish dolomites. The dolomites are often argillaceous and form layers from 1–3 to 15 cm thick.

The next in the succession is the *Andvika Member* (=first and second horizons of the Höferpynten Series at Höferpynten – BIRKENMAJER 1959, pp. 133–134) 300 m thick. In the lower part it consists of grey, black or yellowish dolomites, sometimes with single nodules of black chert. Some cherts show possibly organogenic sponge-like structures. Grey and black laminae often alternate in the dolomite, sometimes they are wavy, but without any characteristic structures, e. g. stromatolites or slumping.

The middle and upper parts of the Andvika Member are made up of grey dolomites (yellow if weathered) with frequent blue or brownish-grey to black chert intercalations. The cherts form bands 1–30 cm thick (usually 10–20 cm thick, seldom up to 1–2 m thick), often nodular or splitting into parallel layers which show internal horizontal lamination. The dolomites are either massive or layered with individual beds from 0.1 to 1 m thick.

Sedimentary breccias (dolomite-flake conglomerates) have frequently been observed as intercalations 2–10 cm thick in the cherts. Here they consist of dolomite flakes 2–5 cm long and 0.5–1 cm thick. Some cherts show granular structure either at the bottom or at the top of the intercalations, which could be recrystallized clastic quartz grains.

The Andvika Member is not developed at Fannytoppen (north of Hornsund), but is present in the western part of Kviveodden (see Figs. 1 and 2) where it is about 200 m thick.

The *Wurmbrandegga Member* (= third horizon of the Höferpynten Series at Höferpynten – BIRKENMAJER 1959, p. 134) is made up of dark (grey, blackish) dolomites (yellow or orange if weathered) 350 m thick, with frequent intercalations of sedimentary dolomite breccias. The dolomites are either massive or feebly bedded (beds 0.5–2 m thick). In the uppermost part of the member there occur stromatolitic structures (see below, and Figs. 5A, B and 6) associated with sedimentary breccias (dolomite-flake conglomerates) 2–20 cm thick, consisting of flat dolomite flakes and of laminated stromatolite fragments 1–3 cm long and 1–3 mm thick.

The Wurmbrandegga Member is present north of Hornsund at Fannytoppen (light dolomites – BIRKENMAJER 1958, p. 146; grey dolomites with sedimentary microbreccias, 14 m thick – BIRKENMAJER 1960c, p. 67) and at Dunøyane (lowest horizon: massive or laminated dark dolomites – BIRKENMAJER 1959, p. 131), also in the eastern part of Kviveodden in Sørkapp Land (Figs. 1 and 2) where the dolomites are strongly brecciated and mineralized with sulphides.

For the youngest member of the Höferpynten Dolomite Formation at Hornsund I propose the name *Dunøyane Member* (from Dunøyane, north-west of Hornsund, middle horizon: "light dolomites interbedded with dolomitic oolites and pisolites", and upper horizon: "thin layer of dolomite with... *Collenia*" – BIRKENMAJER 1959, p. 131). At Store Dunøya the member is c. 200 m thick, along the west coast of Gåshamna at Höferpynten, and farther south at Wurmbrandegga (Figs. 1 and 2) – 40 m thick. In the vicinity of Gåshamna it consists of grey or blackish (grey-yellowish if weathered) oolitic and pisolitic dolomites often showing small-scale current lamination (= "fourth horizon of the Höferpynten Series" – BIRKENMAJER 1959, p. 134), which will be described in more detail in the next section of this paper. The dolomites are poorly bedded (layers from 10 cm to 3 m thick) but well stratified, what is visible in the arrangement of ooids, may be either horizontal or diagonal. The ooid diameters vary from 0.5–1 mm to 1–2 mm (ooids) to 2–15 mm (pisoids). They are ovoidal, ellipsoidal or spheroidal. Some dolomites show slump lamination, others graded bedding, both expressed in ooid arrangement. Sometimes, fragments (clasts) of medium-grade oolites occur in fine or coarse-grade oolitic matrix. Here and there the carbonate in ooids has been replaced by quartz.

Subordinately there occur also intercalations of grey dolomitic shales (yellow if weathered) 0.5–1 m thick. About 7 m below the contact with the quartzites of the Gåshamna Phyllite Formation has been found an intercalation of black shale about 30 cm thick. Some other black shale intercalations 0.1–0.5 m thick may be found in the lower part of the Dunøyane Member.

The contact of the Dunøyane Member with the Gåshamna Phyllite Formation is poorly exposed at Höferpynten. Farther south, along the eastern slope of Wurmbrandegga, a thin layer with stromatolitic ("*Collenia*-like") structures has been found between the oolites and quartzites (BIRKENMAJER 1959, p. 134).

To the north of Hornsund the Dunøyane Member occurs at Fannytoppen (dolomitic oolites and pisolites, c. 24 m thick – BIRKENMAJER 1958, p. 146; 1960, p. 67) and at Dunøyane (see above).

The Höferpynten Dolomite Formation correlates with the Akademikerbreen Group in Ny Friesland, and the Hunnberg and Ryssö formations (Roaldtoppen Group) in Nordaustlandet (see MAJOR & WINSNES 1955; HARLAND & WILSON 1956; BIRKENMAJER 1958, 1959; HARLAND 1960, 1961, 1969; WINSNES 1965; FLOOD et al. 1969, Fig. 10), as it is shown in Table 2. The oolites and stromatolites are present mostly at the stratigraphic top of the sequences, in the Dunøyane Member, the Backlundtoppen Formation and the Ryssö Formation which, therefore, easily correlate with one another. Lower down in the succession both the lithologies and sequences vary greatly between the three areas, and even within the same area, and correlation becomes difficult.

Table 2

Correlation of the main late Precambrian carbonate sequences of Spitsbergen and Nordaustlandet (thickness in metres)

Southern Spitsbergen (this paper)			Ny Friesland (HARLAND & WILSON 1956; HARLAND 1969, and others)		Nordaustlandet (KULLING 1934; FLOOD et al. 1969, and others)	
Group	Formation	Member	Group	Formation	Group	Formation
Sofiebogen	Höferpynten	Dunøyane 24–40	Akademikerbreen	Backlundtoppen 360–700	Roaldtoppen	Ryssö 750
		Wurmbrandegga 14–350		Draken Cgl. 25–300		Hunnberg 500
		Andvika 200–300		Svanbergfjellet 100–625		
		Fannytoppen 20-80		Grusdievbreen 865		

3. Gåshamna Phyllite Formation

The Gåshamna Phyllite Formation at Gåshamna begins with a horizon 40–50 m thick of black quartzites alternating usually with black shales and phyllites. The quartzites form layers from 0.1 to 2–3 m thick (usually 0.5–1 m thick) and are veined with quartz. The intervening shales or phyllites are black (graphitic) or greenish, usually 0.1–0.2 m thick, sometimes up to 2 m thick. The ratio of quartzites to shales varies from 3:1 to 4:1. The quartzites are often indistinctly laminated with black graphite-like substance. In the stratigraphically top parts of the quartzite layers there occur sometimes black phyllite pellets 1–5 cm long and 0.5–1 cm thick. Tectonically reversed normal graded bedding with quartz grains 0.5–2 mm in diameter at the stratigraphic bottom, and 0.5–0.1 mm in diameter at the stratigraphic top, has also been found.

It seems that there is a transition from the Höferpynten Dolomite Formation to the basal quartzitic horizon of the Gåshamna Phyllite Formation, as indicated by the presence of black shale intercalations in the Dunøyane Member at Gåshamna (see above). The lowermost part of the Gåshamna Phyllite Formation begins here often with a 3 m thick layer of black and green, often quartzitic shales and phyllites in bands 1–2 m thick, intercalated with blackish quartzites 5–10 cm thick.

Above the basal quartzitic horizon of the Gåshamna Phyllite there occur green, greyish, sometimes also violet and yellow phyllites. They are visible at low tide in the western part of Gåshamna, and are well exposed in the southern part of Wurmbrandegga. More quartzitic horizons and a phyllitic limestone intercalation appear higher still south and east of Gåshamna (see BIRKENMAJER 1960b, Fig. 2, 1964, Figs. 10 and 11). The total thickness of the Gåshamna Phyllite Formation in the vicinity of Gåshamna amounts to about 2500 m.

In the eastern part of Andvika the Gåshamna Phyllite (black and dark-green phyllites) is exposed poorly below the unconformable Lower Carboniferous sandstones. Here it is separated from the Höferpynten Dolomite Formation on the east by a fault (Figs. 1 and 2).

Tectonically reversed sedimentary structures in the Höferpynten Dolomite Formation

CROSS-BEDDING

Small-scale cross-bedding is often present in the Dunøyane Member along the western coast of Gåshamna. The cross-bedding is visible in dolomites, especially when fine-grained or made up of fine-grade oolites (below 0.2 mm in diameter). In medium-grade oolites or in pisolites the cross-bedding is more seldom encountered.

Within individual sets of cross-laminae, which are from 1 mm to 1 cm thick, the bottom-sets and fore-sets are best developed, while the top-sets are usually missing. Each set of laminae is truncated by erosion surface upon which new set

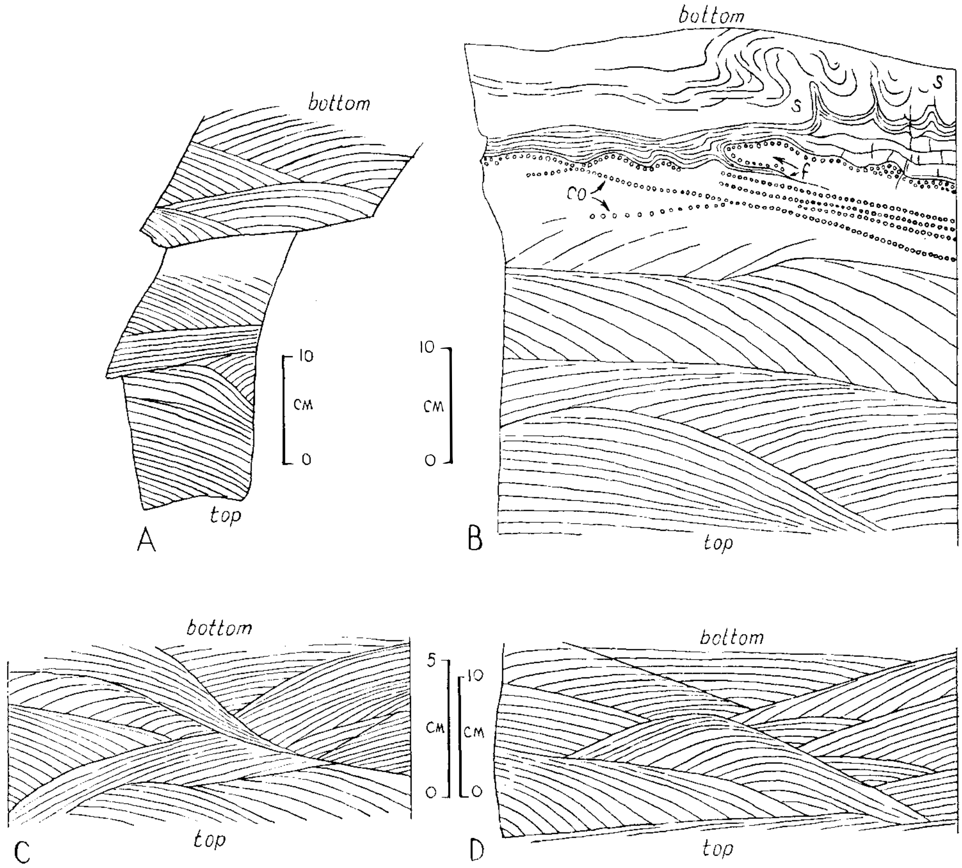

Fig. 4. A–D. *Tectonically reversed small-scale cross-bedding from the Höferpynten Dolomite Formation (Dunøyane Member) at Höferpynten. co – cross-bedding marked by ooids; f – flowage marking; s – slump structures.*

appears. The erosional surfaces between the sets are predominantly concave, thus indicating a trough-cross-stratification type. Planar cross-bedding is more seldom.

Fig. 4A–D shows four examples of cross-bedding from the Dunøyane Member at Höferpynten in their present, tectonically overturned position. The designations of "bottom" and "top" refer to the stratigraphical bottom and top respectively. These examples give a convincing evidence of the tectonically reversed order in the Höferpynten Dolomite Formation at Höferpynten, and confirm the already established stratigraphic sequence within the Hecla Hoek Succession of the area.

Some layers of cross-bedded dolomites begin with flowage markings (flame structures), involving plastic deformation of the underlying thin argillaceous (shaly) dolomite prior to the deposition of the cross-bedded unit (Fig. 4B). Below flowage-marked sole of the cross-bedded layer, the top surface of another (lower) layer may show incipient slump structures (Fig. 4B: bottom) thus indicating mobility in partly diagenesized carbonate prior to the deposition of the cross-bedded dolomite. The latter was deposited by a current of decreasing transporting force, as is shown by the diameters of ooids involved (1–2 mm at the bottom and less than 0.1 mm at the top), and by the thicknesses of the laminae: up to 25 mm at the bottom and down to 1–2 mm at the top. This is an example of normally graded cross-bedding.

Detailed measurements of the direction of trough-cross-stratification have not been possible due to the lack of suitable exposures. Generally it seems that the erosional troughs were directed roughly W–E, while the accumulation of foresets proceeded either from W to E or from E to W. It seems possible that the scouring of the bottom had occurred at low tide, and was caused by ebb currents gouging parallel or subparallel rills in the soft sediment. The subsequent cross-laminated sediment probably represents ripple drift formed at flood tide.

The presence of the above described small-scale cross-stratification points to the existence of a very shallow marine environment during the formation of the Dunøyane Member carbonates.

STROMATOLITES

1. Description

The stromatolites shown in Figs. 5 and 6 occur in the uppermost part of the Wurmbrandegga Member. The structures are made up of alternating lighter and darker laminae of fine-grained dolomite and are regarded by me as algal organo-sedimentary structures. Some are less regular (Fig. 5A), the others show a marked tendency to form individual offshots, often budding from a less regular, reef-like algal mat, sometimes branching, anastomosing or joining each other.

Figures 5A and B show the algal structures in the present, tectonically reversed position. The designations of "bottom" and "top" refer to the stratigraphic bottom and top respectively. These examples provide a further convincing evidence for the stratigraphic order in the Höferpynten Dolomite Formation at Höferpynten.

The structures shown in Fig. 5B have been more closely investigated in the field. In Fig. 6 they are shown in the normal, growth position. The individual, columnar offshots are 0.5–2 cm in diameter at the bottom and up to maximum 5 cm in diameter at the top. Their cross-section is roughly circular or elliptical. Usually they are 5–10 cm high, but may join each other in vertical succession thus becoming up to 30 cm high. Branching or budding usually starts from more flat, horizontally extended structures at the border between the layers. There are also zones either independent of columnar forms or connected with them, where the structures again become more flat, wavy, reef-like, extending parallel to the stratification of the dolomite. And again the budding begins above the next stratification plane.

It seems that budding and vertical growth of columnar stromatolites proceeded along with comparatively quicker deposition of fine carbonate (now: dolomicrite and dolarenite), forcing the algae to find their way up the sediment to the surface of the sea-bottom, in order to acquire better conditions for light-generated metabolism (photosynthesis). The stratification surfaces marked between the layers

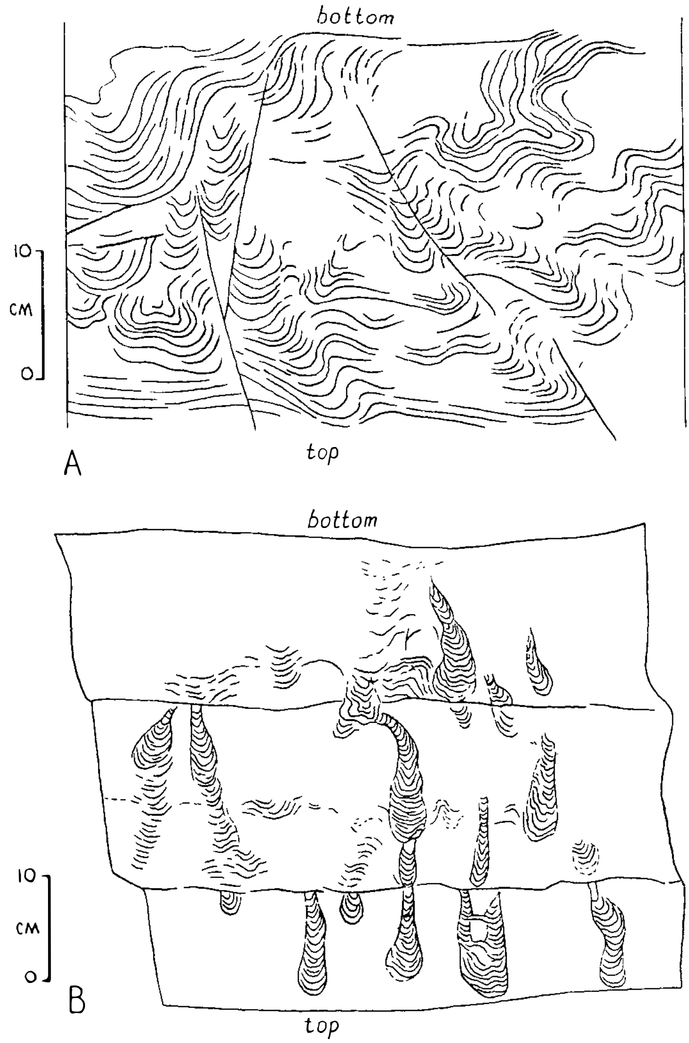

Fig. 5 A–B. *Tectonically reversed stromatolitic structures from the Höferpynten Dolomite Formation (Wurmbrandegga Member) at Höferpynten.*

A/*B*, *B*/*C* and, fainter, *a*/*b* (Fig. 6) could correspond to periods of relative stagnation in carbonate deposition. During such periods the algal stromatolites tended to spread out flat over the bottom.

The three sedimentary units (layers) *A*, *B* and *C* are 15 cm, 17 cm, and 11 cm thick respectively. Taking into account the fostered growth of the algal offshots (columns) at the bottom of each of the three layers as the proof of relatively faster deposition of carbonate, and the expansion of stromatolites in lateral directions in the top parts of these layers as the result of decreasing rate of deposition, we could interpret this as cyclic deposition, the *A*, *B* and *C* units representing the successive cycles. The *B* unit can be, moreover, subdivided into two less marked cycles *a* and *b*, separated with a fainter marked stratification surface *a*/*b*, where another slowing down of the sedimentation occurred.

As already mentioned, the stromatolitic structures show well marked growth lines expressed in the alternation of lighter and darker laminae of dolomite. The

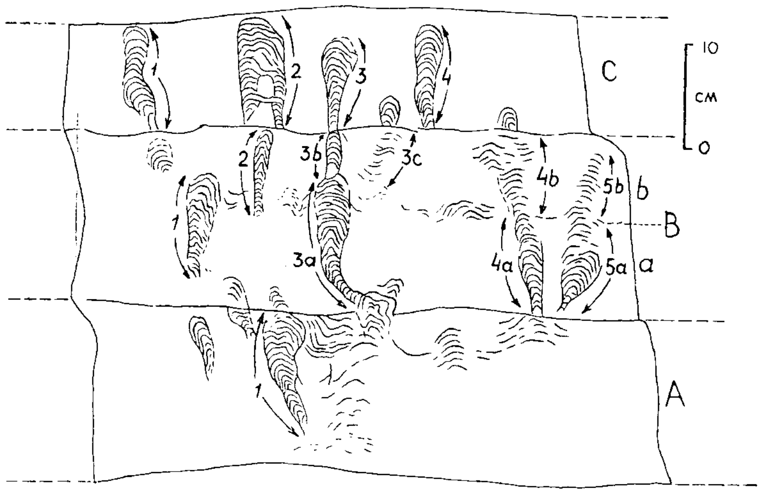

Fig. 6. *Stromatolitic structure from Fig. 5B shown in a growth position. Numbers and letters refer to those in Table 3.*

lighter laminae are from 0.2 to 2 mm thick, and the darker ones from 0.5 to 2 mm thick. The nature of the colouration is uncertain, but may be due to a higher content of organic (now graphitic) matter in the darker laminae. Sometimes the darker laminae show still finer darker and lighter lamellae, but usually these are obliterated by recrystallization. The light laminae are often replaced by yellowish or orange ankerite.

It is assumed that the lighter laminae were formed during comparatively shorter periods of quicker algal growth, and that the dark ones (with internal second-order lamellae) correspond to comparatively longer periods of slower algal growth. The light and dark colouration could, moreover, reflect repeating conditions of better and worse oxidation respectively.

An attempt is being made to explain the alternation of dark and light laminae in stromatolites as the result of the annual cycle of insolation, the lighter laminae corresponding to summer months of better insolation and the darker laminae to autumn, winter, and spring months of reduced insolation. A pair of laminae would correspond to one year.

The lamination of stromatolites could, therefore, be a proof of seasonally differentiated climate during the late Precambrian on the northern hemisphere. This agrees well with the evidences of an extensive late-Precambrian (Varangian) glaciation in the rocks immediately succeeding the Höferpynten Dolomite Formation and its equivalents in Svalbard, North-Norway, Greenland, and elsewhere (see KULLING 1934; HARLAND 1964; HARLAND & RUDWICK 1964).

Table 3 shows the number of lighter laminae in individual columnar stromatolites, as well as the ranges and mean numbers of these in successive cycles. The range in "mature" columnar structures is from 35 to 98 laminae per individual; this could represent the age range of individual colonies. The mean number of light laminae per layer is about 50 for *A* and *C* layers (49 and 54 respectively) and

Table 3
Number of light laminae in stromatolitic structures (see Fig. 6)

Layer		Specimen No./Number of light laminae	Range	Mean
C		*1*:55 *2*:40 *3*:45 *4*:55	35-55	c. 49
B	b	*1*:40 *2*:48 *3b*:28 *3c*:25 *4b*:20 *5b*:20	40–98	66
	a	*3a*:70 *4a*:46 *5a*:30		
A		*1*:54	54	54

66 for *B* layer. The maximum number of light laminae counted in *B* layer is 98, i.e. twice as high as for *A* and *C* layers respectively, but this correlates with a subordinate stratification surface marked as *a/b*.

It should be borne in mind that the structures shown in Fig. 6 (Table 3) were investigated only in vertical, thus two-dimensional, cross section. However, some of the structures could be tilted; thus the top parts of these would escape observation. Unfortunately, it has not been possible to obtain proper samples for three-dimensional counting of the laminae, as the exposed rock surface was of abrasion-polished strandflat.

Notwithstanding the error in counting the number of laminae, which by no means exceeds 5–10%, the duration of each of the four cycles *A*, *Ba*, *Bb* and *C* was of the same order, about 50 years. This could, furthermore, lead to a conclusion that the c. 50 year cycle directly reflected the late-Precambrian sunspot cycle of the same duration, as compared with the present waxing and waning in strength of the sunspots every 11 years, being part of a longer, 22-year cycle (cf. BERGAMINI 1964, p. 90).

If the above calculations are true, then the mean rate of sedimentation during the *A–C* cycles was c. 0.21 cm per annum (43 cm in 200 years).

2. Classification

Stromatolitic structures have been described and illustrated from the beds equivalent to the Höferpynten Dolomite in Svalbard especially by KULLING (1934), WILSON (1961), WINSNES (1965), KRASILŠČIKOV et al. (1965), GOLOVANOV (1967), and FLOOD et al. (1969), and in Finnmark, North-Norway, by HOLTEDAHL (1918, 1960) and WHITE (1969). In Nordaustlandet (Svalbard) they occur in the Murchisonfjorden Supergroup (Ryssö Dolomite – KULLING 1934; Hunnberg Fm. – KRASILŠČIKOV et al. 1965; Hunnberg Fm. and Ryssö Fm. – GOLOVANOV 1967; Ryssö Fm. – FLOOD et al. 1969), in Ny Friesland (Spitsbergen) – predominantly in the Akademikerbreen Group (mainly in the Backlundtoppen Fm. and the Svanbergfjellet Fm. – HARLAND & WILSON 1956; WILSON 1961).

The stromatolites of Svalbard show a variety of sizes and shapes, geometrically falling into three categories:

(*A*) reef-like mats, spreading parallel or subparallel to the stratification of the rock, with wavy or crenulated tops (*Collenia*, types *a* and *b* of WILSON 1961, Fig. 2);

(*B*) spheroidal and hemispheroidal colonies (*Collenia*, types *d* and *h* of WILSON 1961, Fig. 2; *Collenia* structures – BIRKENMAJER 1958, 1959);

(*C*) vertically elongated or columnar, often branching colonies (*Gymnosolen* of KULLING 1934, Fig. 5; *Collenia*, types *c*, *e*, *f*, *g* and *i* of WILSON 1961, Fig. 2; stromatolite – WINSNES 1965, Fig. 5; *Inseria, Kussiella* (?) and *Conophyton* of KRASILŠČIKOV et al. 1965, Pls. I–III; *Inseria*, *Kussiella, Gymnosolen* and *Conophyton* of GOLOVANOV 1967, Figs. 1–5, Pls. III–VIII; columnar stromatolites – FLOOD et al. 1969, Fig. 9).

Of the stromatolitic structures illustrated in the present paper the one in Fig. 5A falls into the *A*-type of reef-like mats, while the others in Figs. 5B and 6 simultaneously show characteristics of both the *A* (reef-like) and *C* (vertically elongated, columnar) types. The latter are undoubtedly parts of the same algal colonies, their morphological (geometric) differentiation being the result of cyclically repeated changing environmental conditions: decrease in carbonate deposition rate favouring the growth of reef-like mats (*A*-type), increase in carbonate deposition rate fostering the growth of vertical offshots (*C*-type). Different generic and specific names will be used for various parts of the structures represented in Figs. 5B and 6 when following the binominal (or trinominal) palaeontologic classification as that applied by KRASILŠČIKOV et al. (1965) and GOLOVANOV (1967). The present example clearly shows, however, that the geometric form of the colonies, as well as the sizes and arrangement of particular laminae, were strongly controlled by environmental conditions. It follows, therefore, that the taxa both at the generic, specific, and variety levels have doubtful palaeontological meaning and, consequently, their stratigraphical value should not be overestimated.

Here I follow the conclusions already reached by HOLTEDAHL (1918, pp. 229–232; 1960, pp. 116–117: footnote) who objected to the use of generic names like *Gymnosolen, Collenia* and *Cryptozoon,* and proposed to use the general term stromatolite instead, introduced as far back as in 1908 by KALKOWSKI for structures in Lower Triassic limestones of Germany.

This approach is also shared by LOGAN et al. (1964) who regard the stromatolites as organosedimentary structures, their variation in shape being a function of the environment in which the algal mats develop. Based on their observations of recent occurrences, LOGAN et al. classify algal stromatolites into three main types, two of which correspond to the attached forms – divided into laterally linked hemispheroids and discrete, vertically stacked hemispheroids – and the other to unattached.

Stromatolitic structures of the Porsanger Dolomite Formation in Finnmark, North-Norway, a lithostratigraphical equivalent to the Höferpynten Dolomite Formation in southern Spitsbergen, have been described by HOLTEDAHL (1918, 1960) and recently by WHITE (1969). WHITE has tried to apply both the geometric classification of LOGAN et al., and the palaeontological classification as used mainly by the Russian authors (KRYLOV and others). According to WHITE the laterally continuous, wavy laminated stromatolites of the Porsanger Dolomite would be laterally linked hemispheroids of LOGAN et al. or *Collenia* structures, and the discrete columnar forms – the stacked hemispheroids of LOGAN et al. or *Cryptozoon* structures. Another group would include the discrete columnar branched structures *Collenia* (*Gymnosolen*).

Sedimentary environment of the Höferpynten Dolomite Formation

The sedimentary environment of the Höferpynten Dolomite Formation was shallow-marine, best marked in the Wurmbrandegga and Dunøyane members. The shallow-marine sedimentation is evidenced by the occurrence of oolitic-pisolitic rocks which often show small-scale trough-cross-stratification, of dolomite-flake conglomerates (sedimentary breccias), and stromatolitic structures. The character of the cross-bedding points to the presence of possibly intertidal flats where the scouring of the bottom by ebb currents produced small rills, and ripple drift formed during flood tide. Submarine slumping played a minor role, while bottom erosion was often strong enough to fragmentate already diagenesized oolites, the clasts of which frequently occur within micro-oolitic, meso-oolitic or macro-oolitic (pisolitic) layers.

The origin of frequent dolomite-flake conglomerates (sedimentary breccias) can be explained by fragmentation of laminated, already partly diagenesized carbonate which quickly desiccated and cracked when exposed to relatively warm air at low tide, then was redeposited by tidal currents.

The carbonate rocks seem to be represented mostly by dolarenites and dolomicrites. The varying rate of carbonate deposition controlled the mode of growth and shapes of algal stromatolites which grew in slightly deeper waters, possibly just below the low-tide mark. Fragmentation of algal structures also occurred, and stromatolite clasts are rather frequent. Cyclic sedimentation reflected in recurrent reef-like algal mats, and columnar algal colonies, could be related to sunspot cycle.

Little is known about sedimentary conditions of the Fannytoppen and Andvika members, where the recrystallization is strongest. Frequent chert intercalations in the Andvika Member seem to represent diagenetic cherts formed due to recrystallization of quartz sand, as indicated by the presence of relic quartz grains in many of them.

Similar conditions prevailed during the deposition of the rocks equivalent to the Höferpynten Dolomite in Nordaustlandet, Ny Friesland, and Finnmark. WILSON (1961, pp. 108–110) discussed the mode of formation of the Akademikerbreen Group in Ny Friesland. Cyclic sedimentation was recognized by him in the Upper Svanbergfjellet Limestones. He accepted very shallow-water, even intertidal, sedimentary environment for the rocks (particularly the Svanbergfjellet Fm. and Backlundtoppen Fm.) containing intraformational conglomerates, oolites, oolitoids, desiccation cracks, false bedding, ripple marks, and *Collenia* beds. A detailed account of the sedimentary conditions which prevailed during the formation of the Porsanger Dolomite in Finnmark was presented by WHITE (1969). The environment of this dolomite represented the establishment of wide intertidal and supratidal areas, with warm waters and a relatively humid climate. Many of the sedimentary features of the Porsanger Dolomite described by WHITE bear a striking resemblance to those of the Höferpynten Dolomite in southern Spitsbergen.

Acknowledgements

The author wishes to express his sincere gratitude to Norges Teknisk-Naturvitenskapelige Forskningsråd (The Royal Norwegian Council for Scientific and Industrial Research, Oslo) whose post-doctoral fellowship enabled him to elaborate the data collected in Spitsbergen while working at Norsk Polarinstitutt in Oslo. Dr. T. GJELSVIK, the Director, kindly made the facilities of the Institute readily available to him, for which he is most grateful.

Appendix

Andvika Member: second division of the Höferpynten Dolomite Formation. Name from Andvika, Sørkapp Land. Type section: western part of Höferpynten; thickness of unit in the type section 300 m; illustrated in Text-Figs. 1–3; also illustrated by MAJOR & WINSNES (1955, Fig. 2a) and BIRKENMAJER (1960b, Fig. 2, 1964, Figs. 10 and 11). Dominant lithology: dolomite with chert intercalations. Age: Precambrian. Synonyms: first and second horizons of the Höferpynten Series at Höferpynten (BIRKENMAJER 1959, pp. 133–134).

Deilegga Group: consists of three unnamed units (formations). Name from Deilegga, Wedel Jarlsberg Land (BIRKENMAJER 1958: Deilegga Formation). Thickness of unit up to c. 3500 m; distribution shown by BIRKENMAJER (1960b, Fig. 2; 1960c, Fig. 1). Dominant lithology: green phyllites and schists (lower unit), green chloritic schists with alum shale and dolomite (middle unit), green chloritic schists with light quartzite intercalations (upper unit). Age: Precambrian.

Dunøyane Member: upper (fourth) division of the Höferpynten Dolomite Formation. Name from Dunøyane, NW of Hornsund. Type sections: Store Dunøya "light dolomites interbedded with dolomitic oolites and pisolites", and "thin layer of dolomite with... *Collenia*" – BIRKENMAJER 1959, p. 131), Fannytoppen, Wedel Jarlsberg Land (dolomitic oolites and pisolites – BIRKENMAJER 1958, p. 146; 1960c, p. 67) and Höferpynten, Sørkapp Land (BIRKENMAJER 1959, p. 134: fourth horizon of the Höferpynten Series). Thickness of unit in the type sections: Store Dunøya c. 200 m, Fannytoppen c. 24 m, Höferpynten 40 m; illustrated in Text-Figs. 1–3; also illustrated by MAJOR & WINSNES (1955, Figs. 2a and 7) and BIRKENMAJER (1960b, Fig. 2; 1964, Figs. 10 and 11). Dominant lithology: oolitic dolomites with stromatolites. Age: Precambrian.

Fannytoppen Member: lower (first) division of the Höferpynten Dolomite Formation. Name from Fannytoppen, Wedel Jarlsberg Land. Type sections: Fannytoppen ("lowermost part of the Höferpynten Series" – BIRKENMAJER 1960c, p. 67) and Höferpynten, Sørkapp Land. Thickness of unit in the type sections: Fannytoppen 80 m, Höferpynten 20 m; illustrated in Text-Figs. 1–3. Dominant lithology: phyllitic limestones and dolomites. Age: Precambrian.

Gåshamna Phyllite Formation: upper (third) division of the Sofiebogen Group. Name from Gåshamna, Sørkapp Land (MAJOR & WINSNES 1955: Gåshamna phyllite). Thickness of unit in the type section 2500 m; illustrated by MAJOR & WINSNES (1955, Figs. 2a and 7) and BIRKENMAJER (1960b, Figs. 2 and 3); also illustrated by BIRKENMAJER (1960c, Fig. 1; 1964, Figs 10 and 11). Dominant lithology: phyllite (with quartzite, dolomite and phyllitic limestone horizons) (see BIRKENMAJER 1958, 1959, 1960c). Age: latest Precambrian ("Eocambrian"). Synonyms: Gåshamna group (WINSNES 1965, Tab. 4), Gåshamna Formation (HARLAND 1969, Tab. III).

Höferpynten Dolomite Formation: middle (second) division of the Sofiebogen Group. Consists of four members: Fannytoppen Mb., Andvika Mb., Wurmbrandegga Mb., and Dunøyane Mb. Name from Höferpynten, Sørkapp Land (MAJOR & WINSNES 1955: Höferpynten series). Thickness of unit in type section 710 m; illustrated by MAJOR & WINSNES (1955, Figs. 2a and 7) and BIRKENMAJER (1960b, Figs. 2 and 3); also illustrated by BIRKENMAJER (1960c, Fig. 1; 1964, Figs. 10 and 11), and in Text-Figs. 1–3. Dominant lithology: dolomite (with cherts, stromatolites and oolites), subordinately limestone. Age: Precambrian. Synonyms: Höferpynten group (mis-spelled: Høferpynten – WINSNES 1965, Tab. 4), and Höferpynten Formation (mis-spelled: Høferpynten – HARLAND 1969, Tab. III).

Slyngfjellet Conglomerate Formation: lower (first) division of the Sofiebogen Group. Name from Slyngfjellet, Wedel Jarlsberg Land (BIRKENMAJER 1958, p. 146: Slyngfjellet conglomerate). Consists of two unnamed units (members). Thickness of unit in the type section c. 500 m; distribution shown by BIRKENMAJER (1960b, Figs. 1 and 2; 1960c, Fig. 1); also illustrated by BIRKENMAJER (1964, Figs. 10 and 11) and in Text-Figs. 1–3. Dominant lithology: yellow or brown quartzite conglomerate (lower member) and green quartzite-limestone conglomerate with subordinate shale and sandstone intercalations (upper member). Age: Precambrian. Synonyms: Slyngfjellet conglomerate (group) (WINSNES 1965, Tab. 4).

Sofiebogen Group: consists of three formations, the Slyngfjellet Conglomerate (lower), the Höferpynten Dolomite (middle) and the Gåshamna Phyllite (upper). Name from Sofiebogen, Wedel Jarlsberg Land (BIRKENMAJER 1958: Sofiebogen Formation). Thickness of unit 2500–3000 m; distribution shown by BIRKENMAJER (1960b, Fig. 2; 1960c, Fig. 1). Age: Precambrian.

Sofiekammen Group: name from Sofiekammen, Wedel Jarlsberg Land (BIRKENMAJER 1958: Sofiekammen Formation). Includes several units described by MAJOR & WINSNES (1955) and BIRKENMAJER (1958, 1959, 1960a–c) which will be redefined in a forthcoming paper. Thickness of unit. c. 800 m; distribution of unit shown by BIRKENMAJER (1960b, Fig. 1; 1960c, Fig. 1). Age: Cambrian.

Sørkapp Land Group: name from Sørkapp Land (BIRKENMAJER 1958: Sørkappland Formation). Includes several units described by MAJOR & WINSNES (1955) and BIRKENMAJER (1958, 1959, 1960a –c) which will be redefined in a forthcoming paper. Thickness of unit c. 1700 m; distribution shown by BIRKENMJAER (1960b, Fig. 1; 1960c, Fig. 1). Age: Ordovician (Lower Ordovician).

Wurmbrandegga Member: third division of the Höferpynten Dolomite Formation. Name from Wurmbrandegga, Sørkapp Land. Type section: middle part of Höferpynten; thickness of unit in the type section 350 m; illustrated in Text-Figs. 1–3; also illustrated by MAJOR & WINSNES (1955, Figs. 2a and 7) and BIRKENMAJER (1960b, Fig. 2; 1964, Figs. 10 and 11). Dominant lithology: massive or poorly bedded dolomite with intercalations of dolomite-flake conglomerates and with stromatolites. Age: Precambrian. Synonyms: third horizon of the Höferpynten Series at Höferpynten (BIRKENMAJER 1959, p. 134), light dolomites at Fannytoppen (BIRKENMAJER 1958, p. 146), grey dolomites with sedimentary microbreccias at Fannytoppen (BIRKENMAJER 1960c, p. 67), lowest horizon, massive or laminated dark dolomites at Dunøyane (BIRKENMAJER 1959, p. 131).

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Igneous and fossiliferous sedimentary drift pebbles in marine Tertiary of Torell Land, Spitsbergen

BY

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Contents

Abstract

In the Lower Tertiary marine strata of Spitsbergen there occur pebbles of rhyolite porphyry (Precambrian), granite (possibly post-Ordovician but pre-Devonian), vein quartz (pre-Devonian), quartzitic sandstone, fossiliferous chert (Permian) and dolerite (Upper Jurassic – Lower Cretaceous). Their mode of occurrence suggests that these are drift pebbles carried to the place of their deposition by driftwood and/or by floating islets of tangled growth. The main source of the pebbles were most probably river outlets and coastal beaches of a land which included the northern and north-eastern parts of the Svalbard archipelago. Petrographical description of igneous rocks and determination of fossils from Permian cherts are presented.

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A. Geological part

BY

K. BIRKENMAJER

GEOLOGICAL POSITION OF PEBBLES

Igneous and fossiliferous sedimentary drift pebbles have been collected by the author in 1966 during geological investigations in Torell Land, Spitsbergen, sponsored by Norsk Polarinstitutt, Oslo. They occur in marine strata of Lower Tertiary age, the "green sandstone" and the "upper black shale" divisions of NATHORST (1910), for which the names Sarkofagen Formation and Gilsonryggen Formation have been introduced by H. MAJOR in the map of Adventdalen (1:100,000) printed by Norsk Polarinstitutt in 1964 but not yet published.

The collection of pebbles described in this paper consists of 17 specimens, of which 12 are from Bendefjellet (Gilsonryggen Fm.), 4 from Sølvknappane (Gilsonryggen Fm.), and one from Volkovitsjfjellet (Sarkofagen Fm.).

Table 1
The Tertiary succession in Spitsbergen.

Group*	Formation**	NATHORST (1910)	VONDERBANK (1970)
	Aspelintoppen	Upper plant-bearing sandstone	Nordenskiöld-fjellet Schichten
	Battfjellet	Fissile (flaggy) sandstone	Fardalen Schichten
Van Mijen-fjorden	Gilsonryggen	Upper black shale	
	Sarkofagen	Green sandstone	
	Basilika	Lower dark shale	Grumantdalen Schichten
	Firkanten	Lower light sandstone (with coal seams)	Adventfjorden Schichten

* Group name – see HARLAND (1969). ** Formation names are those used by Norsk Polarinstitutt map of Adventdalen (1:100,000), printed in 1964 but not yet published.

Bendefjellet (Fig. 1C). The eastern part of Bendefjellet is made up of four Tertiary formations: Firkanten, Basilika, Sarkofagen and Gilsonryggen, of which the lowest (Firkanten Fm.) rests directly upon the Lower Cretaceous Carolinefjellet Formation (*Ditrupa* beds). The Tertiary rocks dip towards NE at an angle of 10°.

The Gilsonryggen Formation consists here, as usual, of black shales splitting into prisms or irregular angular debris. The shales contain infrequent small discoidal red-weathering clay-ironstone concretions 5–10 cm in diameter, and spheroidal calcite concretions with radial internal structure ("rosettes") 6–8 cm in diameter. Scattered along the exposures of black shale are rounded or well rounded pebbles: grey granite, graphic granite and rhyolite porphyry (2–30 cm in diameter), diabase resp. dolerite (up to 35 cm in diameter), vein quartz and grey quartzitic sandstone (2–10 cm in diameter), and black or bluish banded Permian chert (2–30 cm in diameter).

Sølvknappane (Fig. 1B). The peaks of Sølvknappane are made up of the Gilsonryggen Formation, below which the Sarkofagen and the Basilika formations crop out. The Tertiary strata are here horizontal or dip at very low angles (up to 2°) towards ESE.

The dominating rocks of the Gilsonryggen Formation are shales and silty shales, black or dark grey, splitting into fine, usually sharp-edged fragments. Towards the base of the formation there appear several thin (10–15 cm) intercalations of greenish-brown fine-grained sandstone with worm trails. Discoidal or ellipsoidal clay-ironstone concretions, red if weathered, 5–10 cm in diameter, are scattered at random in the shales, mostly in the lower part of the formation. Here these are associated with randomly distributed pebbles of white vein quartz, grey quartzite and blue or black Permian chert, 5–10 cm in diameter. The Permian cherts are often fossiliferous, and contain brachiopods, crinoids, corals, bryozoans and foraminifers (described under section C of this paper).

Volkovitsjfjellet (Fig. 1B). The Tertiary strata at Volkovitsjfjellet consist of four formations: Firkanten, Basilika, Sarkofagen and Gilsonryggen. The rocks lie horizontally in the western part of Volkovitsjfjellet, but dip WSW 2–6° in the central and eastern parts of the mountain. The Lower Cretaceous Carolinefjellet Formation (*Ditrupa* beds) is exposed below the Firkanten Formation in the easternmost part of Volkovitsjfjellet.

The Sarkofagen Formation of Volkovitsjfjellet consists of medium to fine-grained homogenous, often glauconitic, sandstone, grey-green, grey or yellowish, often orange-red if weathered. The sandstone splits into irregular blocks or in slabs. Bedding is poor, and pronounced best in the lower part of the formation, where layers 0.5 to 1.5 m thick can be recognized. Small isolated concretions of clay-ironstone 1–3 cm in diameter, or clay-ironstone bands 5–10 cm thick, occur in the lower part of the formation. Scattered at random within the sandstone are quartz pebbles 0.5 to 2 cm in diameter. Sometimes they occur in greater number giving rise to thin conglomerate bands. On the ridge branching towards the east from point 714.3 a single pebble of silicified solitary Permian coral, *Caninophyllum* cf. *belcheri* (HARKER), has been found (see section C of this paper).

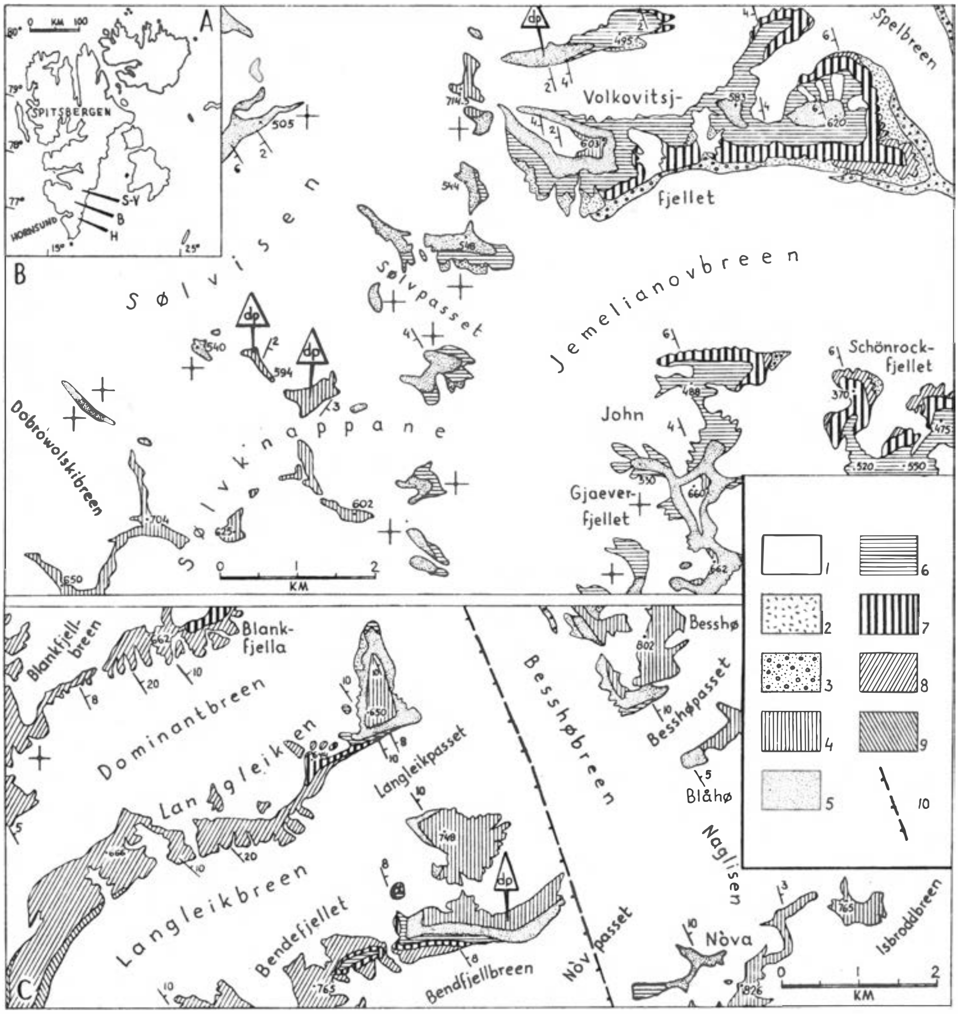


Fig. 1. A. *Key map to show the location of Lower Tertiary strata with drift pebbles. B – Bendefjellet; H – Hedgehogfjellet; S-V – Sølvknappane and Volkovitsjfjellet.* B. *Geological map of a part of NE Torell Land.* C. *Geological map of a part of central Torell Land.* 1 – *glacier;* 2 – *talus;* 3 – *moraine;* 4 – *Gilsonryggen Fm.;* 5 – *Sarkofagen Fm.;* 6 – *Basilika Fm.;* 7 – *Firkanten Fm.* (4–7 – *Lower Tertiary*); 8 – *Carolinefjellet Fm.* (*Aptian-Albian*); 9 – *Helvetiafjellet Fm.* (*Barremian*); 10 – *fault;* dp – *localities with drift pebbles.*

AGE AND PROVENANCE OF PEBBLES

The pebbles in question are scattered at random within the marine Tertiary strata at Bendefjellet, Sølvknappane and Volkovitsjfjellet. It can be assumed that these are drift pebbles carried to the place of their deposition by driftwood or by floating islets of tangled growth. Such an explanation has already been offered by BIRKENMAJER and NARĘBSKI (1963) for similar pebbles from the Gilsonryggen Formation at Hedgehogfjellet, Sørkapp Land. It should also be mentioned that rafting by kelp of Permian chert pebbles found in the marine Tertiary strata of Spitsbergen had been suggested already by NATHORST (1910).

Rhyolite porphyries. The rhyolite porphyries from Bendefjellet find their closest equivalents in intrusive quartz porphyries from the Kapp Hansteen Formation (Botniahalvøya Group, Precambrian) of the Hecla Hoek succession in Nordaustlandet. The petrographic characteristics given by SMULIKOWSKI (see section B of this paper) for the rhyolite porphyry pebbles from Bendefjellet, and by FLOOD (in FLOOD et al. 1969, pp. 57—61) for the Kapp Hansteen Formation porphyries from Botniahalvøya and Sabinebukta (Nordaustlandet) appear to be very similar.

Granites. The granite pebbles from Bendefjellet show very slight evidences of tectonic stress. This is evident from uniform or only slightly undulating light extinction in quartz (see section B of this paper). Taking this into consideration both the common and graphic granites could correspond to post-orogenic granites of Laponiahalvøya, Nordaustlandet, described by HJELLE (in FLOOD et al. 1969, pp. 121—128), and to batholitic and related granitic rocks of Ny Friesland and north-west Spitsbergen (see HARLAND 1961, Fig. 2; HJELLE 1966). The isotopic age determinations of granitic intrusions both in Spitsbergen and Nordaustlandet show a concentration of ages about 350—400 m. y. (see review by GEE – in FLOOD et al. 1969, p. 131 et seq.).

Vein quartz. The Hecla Hoek rocks in Spitsbergen are often crossed by ore-bearing quartz-, ankerite- and ankerite-quartz veins. The veins are cutting through most of the rocks from the Precambrian up to the Cambrian and Ordovician. Pebbles of vein quartz similar to that of the veins cutting through the Hecla Hoek rocks, have been reported from the Lower Devonian and younger sediments of the Hornsund area. Hence BIRKENMAJER and WOJCIECHOWSKI (1964) concluded that the veins are pre-Devonian and post-Hecla Hoek (post Lower Ordovician), probably Silurian in age, and regarded them as evidence of late orogenic meso-thermal activity of the main Caledonian orogeny in Svalbard. A similar view was also shared by FLOOD (1969) who assumed a pre-Devonian and post-Middle Ordovician age for most of the ore-bearing veins on a wide evidence from Spitsbergen and Bjørnøya.

The vein quartz pebbles found at all localities discussed could have derived either directly from the pre-Devonian veins or from vein quartz pebbles present as secondary deposit in the Devonian to Cretaceous rocks.

Quartzitic sandstone. The age of grey quartzitic sandstone found as pebbles at Sølvknappane and Bendefjellet is difficult to determine. Low grade of recrystallization of quartz grains and the presence of sporadic fragments of fine-grained siliceous rocks, and radially arranged chalcedony aggregates (see section B of this paper), would rather suggest a post-Hecla Hoek, either late Palaeozoic or even Mesozoic, age. Siliceous rock fragments found in the sandstone could eventually derive from Ordovician or Permian cherts, or from both.

Permian cherts. The only pebbles which contained fossils were Permian cherts. Their lithologic character is the same as that of the cherts from the Kapp Starostin Formation (Tempelfjorden Group), previously known as the brachiopod cherts, which represent Kungurian and Upper Permian (see CUTBILL & CHALLINOR 1965). The fossils determined by FEDOROWSKI (see section C of this paper) include the foraminifers *Pseudofusulina* sp., bryozoans *Fenestella* sp., *Goniocladia* sp. and

Rhabdomeson sp., and the rugose corals *Kleopatrina* (*Kleopatrina*) *magnifica* (Porfiriev) and *Caninophyllum* cf. *belcheri* (Harker). *Caninophyllum belcheri* has been reported from the upper part of the Treskelodden Formation (Lower Permian) at Hornsund (see Fedorowski 1965; Birkenmajer 1964). The latter formation at Hornsund or its equivalents elsewhere in Svalbard could have been the source for this coral pebble in the Sarkofagen Formation at Volkovitsjfjellet.

Dolerite. The diabase pebble described by Smulikowski (see section B of this paper) from Bendefjellet represents a white-trap dolerite variety of Tyrrell and Sandford (1933), resp. "diabase calcaire" of Backlund (1907). The white-trap variety of dolerite is widely distributed in the area between Storfjorden and Hinlopenstretet (eastern part of Svalbard). Pebbles of white-trap dolerite have been described from the Gilsonryggen Formation of NE Sørkapp Land (Hedgehogfjellet) by Birkenmajer and Narebski (1963).

The dolerite intrusions in Svalbard are the result of Upper Jurassic to Lower Cretaceous igneous activity (radiometric data given by Gayer et al. 1966). In the western part of Svalbard this activity was strongest at the boundary of the Upper Jurassic and Lower Cretaceous, but on Kong Karls Land (eastern Svalbard) the dolerites and associated basalts are younger, possibly Barremian (Parker 1966, 1967).

Table 2 shows stratigraphical distribution of drift pebbles within the Tertiary formations of Torell Land and Sørkapp Land.

Table 2

Age and distribution of drift pebbles within the Lower Tertiary of Torell Land and Sørkapp Land, Spitsbergen.

Formation	Locality	Rhyolite porphyries (Hecla Hoek, Precambrian)	Granites (late-Caledonian: post-Ordovician, but pre-Downtonian)	Vein quartz (late Caledonian)	Quartzitic sandstone (post-Caledonian)	Fossiliferous chert (Permian)	Dolerite, white trap variety (Upper Jurassic–Lower Cretaceous)
Gilsonryggen	Sølvknappane, NE Torell Land	—	—	+	+	+	—
	Bendefjellet, Central Torell Land	+	+	+	+	+	+
	Hedgehogfjellet, NE Sørkapp Land	—	—	+	+	+	+
Sarkofagen	Volkovitsjfjellet, NE Torell Land	—	—	+	—	+	—

PALAEOGEOGRAPHIC CONCLUSIONS

Fig. 2 shows the present distribution of Tertiary rocks, and possible extensions of Tertiary sedimentary basins in Svalbard. The suggested source areas of drift pebbles are shown for granites, porphyries and dolerites, and these indicate that the drift pebbles came mainly from the north or north-east. Other drift pebbles (vein quartz, quartzitic sandstone, Permian cherts) could have also derived from the north or north-east, but the western border of the main Tertiary basin could have also supplied them. The latter possibility is suggested by a solitary coral pebble (*Caninophyllum* cf. *belcheri*) possibly derived from the Treskelodden Formation of Hornsund.

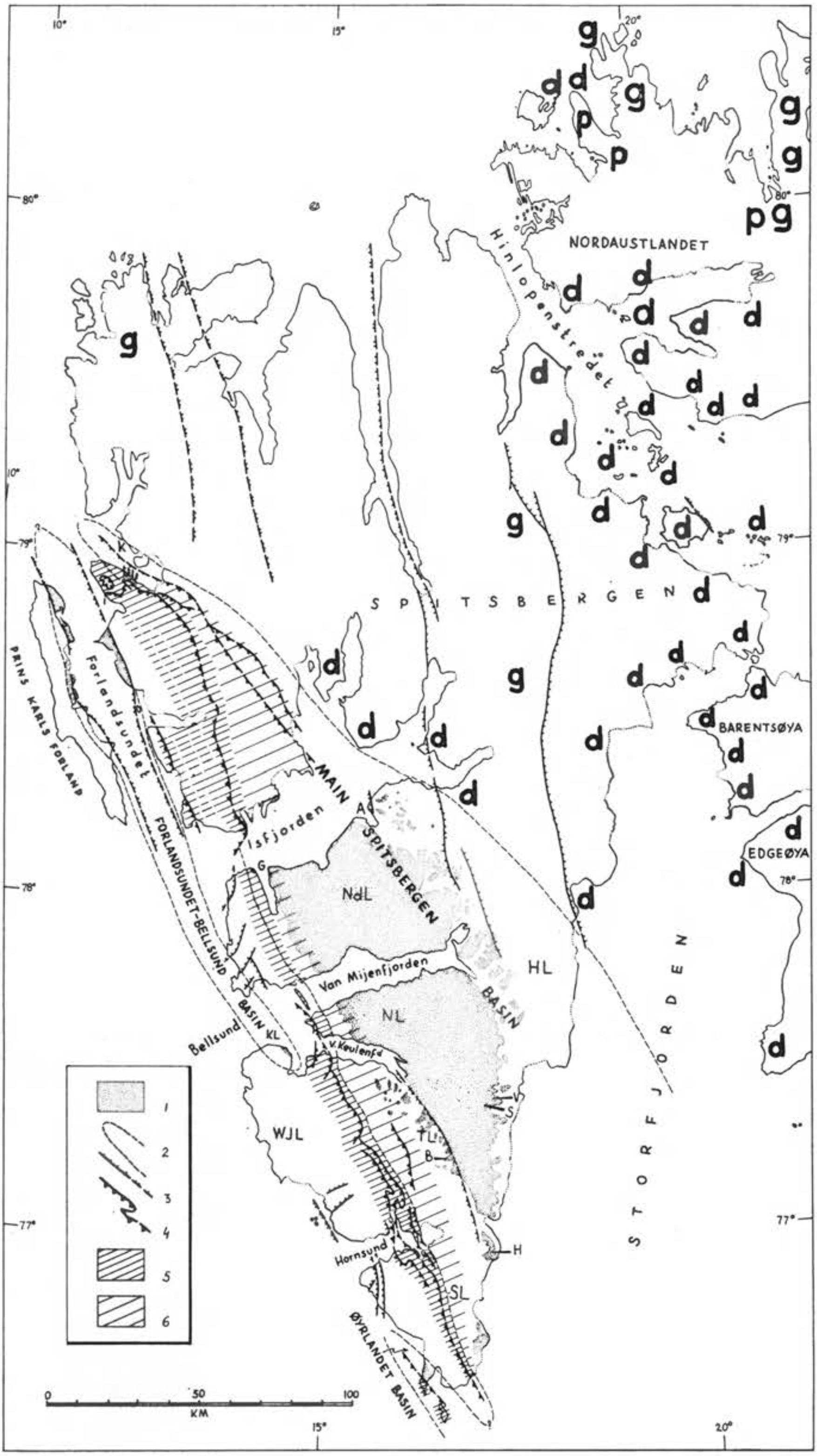
The drift pebbles appear already in the marine shale of the Basilika Formation, but become more and more common in the succeeding Sarkofagen and, especially, Gilsonryggen formations (see data in NATHORST 1910; ORVIN 1934, 1940; FREBOLD 1935, 1951; BIRKENMAJER & NARĘBSKI 1963). It seems that the major source of drift pebbles were river outlets and coastal beaches of a land mass which included the northern part of the Spitsbergen island, Nordaustlandet, and the islands to the east of Storfjorden – Barentsøya and Edgeøya. The total area of the Lower Tertiary sea in Svalbard would have been much smaller than that indicated by ORVIN (1940, Fig. 7) and VONDERBANK (1970, Fig. 31).

Fig. 2 shows a further attempt to reconstruct the distribution of Lower Tertiary sedimentary basins in Svalbard. The main basin extending from Kongsfjorden to Storfjorden was probably separated from a minor basin which extended from Forlandsundet to Bellsund. The position of Tertiary strata at Øyrlandet, Sørkapp Land, is less clear. It could be either a separate basin situated on the prolongation of the Forlandsundet–Bellsund basin, or a branch of the main Tertiary basin of Spitsbergen.

It should be added that the land comprising the northern and north-eastern parts of Svalbard, active as a source of clastics during the Lower Tertiary, had emerged from the sea already during the Lower Cretaceous (see BIRKENMAJER 1966, Fig. 6).

→

Fig. 2. *Relation of the Lower Tertiary basins to the zone of Alpine folding of Spitsbergen, and possible sources of drift pebbles. Tectonic features selected and reinterpreted from the data of* ORVIN (1934, 1940), DINELEY (1958), RÓŻYCKI (1959), HARLAND (1961, 1969), HJELLE (1962), *and of the present* author. 1 – *exposures of Lower Tertiary sediments (after* ORVIN 1940; RÓŻYCKI 1959; NAGY 1970, *and the present author)*; 2 – *possible maximum extensions of Lower Tertiary basins*; 3 – *normal faults (Tertiary)*; 4 – *overthrusts and reverse faults (Tertiary)*; 5 – *zone of intense tectonic deformations (Alpine fold belt)*; 6 – *zone of less intense tectonic deformations (foreland of the Alpine fold belt)*; d – *main outcrops of dolerite (Upper Jurassic – Lower Cretaceous)*; g – *main outcrops of post-orogenic (late-Caledonian) granite*; p – *main outcrops of intrusive porphyries (Precambrian)*; A – *Adventfjorden*; B – *Bendefjellet*; G – *Grønfjorden*; H – *Hedgehogfjellet*; HL – *Heer Land*; K – *Kongsfjorden*; KL – *Kapp Lyell*; NL – *Nathorst Land*; NdL – *Nordenskiöld Land*; S – *Sølvknappane*; SL – *Sørkapp Land*; TL – *Torell Land*; WJL – *Wedel Jarlsberg Land*.


NORDAUSTLANDET
Hinlopenstredet
SPITSBERGEN
PRINS KARLS FORLAND
Forlandsundet
FORLANDSUNDET-BELLSUND BASIN
MAIN SPITSBERGEN BASIN
Isfjorden
Van Mijenfjorden
Bellsund
Hornsund
ØYRLANDET BASIN
BARENTSØYA
EDGEØYA
STORFJORDEN
NdL
NL
HL
WJL
SL
KM

B. Petrographical part

BY

W. SMULIKOWSKI

The rocks described here are represented by 12 drift pebbles (Nos. 1—12) collected in 1966 by K. BIRKENMAJER from the marine Gilsonryggen Formation at Bendefjellet, Torell Land. Eight out of them are granites, of which three show micrographic textures (pebbles Nos. 1, 3, 12) while the rest are common granites (pebbles Nos. 2, 4, 6, 7, 10). Of the remaining pebbles, three are volcanic rocks: diabase (No .5) and rhyolite porphyry (Nos. 9 and 11), and one is quartz sandstone (No. 8). The petrographic characteristics presented below are based on microscopic examination of thin sections.

COMMON GRANITES

The common granites (Nos. 2, 4, 6, 7, 10) are grey, medium-grained rocks with grey quartz and black chloritized biotite plates uniformly distributed in white feldspar background. Single, larger feldspar phenocrysts up to 8×5 mm in diameter, may sometimes be found. Samples Nos. 6 and 10 show also the presence of fine-grained xenoliths, grey or with greenish tint, up to several centimetres in diameter. Sample No. 4 differs slightly from the others. This is a coarser-grained granite with light-olive plagioclase, with white or slightly pinkish potassium feldspars.

The texture is subhedral-granular due to plagioclases which usually form short laths and, to a lesser degree, to K-feldspar. The quartz is always anhedral. Grain size variable, some samples show also porphyritic texture. Grain size 0.5—1 mm in the matrix, up to several millimetres in diameter for quartz and feldspar phenocrysts. Mean grain diameter 1.5—2.5 mm for sample No. 4.

Qualitative and quantitative mineral composition is similar for all samples, the main differences amounting to the degree of albitization of K-feldspar.

The *quartz* forms amorphous grains of variable size, with uniform or slightly undulating light extinction. It often contains inclusions of small plagioclase laths, more seldom of K-feldspar. Quartz inclusions are absent in plagioclases, and sporadic in K-feldspars.

The *plagioclases* show a constant amount of 0—5% An in albite. Twinning is due to the Albite-, sometimes also the Karlsbad laws, sericitization and cloudiness are variable. Grain margins clean, showing the same mineral composition as the inner parts of the grains. Plates and laths devoid of inclusions are most common.

The *potassium-feldspars* are usually anhedral, the laths are less frequent. The Karlsbad twinning is often present. Various stages of replacing the potassium feldspar by very fine chess-board albite may be recognized in every sample. The albite of sample No. 2 forms rather fine perthite veinlets in K-feldspar. Rather thick perthite-veinlet meshwork, and grain margins replaced by chess-board albite, are visible in samples Nos. 4, 7 and 10. Here the K-feldspar grains are often entirely replaced by the chess-board albite. This is also the case with sample No. 6 where the K-feldspar has been completely transformed into fine chess-board albite.

The above phenomena indicate a secondary replacement of potassium feldspar with albite. A similar process was probably responsible for recrystallization and re-cleaning of grain margins from cloudiness. In the course of replacing the potassium feldspar with albite, a chess-board structure resulted, while the albite which recrystallized upon older albite grains – apparently under the same thermodynamic conditions – developed normal twinning.

The potassium feldspar never shows any distinct twinning meshwork so characteristic of microcline. The light extinction is usually uniform, slightly spotty light extinction is infrequent. The K-feldspar is usually free of pigmentation, but parts of chess-board albite are slightly brownish. Amorphous carbonate inclusions and, sometimes, aggregates of secondary clay minerals are rather frequent.

The dark mineral of the granites in question was the *biotite,* now replaced by light-green *chlorite* with subnormal blue tint. Relictic biotite fragments may sometimes be found within chlorite scales. These vary in size and usually contain frequent non-transparent Fe and Ti-oxides, and fine streaks of a Ti-mineral pigment produced from decomposition of biotite.

The post-biotite chlorite scales are the main source of *accessory minerals.* The zircon forms fine prisms always surrounded with pleochroic haloes. Fine grains of probably isotropic allanite are also present, anatase inclusions (usually automorphic) are comparatively frequent, while apatite is more seldom. Muscovite-flake inclusions often occur within the post-biotitic chlorite. Plagioclase (albite) inclusions may be recognized sometimes within the chlorite.

The *muscovite* occurs as small clusters and fine scales. This seems to be the result of secondary recrystallization of sericite. However in samples Nos. 2 and 6, where the muscovite occurs also as plates, it could be a primary component of the granite.

Xenoliths in granites. Sample No. 6 contains a roundish, grey, fine-grained xenolith, several centimetres in diameter, with white feldspar phenocrysts up to several millimetres in diameter (maximum 8×2 mm). A similar, but smaller, xenolith was found also in sample No. 10; its colouration is grey-green and it lacks phenocrysts.

The xenoliths consist of elongated albite prisms randomly distributed, the interstitia being filled with anhedral quartz (Fig. 3A). The phenocrysts are albite; K-feldspar and chess-board albite have not been found. The dark mineral, as in the surrounding granite, is represented by chlorite. In the xenolith from sample No. 6 this chlorite is certainly post-biotitic and shows an association of accessories similar to that of the granite. The xenolith from sample No. 10 shows longer albite prisms, while the chlorite, besides plates, forms also long thin needles. The latter could be a post-amphibole chlorite.

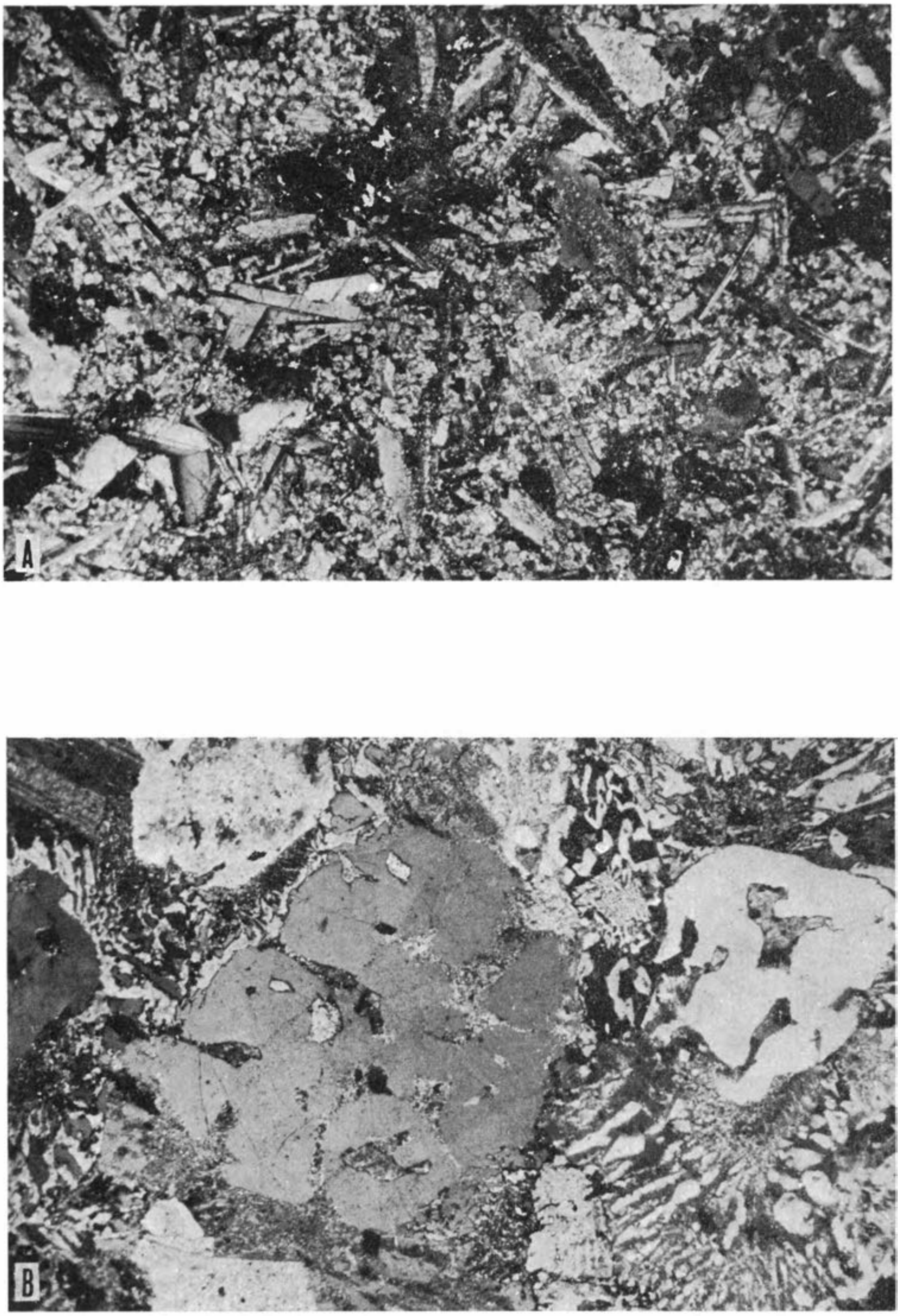


Fig. 3. A. *Xenolith in granite drift pebble (sample No. 6, Bendefjellet).* ×*c.* 30.
B. *Quartz grains with complex shapes in graphic granite drift pebble (sample No. 3, Bendefjellet).* ×*c.* 30.

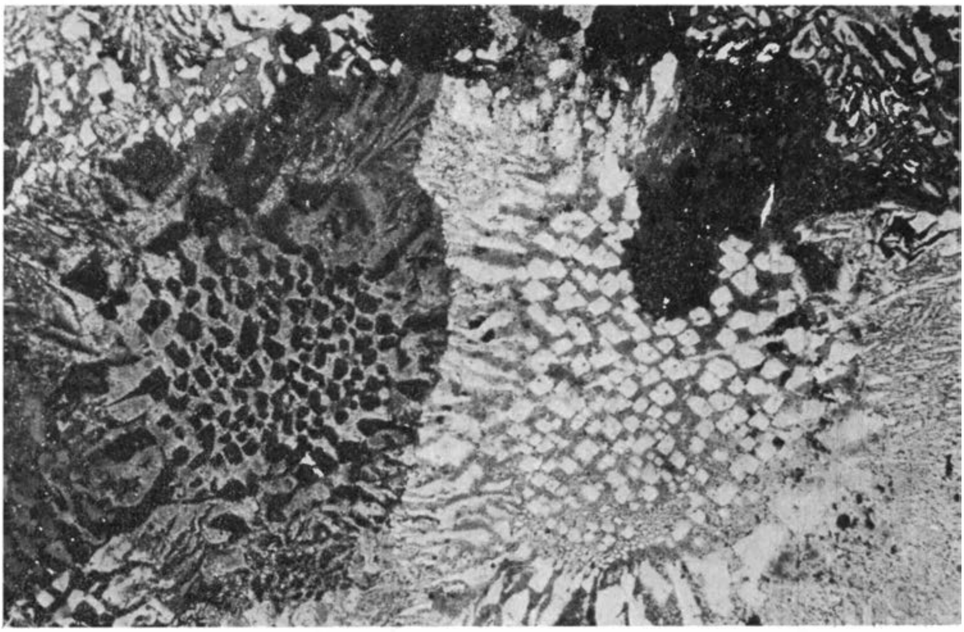


Fig. 4. *Micrographic intergrowths in granite drift pebble (sample No. 12, Bendefjellet).* × *c. 30.*

GRAPHIC GRANITES

The graphic granites (samples Nos. 1, 3, 12) are poor in dark minerals, their general appearance being spotty grey and pink. The rock consists mainly of quartz-feldspar intergrowths. The feldspar is albite with very fine chess-board twinning, with slightly brownish tint, analogous to that in the common granites. As in the case of common granites, this seems to be a secondary albite after potassium feldspar. The intergrowths are micrographic and usually concentric over plagioclase grains. The grain size of quartz and plagioclase is from 0.5 to 2 mm, up to 4 mm for quartz-plagioclase intergrowths (Fig. 4). The intergrowths are fine-grained in the inner, and become coarser and coarser-grained in the outer part of clusters. Both quartz and feldspar are crystallographically oriented with respect to each other, their grains being divided into irregular sectors. Chess-board albite devoid of quartz intergrowths is rather seldom.

The quartz may also occur as separate grains of variable size, sometimes roundish but usually digitated, with frequent embayments, always with extremely uniform light extinction (Fig. 3B). The plagioclase grains are often pericline twins corresponding to 0–5% An albite. Usually slightly sericitized, they contain sometimes irregular calcite inclusions. Chlorite aggregates associated with Fe-oxides and uncommon sericite, are extremely rare.

RHYOLITE PORPHYRY

These rocks are represented in the collection by two samples: the rhyolite porphyry (No. 11) and the albite-rich rhyolite porphyry (No. 9).

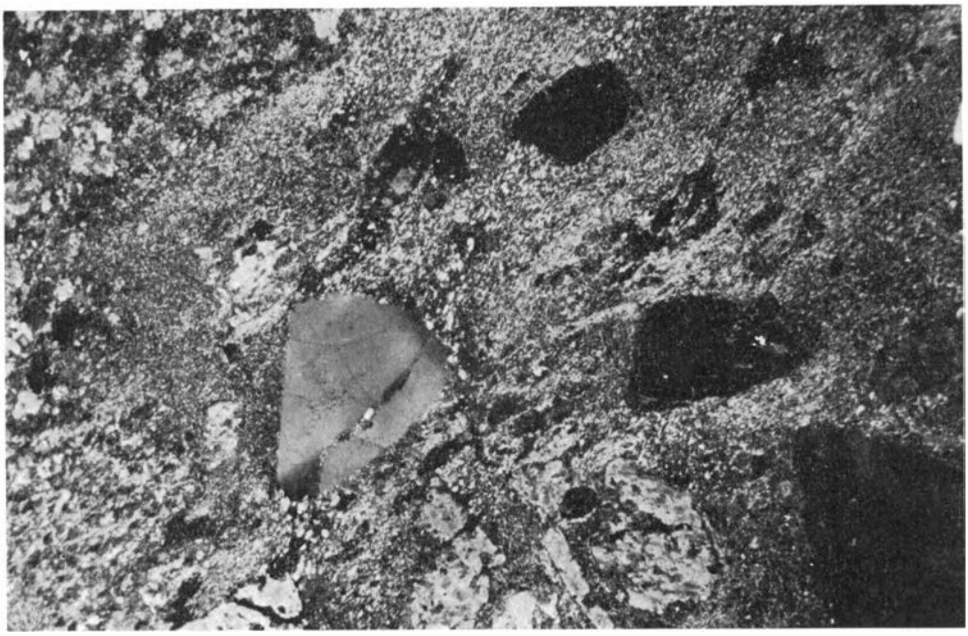


Fig. 5. *Rhyolite porphyry drift pebble (sample No. 11, Bendefjellet).* ×*c. 30.*

Rhyolite porphyry (sample No. 11). Roundish phenocrysts of quartz and white-pinkish, often euhedral feldspar, up to several millimetres in diameter, are visible against a dark-green aphanitic matrix (Fig. 5). The texture is typically porphyric, the structure shows slightly directional arrangement of phenocrysts, thus resembling fluidal structure. The matrix is either fine-grained, nearly submicroscopic, or slightly coarser-grained. It consists of quartz and albite, with a considerable admixture of fine sericite flakes. The latter show a preferred orientation. Some parts of the matrix display an advanced recrystallization.

The quartz is the most frequent among the phenocrysts. Its grains display a variety of shapes, from partly euhedral to digitated (embayed). Nearly as frequent are usually euhedral grains of potassium feldspar, most often replaced by chess-board albite. A part of the feldspar grains are entirely transformed, the rest show intergrowths of K-feldspar and chess-board albite in various amounts. Plagioclases are less frequent among the phenocrysts. They show a rather advanced sericitization and protoclasis. The composition of plagioclases, as determined on scarce twinning, corresponds to 0–3% An albite. Dark minerals are absent, save for scattered fine Fe-oxides. Small aggregates of light-brown to olive-green biotite associated with Fe-oxides are sporadically found. The accessories are represented by rather frequent zircon developed as automorphic prisms.

Albite-rich rhyolite porphyry (sample No. 9). This is a grey rock with uniform, medium-size grain (c. 1–2 mm in diameter), with dominant short-prismatic feldspars visible already to the naked eye. Irregular black spots are biotite clusters, the composition of the matrix can be recognized only under the microscope.

The microscopic examination reveals the presence of very distinct porphyric texture, with phenocrysts dominating over the matrix, without any preferred orientation. The majority of phenocrysts are roundish or amorphous albite grains (0–5% An) up to 2.5 mm in diameter. Euhedral albite is very seldom. Albite- and, rarely, Karlsbad-twins may be found. Sericitization is slight, zonal structure in albite is absent. Less frequent than the albite, but often larger (up to 3 mm in diameter), are quartz grains. They have a complex shape (as in sample No. 11) with frequent embayments, and show undulating light extinction. Potassium feldspar phenocrysts are extremely rare, exactly the same as in sample No. 11, nearly entirely albitized and replaced by chess-board albite. Protoclasis is a frequent phenomenon within the phenocrysts. The fine-grained matrix consists mainly of albite and quartz associated with fine sericite flakes.

Among the dark minerals, the biotite forms small irregular flakes single or in clusters, always associated with Fe-oxides. Euhedral small sphene grains with ilmenite rims are seldom met with.

The rock contains also an admixture of calcite, either as grains in albitized potassium feldspar or, sometimes, in the matrix. According to JOHANSEN's classification modified by K. SMULIKOWSKI (1934), which includes plagioclases containing less than 12.5% An to alkali plagioclases, the rock in question would correspond to an albite-rich rhyolite.

DIABASE (DOLERITE)

The diabase is represented only by sample No. 5. This is a grey, slightly greenish rock, with rusty Fe-hydroxide coating on the surface. The plagioclase laths up to 0.5 mm long are visible already to the naked eye. Under the microscope they are either distributed at random or arranged as if due to ophitic texture. They are devoid of sericite and show common Albite-, sometimes also Karlsbad- and Pericline-twinning. The inner parts of crystals correspond to 60% An, the outer parts to oligoclase. The interstices are filled with grey-brownish, fine-grained carbonate aggregates, in rare cases also with a light-green mineral resembling mica or talc.

Irregular grains with granophyric intergrowths of oligoclase and quartz are very infrequent. Single quartz grains are always very fine, irregular in shape, with normal light extinction. Accessories are represented by thin prisms of apatite and, often euhedral, ilmenite grains sometimes replaced in the inner part with sphene. Fe- and Ti-oxides may form irregular clusters. The rock corresponds to white traps (dolerites) from drift blocks of Sørkapp Land, as described by BIRKENMAJER and NARĘBSKI (1963).

SANDSTONE

This is a grey-yellowish, uniformly grained sandstone, as if quartzitic to the naked eye (sample No. 8). Under the microscope it shows equal quartz grains 0.1–0.3 mm in diameter, devoid of preferred orientation. Recrystallization of the quartz grains is a characteristic feature. Light extinction in quartz is slightly undulating or spotty. Regeneration rims are very frequent on quartz grains, their primary shapes showing a low grade of roundness. Weathered feldspars are infrequent as compared to quartz. Probably they belong both to plagioclase and potassium feldspar. Sporadic are fragments of fine-grained siliceous rocks and radially arranged aggregates of chalcedony. Small admixture of clay minerals (hydromicas and other clay minerals of low birefringence) occur between the grains. Rather frequent are small rounded zircon prisms and fine Fe-oxide minerals. Small roundish grains of olive-green tourmaline may sometimes be found.

C. Palaeontological part

BY

J. FEDOROWSKI

FAUNA FROM PERMIAN PEBBLES

Distribution

The fauna described here comes from five drift pebbles collected by K. BIRKENMAJER in 1966 from the marine Lower Tertiary (Sarkofagen Fm. and Gilsonryggen Fm.) of Torell Land.

Sølvknappane N: Three pebbles of Permian chert (specimens Nos. 13, 14, 15) from the Gilsonryggen Formation. Specimen No. 13 – *Kleopatrina* (*Kleopatrina*) *magnifica* (PORFIRIEV); specimen No. 14 – *Fenestella* sp. and *Rhabdomeson* sp.; specimen No. 15 – *Pseudofusulina* sp.

Sølvknappane E, above Jemelianovbreen: Pebble of Permian chert (specimen No. 16) from the Gilsonryggen Formation – *Goniocladia* sp.

Volkovitsjfjellet W (southern ridge between Volkovitsjfjellet and Spelen, above Spelbreen): Pebble of silicified solitary coral (specimen No. 17) from the Sarkofagen Formation – *Caninophyllum* cf. *belcheri* (HARKER).

More information on the geological position of these pebbles is given under section A of this paper.

Preservation

The fauna is rather poorly preserved, which makes it difficult to determine the species in the majority of cases. All specimens are silicified and, as a rule, fragmentary. The scanty material available did not make it possible to obtain enough properly oriented thin-sections of foraminifers and bryozoans; this had a bearing on the accuracy of palaeontological determination.

The bryozoans are represented only as small fragments of colonies insufficient for specific determination.

Age

The Foraminifera and Tetracoralla of the chert pebbles show rather Upper Sakmarian than Lower Artinskian affinities, but the latter age cannot be excluded.

The Bryozoa were too poorly preserved (due to silicification) and too scanty to allow specific determination. Stratigraphically they indicate the Palaeozoic (genus *Fenestella:* Ordovician to Permian) resp. Upper Palaeozoic (genera *Goniocladia* and *Rhabdomeson:* Carboniferous to Permian) ages.

SYSTEMATIC DESCRIPTION

Genus *Pseudofusulina* DUNBAR & SKINNER, 1931[1]

Pseudofusulina sp.
Pl. 1, fig. 1a, b

Locality. Sølvknappane N, Torell Land, Spitsbergen (sample No. 15).

Remarks. Pebble No. 15 contains several sections of pseudofusulinids. The structure of keriotheca and the number of volutions are not recognizable due to strong silicification. The length/width ratio of the illustrated specimen resembles that for the Sakmarian, rather than the Artinskian pseudofusulinids, the latter being more slender.

Genus *Caninophyllum* LEWIS, 1929

Caninophyllum cf. *belcheri* (HARKER)
Pl. 1, fig. 2

Locality. Volkovitsjfjellet W, Torell Land, Spitsbergen (sample No. 17).

Remarks. Specimen in pebble No. 17 shows similarities to *Caninophyllum belcheri* (HARKER) (see HARKER & THORSTEINSSON 1960). It has a similar diameter of tabularium (c. 3 cm), only slightly smaller number of the 1st-order septa (50), similar length of septa and the shape of cardinal fossula. Specific determination uncertain due to an almost complete destruction of dissepimentarium by silicification processes. Longitudinal section not investigated due to the lack of suitable material.

Genus *Kleopatrina* McCUTCHEON & WILSON, 1963

Kleopatrina (*Kleopatrina*) *magnifica* (PORFIRIEV)
Pl. 1, figs. 3a, b

1941 *Wentzelella magnifica* PORFIRIEV; PORFIRIEV, G. – In SOSHKINA et al., p. 265, Pl. 53, figs. 1a–c; Pl. 54, figs. 1a, b.

1967 *Kleopatrina* (*Kleopatrina*) *magnifica* (PORFIRIEV); FEDOROWSKI, J., p. 27, Pl. 5, figs. 1a, b (cum synon.).

Locality. Sølvknappane N, Torell Land, Spitsbergen (specimen No. 13).

Diagnosis. Consistent with PORFIRIEV's diagnosis of *Wentzelella magnifica* PORFIRIEV (in SOSHKINA et al. 1941, p. 199): "Cerioid coralla. Corallites 9–15 mm

[1] After restudy of the genotypus *Schwagerina princeps* MØLLER, 1822, by DUNBAR and SKINNER in 1936 it was discovered that the shell features were those for which DUNBAR and SKINNER had in 1931 proposed the name *Pseudofusulina*. Following the international rules of nomenclature, the name *Pseudofusulina* has by most authors been supressed as a synonym for *Schwagerina*. (Editor's note.)

Table 3
Comparison of Kleopatrina (Kleopatrina) magnifica (PORFIRIEV)

Specimen	Corallite diameter	Number of septa
Present specimen	up to 14.0×19.0 mm	up to 24×2
Holotype (after PORFIRIEV, in SOSHKINA et al. 1941)	up to 14.0×15.0 mm	up to 22×2
Specimens from Hornsund, Spitsbergen (after FEDOROWSKI 1965, 1967)	up to 14.0×19.0 mm	up to 21×2

in greatest diameter, with 15–22 major septa well developed, sometimes disconnected from epitheca. Minor septa short, sometimes lacking. Marginal vesicles rather regular, forming a wide ring. Tabulae in axial part arched, in periaxial part with tabellae. Epitheca continuous. The centre of the corallite occupied by a reticulate axial structure, consisting of median lamellae, axial ends of major septa, and tabellae; locally it is disappearing." New generic and subgeneric determination after MINATO and KATO (1965).

Remarks. The pebble No. 13 is a part of the completely silicified coral colony. The comparisons with other specimens of the species are shown in Table 3. Morphologically the present specimen is closer to other specimens from Spitsbergen than to the holotype. All the Spitsbergen specimens, the present one included, differ from the holotype in having well developed septa of the second order, which often reach the tabularium. Axial structure loose, simple, sometimes represented only by columella, and horizontal arrangement of tabulae devoid of differentiated axial zone (as seen on longitudinal section of the present specimen) are the features transitional between the holotype and the remaining Spitsbergen specimens. Our specimen shows also a slightly greater number of septa.

Occurrence. USSR (the Urals) – limestone with *Pseudofusulina princeps* (MÖLLER), Lower Permian. Spitsbergen (Hornsund) – Treskelodden Formation, upper member (Vth coral limestone horizon), Lower Permian.

Genus *Fenestella* LONSDALE, 1839

Fenestella sp.
Pl. 1, fig. 4

Locality. Sølvknappane N, Torell Land, Spitsbergen (specimen No. 14).

Remarks. The genus Fenestella is known to occur from the Ordovician to Permian inclusively.

Genus *Goniocladia* ETHERIDGE, 1876

Goniocladia sp.
Pl. 1, fig. 5

Locality. Sølvknappane E (above Jemelianovbreen), Torell Land, Spitsbergen (specimen No. 16).

Remarks. The genus *Goniocladia* is known to occur from the Carboniferous to Permian inclusively.

Genus *Rhabdomeson* YOUNG & YOUNG, 1874

Rhabdomeson sp.
Pl. 1, fig. 6

Locality. Sølvknappane N, Torell Land, Spitsbergen (specimen No. 14).

Remarks. The genus *Rhabdomeson* is known to occur from the Carboniferous to Permian inclusively.

Acknowledgements

K. BIRKENMAJER wishes to express his sincere gratitude to Norges Teknisk Naturvitenskapelige Forskningsråd (The Royal Norwegian Council for Scientific and Industrial Research, Oslo) whose post-doctoral fellowship enabled him to prepare his part of the paper while working at Norsk Polarinstitutt in Oslo. Dr. T. GJELSVIK, the Director, kindly made the facilities of the Institute readily available to him, for which he is most grateful.

For the generic determination of *Pseudofusulina* Dr. S. E. ROZOVSKAJA was consulted, for bryozoans Dr. J. P. MOROZOVA, both from the Institute of Palaeontology, USSR Academy of Sciences in Moscow. Their help is gratefully acknowledged here by J. Fedorowski.

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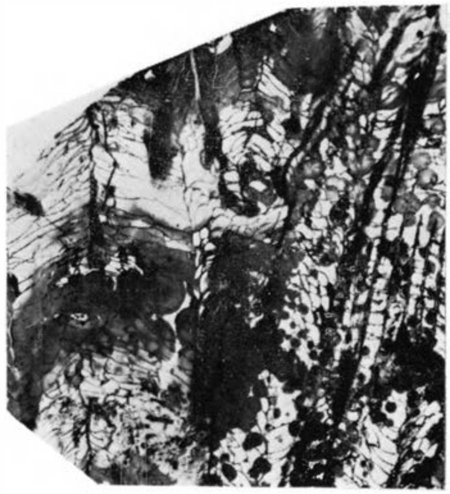

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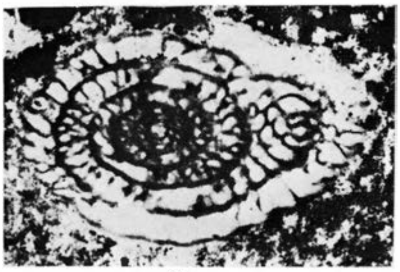

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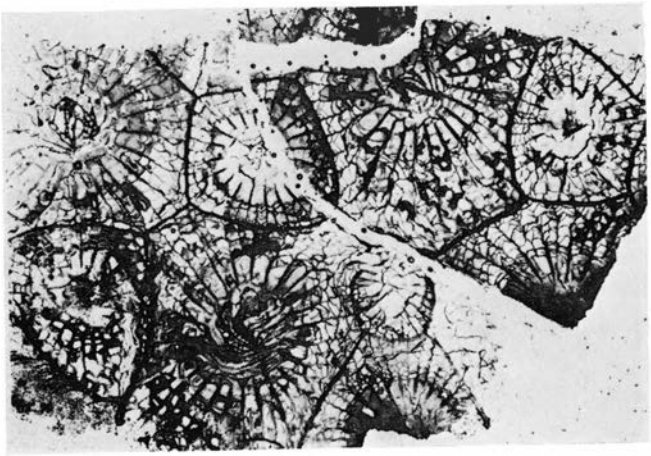

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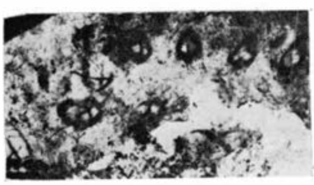

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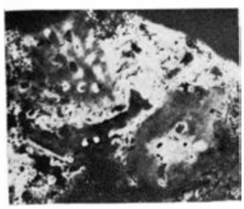

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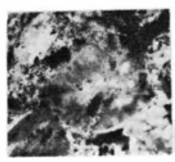

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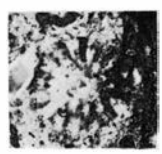

6

Fossils from the Permian drift pebbles in marine Tertiary of Torell Land, Spitsbergen.

(All specimens were collected by K. Birkenmajer and are in the Paleontologisk Museum, Sarsgate 1, Oslo 5, Norway)

Fig. 1. *Pseudofusulina* sp., PMO A32745 (pebble No. 15), Sølvknappane N. ×9. a – longitudinal section; b – oblique section of another specimen.

Fig. 2. *Caninophyllum* cf. *belcheri* (Harker), PMO A32749 (pebble No. 17), Volkovitsjfjellet W. ×2. Transversal section.

Fig. 3. *Kleopatrina* (*Kleopatrina*) *magnifica* (Porfiriev 1941), PMO A32746 (pebble No. 13), Sølvknappane N. ×2. a – transversal section; b – longitudinal section.

Fig. 4. *Fenestella* sp., PMO A32747 (pebble No. 14), Sølvknappane N. ×7. Transversal section of a colony.

Fig. 5. *Goniocladia* sp., PMO A32748 (pebble No. 16), Sølvknappane E. ×7. a, b – slightly oblique sections of three colonies.

Fig. 6. *Rhabdomeson* sp., PMO A32747 (pebble No. 14), Sølvknappane N. ×7. Transversal section of a colony.

Photo: Kazimierz Fryš (Palaeozoological Laboratory, Polish Academy of Sciences, Poznań).

Submarine moraines off the west coast of Spitsbergen

BY
OLAV LIESTØL

Abstract

Norsk Polarinstitutt's chart No. 521, covering the north-west coast of Spitsbergen, shows pronounced moraines outside Raudfjorden and Smeerenburgfjorden. Moraine ridges are also found at the mouth of Danskegattet and Kobbefjorden.

Detailed hydrographic mapping of the north-west coast of Spitsbergen has shown a bottom relief that can only be explained by the presence of moraine ridges. Fig. 1 presents a simplified chart of the bottom topography. The overdeepened fjord basins continue onto the continental shelf where they are limited by semi-circular shoals. Outside Smeerenburgfjorden the proximal side of the moraines is rather steep and rises from a depth of c. 110 m to less than 20 m within 1 km. In contrast to the sharp and rugged coast of the north-west corner of Spitsbergen, the surface of shoals representing the moraines is smooth, indicating abraded soft material. The chart also indicates sand bottom in this area. Three ridges are indicated in Fig. 1. The features are rather vague with small height differences and could also be explained as submarine bars on a sandur or delta plain formed during the eustatic rise of the sea. Outside Raudfjorden and Magdalenefjorden the glacial troughs eroded in the shelf are quite pronounced but the moraines are not so clear as outside Smeerenburgfjorden.

The glacier stream forming the moraines off Smeerenburgfjorden also had overflows to the west in Danskegattet between Amsterdamøya and Danskøya, and to Kobbefjorden. The maximum extension of these glacier tongues is marked by arch-formed submarine moraines at the mouth of the fjords. These pronounced moraines should provide an excellent opportunity to calculate the corresponding ice expansion on land at places where traces of glacial features from this stage could be found. However, neither investigations in the field nor air-photo examination give any indication of ice marginal features. Fig. 2 is a rough sketch of the presumed extent of the ice corresponding to the described moraines. Boulders from the granitic batholith in the northern part of Haakon VII Land are only found south of Kobbefjorden on Danskøya. This indicates that the glacier tongues described here were fed mainly from an icefield covering Vasahalvøya and not

Fig. 1. *Bathymetric map of the north-west coast of Spitsbergen. Moraine ridges are indicated by dotted lines. Depth in metres.*

from the firn area of the present glacier, Smeerenburgbreen, or from a larger ice-field further inland.

The other large, glacial troughs in the shelf outside the fjords of Spitsbergen have no typical end moraines connected to them. A probable explanation is that the glacier tongues extended outside the shelf edge and became floating. However, the bottom topography on both sides of the trough off Kongsfjorden and Woodfjorden indicates side moraines.

Similar features have been described outside the coast of Finnmark in North-Norway by O. Holtedahl (1930). He explains the ridges as morainic accumulation left by a foreland glacier tongue. He also points out that the ridges are broken. In his opinion the gaps have been eroded by running water cutting through the

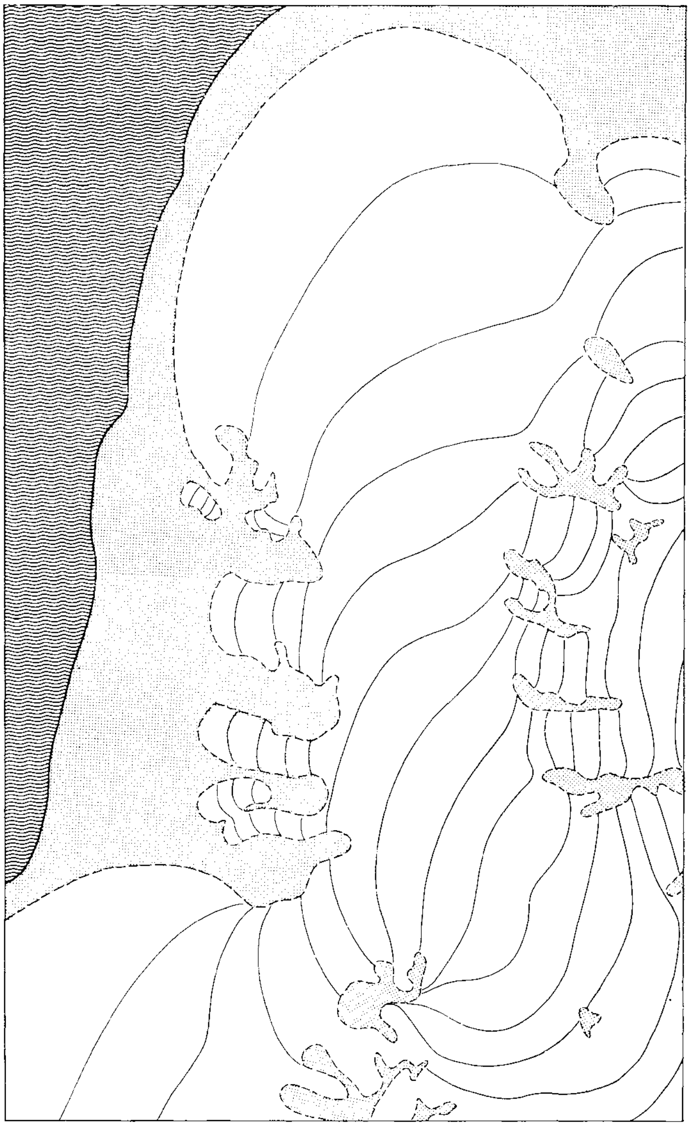

Fig. 2. *A reconstruction of the glacier condition at the time when the old moraines were deposited. Contour lines indicate roughly the topography of the glaciers.*

moraines after the retreat of the glaciers. This means that the sea level was at least 100 m lower than today. In the moraines descıibed in the present paper small depressions are also found, but they are not of such a marked character that they could be explained as river channels. The shoals outside Smeerenburgfjorden have a top level of 15—20 m over large areas. This might be a result of sea abrasion during the rise of sea level. It might also be explained as part of a sandur plane formed in front of the glacier in a corresponding sea level. This does not fit with the assumption that the moraines were formed during the Würm maximum; one should then expect a much lower sea level as the isostatic depression in this peripheric area is small.

The age of the moraines can only be guessed. No relation to raised beaches or other means of dating have been found. The huge accumulation indicates that the moraines are of Würm age and probably represent its maximum stage. The area lies near to the shelf edge and far from the centre of the Würm inland ice cap. High mountains also prevent the ice from the inland area to overflow this part. If the moraines represent the Würm maximum, this also means that there have been relatively large ice-free areas here as indicated on Fig. 2.

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Rayleigh wave dispersion and crustal structure: The Norwegian Sea and adjacent areas

BY

EIVIND RYGG[1]

Contents

Abstract

Rayleigh waves from earthquakes in the Norwegian Sea and adjacent areas have been used for studying the crustal structures between the events and the standard seismograph stations Kevo and Kirkenes.

The suboceanic crust along the Norwegian Sea wavepaths extends to about 15–20 km depth. At greater depths higher velocity (mantle) material is required to explain the high velocities for waves with periods greater than 20 sec. For the Continental Shelf north of Norway the data indicate average sediment thickness of 2–3 km. The latter figures are found assuming crustal velocities typical for northern Scandinavia for these areas.

Introduction

In addition to the longitudinal (P) and transversal (S) waves travelling through the interior of the earth, an earthquake record generally shows later arriving trains of long period waves. These are the surface waves propagating along the surface of the earth and very frequently they are the most dominant features on the seismograms (Fig. 1). According to their particle motion the surface waves are divided in two main classes: the vertically polarized Rayleigh waves and the horizontal,

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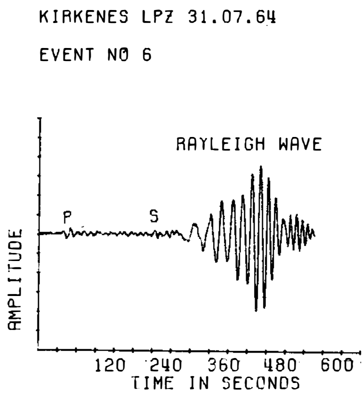

Fig. 1. *An example of a long period seismogram.*

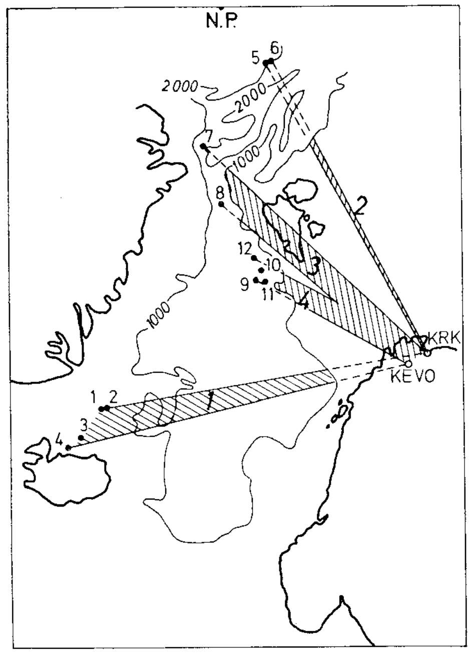

Fig. 2. *Map of the areas investigated showing the locations of the events and stations used. Depth curves are given in fathoms.*

transversal Love waves. Under the conditions in the solid earth, both wavetypes are dispersive, that is: the velocity of propagation depends on the frequency, resulting in extended trains of waves. The degree of dispersion and consequently the shape of the wavetrain depends on the structure and composition of the areas the waves are traversing. Thus the surface waves become an efficient tool for studying average structures in the earth's crust and the upper mantle. In this paper Rayleigh waves recorded at Kevo and Kirkenes are used for studying the layering of the earth under the Norwegian Sea and adjacent areas (Fig. 2).

Methods

With a very crude approximation to the earth — vacuum over a solid elastic half space — it can be shown that vertically polarized plane waves can propagate along the free surface in such a manner that the amplitude decreases with increasing depth (BULLEN 1959). The waves are non-dispersive with elliptical retrograde particle motion.

Surface waves can also be shown to exist in more realistic earth models with one or more homogeneous, isotropic layers over the half space, but these waves are dispersive (EWING, JARDETZKY and PRESS 1957). Consequently the velocity becomes a function of the period. This function can be evaluated by considering plane waves of the Rayleigh type propagating in an earth model represented by homogeneous, isotropic layers over a semi-infinite medium (half space). The layer parameters are: the P-wave velocity (α), the S wave velocity (β), the thickness of the layer (H) and the density (ρ). The surface wave equation for this medium is solved by using the continuity of stresses and displacements across the interfaces.

HASKELL (1953) formulated the dispersion equation in terms of matrices. In matrix notation the dispersion function can be programmed for a digital computer and the relation between velocity and period for various models can be calculated numerically. A convenient way of representing the relationship is by plotting the velocity versus period, thus giving the theoretical dispersion curves. Once a curve is obtained, it can be compared with the corresponding experimental curves as deduced from seismograms.

The experimental dispersion curves are deduced by the standard method of EWING and PRESS (1952). Arrival times of successive crests/troughs on the seismogram are plotted versus crest/trough number and the resulting points are approximated by a smooth curve. It is readily visualized that the tangent to any point on the smoothed curve thus gives the period to the wave arriving at the point of tangening.

Identification of the Rayleigh waves can be done by studying the particle motion. Fig. 3 shows an example of the KEVO long period seismograms of event No. 7. The motion to the north suffers a lag of about $\pi/2$ relative to the vertical motion, quite in accordance with the theory for Rayleigh waves. This picture also demonstrates the relation between the vertical and horizontal amplitude. For Rayleigh waves in a homogeneous medium this ratio should be 3/2 according to theory.

The records contain information about the average dispersive effects of the entire path which the waves have traversed. In many cases, however, the great circle paths between the epicenters and the stations cross areas with widely differing structures. Consequently one has to correct for the dispersion suffered in specific parts of the path in order to get the structure of the remaining part. In this paper such corrections are made partly by using empirical dispersion results and partly by calculating dispersion curves for models that are estimated on the basis of earlier seismological evidence.

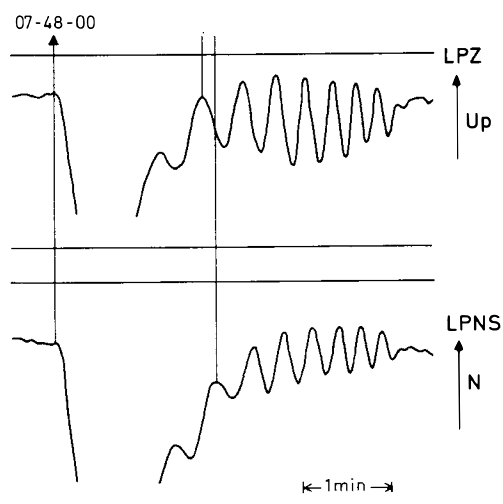

Fig. 3. *Two components of the Kevo recording of event No. 7.*

Data and results

Fig. 2 shows a map of the areas, the stations and the locations of the earthquakes used in this study. The events and the areas are equipped with numbers which will be used in the following. Details of the events are given in Table 1. The epicenters and origin times given by the U. S. Coast and Geodetic Survey have been used.

Area 1

Initially it was intended to test the existence and the extension and depth of a layer with P-wave velocity averaging about 7.5 km/sec as reported for the Norwegian Sea and the Mid-Atlantic Ridge by several authors (EWING and EWING 1959, TRYGVASON 1961, BÅTH 1962). The four events used were located on the Mid-Atlantic Ridge north of Iceland (Fig. 2) at shallow or moderate depths, as normal for earthquakes on submarine ridges. Fig. 4 shows the experimental results and some of the theoretical group velocity curves calculated for the area. The layer parameters are given to the right, and as in the following figures an example of the ocean bottom profile is included. The continental correction for the eastern part of the paths has been made using the dispersion curve for NOR 11 (Fig. 5). This model neglects possible sedimentary layers on the Continental Shelf, since only half of the path to correct for is sea-covered. The shallow areas between Iceland and Jan Mayen are not corrected for, since it is assumed that the structure here resembles the structure under the Norwegian Sea.

The hypothesis that the 7.5 km/sec layer be very thick is not supported by the data (NOR 1). Increasing the velocity in the second solid layer within acceptable limits did not change this picture substantially, neither did reasonable changes in the thickness of the sedimentary layer. Consequently, a half space with higher velocity is necessary to get accordance between the dispersion data

Table 1
List of events

Event No.	Origin time		Epicenter		Depth	Magnitude	
1	15.01.63	01:32:20.0	68.9N	17.1W	33	5	Area 1
2	15.01.63	05:23:10.4	69.0N	16.6W	33	5–5 ¼	Area 1
3	15.10.63	09:59:30.1	67.2N	18.4W	33	5.2	Area 1
4	11.07.64	17:44:29.8	66.4N	19.7W	19	4.9	Area 1
5	31.07.64	21:22:24.3	86.4N	38.5E	33	4.9	Area 2
6	31.07.64	23:45:55.2	86.4N	40.5E	10	5.3	Area 2
7	04.03.63	07:41:51.0	82.9N	7.7W	33	5 ¼	Area 3
8	02.12.63	20:55:58.8	80.1N	0.6W	33	5.1	Area 3
9	13.08.63	13:28:02.2	76.2N	6.4E	33	4.7	Area 4
10	20.09.63	03:03:32.9	76.5N	7.9E	33	4.7	Area 4
11	13.05.64	03:19:43.2	76.0N	8.2E	33	4.5	Area 4
12	04.12.64	07:43:47.0	77.3N	6.4E	33	4.9	Area 4

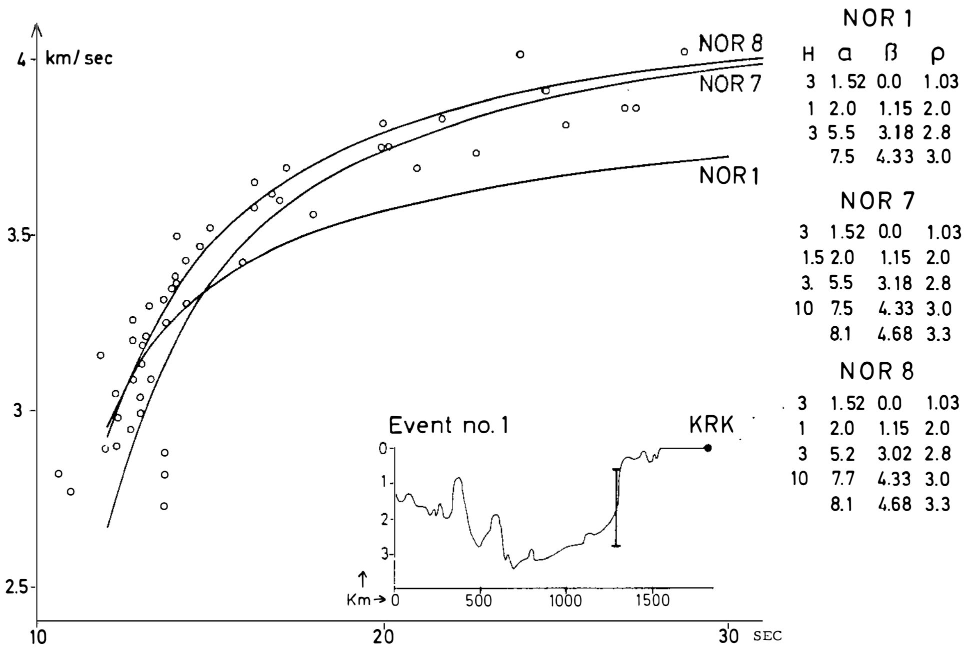

Fig. 4. *Dispersion results for Area 1. For this and the remaining figures: The layer parameters in the theoretical models are: H (depth in km) α (P-wave velocity in km/s), β (S-wave velocity in km/s), ρ (density). The vertical bars on the ocean bottom profiles indicate where the transitions from oceanic to continental crust have been set.*

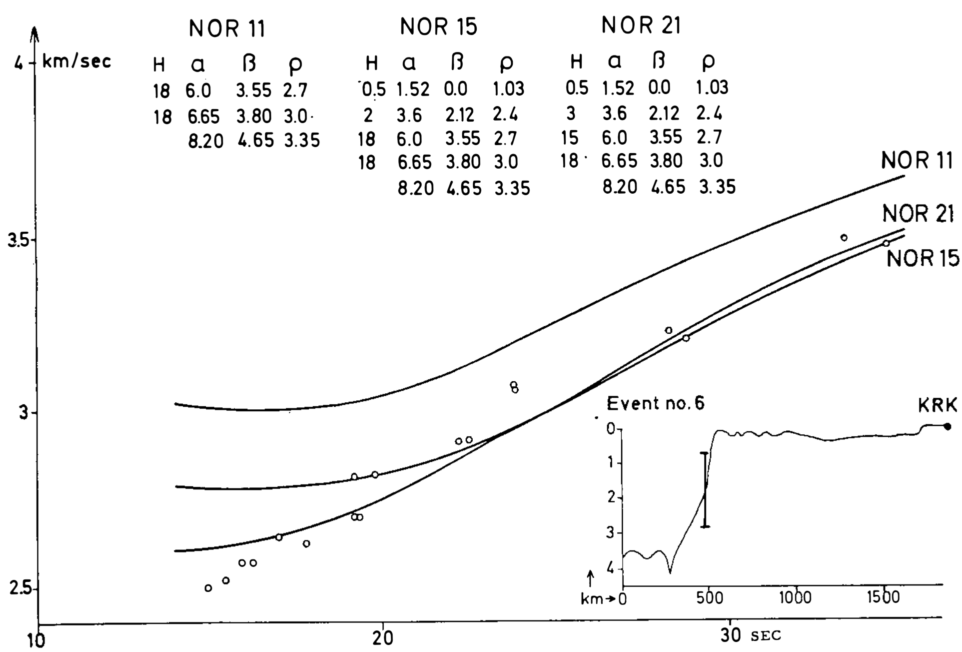

Fig. 5. *Dispersion results for Area 2.*

and earlier results. The composition of the two remaining models, NOR 7 and NOR 8, is based on the assumption that the 7.5 km/sec layer belongs to the crust, or is a mixture of material from the crust and the mantle. Also, in NOR 7 the thickness of the sedimentary material is increased to 1.5 km, thus the model approaches to the results given by BÅTH and VOGEL (1958) for nearly the same area. In all models the first layer includes the water depth and unconsolidated sediments, 2.5 + 0.5 km. In NOR 8 the velocity of the upper layer in the oceanic crust has been changed to $\alpha = 5.2$ km/s, $\beta = 3.02$ km/s (EWING and EWING 1959). The resulting dispersion curve shows good agreement with the experimental results over the entire range of periods covered. It may be mentioned that the two models NOR 7 and NOR 8 are preferred to other "well fitting" models because of better accordance with earlier investigations. The effect of neglecting sedimentary layers in the continental correction model is a decrease in the experimental group velocities, particularly for the shortest periods.

Area 2

The oceanic correction has been made using a model with 13 km crust of about the same structure as was found for the Norwegian Sea. The deeper structures in this area are poorly known and the starting model NOR 11 in Fig. 5 has been chosen in accordance with earlier investigations in Northern Scandinavia (SELLEVOLL and PENTTILA 1964, PORKKA 1966).

The theoretical group velocity curve can be lowered in different ways, i.e. by decreasing the velocities or thickening the crust, but geological conditions and earlier investigations suggest introducing sedimentary layers on top of the crust (NOR 15, NOR 21) (COLLETTE 1958, HOLTEDAHL 1960). Consolidated sediments have also been reported further to the west on the Continental Shelf between Norway and Svalbard (EWING and EWING 1959).

We notice that for waves with periods less than 20 sec the observed group velocities are lower than what is predicted by the theoretical curves, even when the sedimentary layer is 3 km as in NOR 21. In this area the great circle paths between the epicenters and the stations cross the transmission zone between the deep ocean and the Continental Shelf at nearly 90 degrees, and there is no geological evidence for substantial, lateral structural variations. Furthermore, only the first well defined wavepacket of the recordings has been used, thus excluding waves resulting from possible lateral refraction and multipath propagation.

The average value obtained for the sedimentary thickness of course does not apply to the entire wavepath. For example, in the southern part (on land) there are no sediments, and this is also the case at some distance from the coast. On the other hand one may have areas with sedimentary thickness exceeding 3 km. Basins of thick sedimentary layers would largely affect the shorter waves, and the low group velocities of waves with periods less than 20 sec may indicate such concentrations.

Also, semi-consolidated, tertiary sediments (not included in the theoretical models) would have the same effect on the group velocities.

Still, to get a reasonable fit between the theoretical curves and the experimental data it seems to be necessary to introduce a layer of consolidated sediments exceeding 2 km and perhaps closer to 3 km on the average. With the crustal models used, a depth to the Moho of at least 35 km results for the area.

Areas 3 and 4

After studying the experimental group velocities from events in the northern Norwegian Sea it was decided to separate the north-western wavepaths into the areas 3 and 4, and the results for these areas are shown in Figs. 6 and 7. The group velocities for area 3 exceed those found for area 2, and the crustal thickness of the theoretical model has to be reduced if we still use the continental crustal structure. Most likely, part of the increase in the group velocities is due to transition to a more oceanic crust to the north-west of area 3. However, for sake of comparison, and since we are in lack of data for the deeper structures in this area, we have chosen to vary only layer thicknesses of the crustal models already adapted.

Except for the Kirkenes recording of event No. 8, the low group velocities for shorter periods are not found. With the reservation mentioned concerning the varying structure along the wavepaths in mind, the results indicate a structure between the two models NOR 16 and NOR 17 (Fig. 6). This gives 30 km to Moho for the entire area and if we for the southern part adapt the crustal thickness that was found for area 2, a thinning of the crust to the north-west results.

The results for area 4 are shown in Fig. 7. We found no systematic difference between the various wavepaths within the area or between the results from the two stations. As for area 3, we have used a continental model of the crust, although it must be clear that large fractions of the wavepaths are in the transition zone between continental and oceanic crustal structure. It seems, however, that the average crustal and/or sediment thickness for this area exceeds the values found for area 3. The southern parts of the areas 3 and 4 cover nearly the same area, and again this corroborates the thinning of the crust to the north-west as it was found for area 3. The low group velocities for periods less than 17 sec may be caused by lateral refraction, or possibly semi-consolidated sediments on the Continental Shelf.

Conclusive comments

As mentioned above, the group velocity dispersion method is used to estimate average structures only. The theoretical models used in this paper do not contain finer details. For example, except for the unconsolidated sediments included in the water layer, the sedimentary cover has everywhere been reduced to one layer. The idea has been not to allow for finer details in the models than provided by the resolution power of the method.

The existence of a low velocity channel in the upper mantel is well established on most places (DORMAN et al. 1960, GUTENBERG 1959). As demonstrated by DORMAN and PRENTISS (1960), the assumption of a homogeneous mantle may lead to estimates of the crustal thicknesses which are too small by the order of 10%. The reason for not including low velocity layers in our models is first of all the

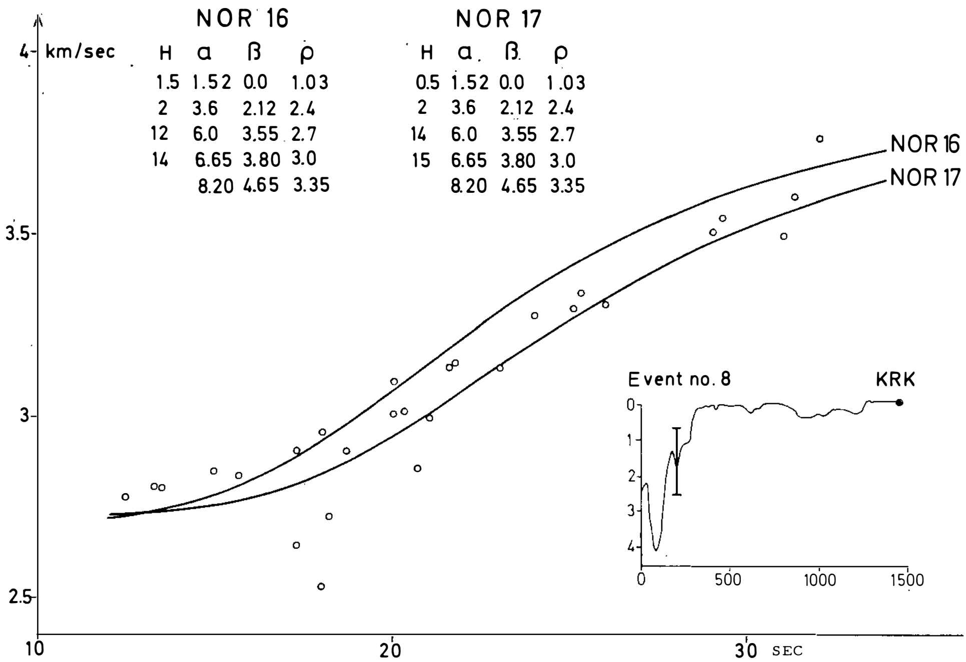

Fig. 6. *Dispersion results for Area 3.*

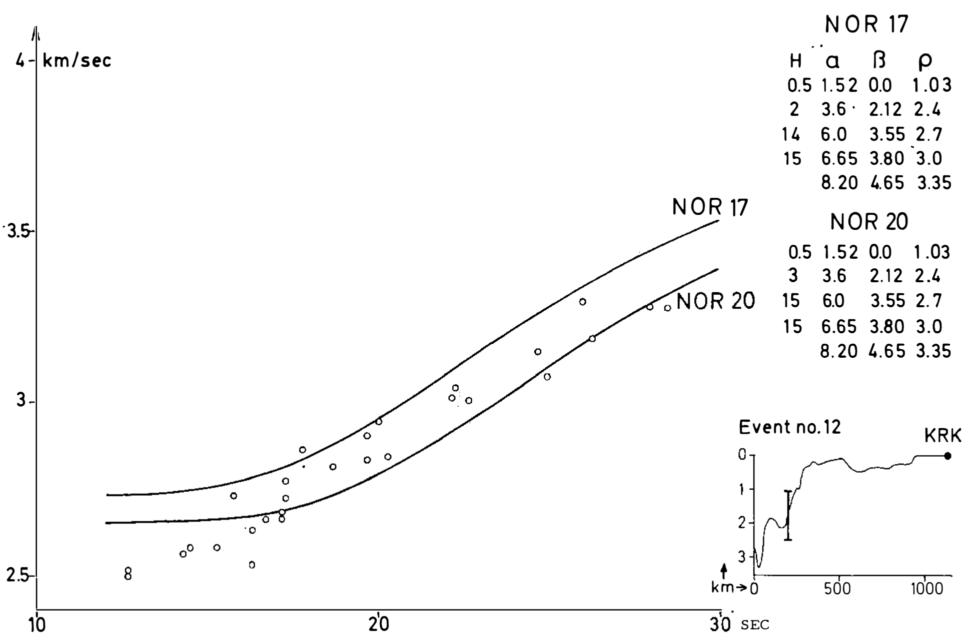

Fig. 7. *Dispersion results for Area 4.*

poor knowledge of the deeper structures in the areas studied. Besides, the shorter the waves, the less the influence of the deeper layers. In our case, with periods between 10 and 35 sec the propagation is largely governed by the elastic constants in the crust and upper layers and the velocity contrast at the Mohorovicic discontinuity.

Acknowledgement

The author is indebted to Dr. JAMES DORMAN who gave permission to use his surface wave dispersion program PV 7.

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Bones of Bison from Ajon island.
Finds from Amundsen's Expedition in 1918-20

(Кости бизона с остова Айон)

BY

ULRIK MØHL[1]

Contents

Abstract

Limb bones of a subfossil bison brought home from Amundsen's expedition (1918–20) from the North-Siberian island Ajon are discussed. A survey of the evolution of the bisons in Pleistocene and Holocene is given. The climatic fluctuations' influence on the biotopes: steppe contra mountainous areas is considered in relation to the migrations and extinction of the bisons. Increase of weight of the bones found in the surface layers, subfossil bones from arctic areas are discussed. The Ajon bison's relation to other bovines is shown in tables and plates, similarities in morphology and biotope are touched upon. Agreement in characters of the Ajon bison with recent American bisons is stated.

Introduction

In the collection of The Paleontological Museum in Oslo are some large bones of fossil mammals, found by Amundsen during the famous voyage with the "Maud" along the northern shore of Siberia, 1918–20.

Before giving a detailed account of the bones it is perhaps useful to say something about the primary and secondary appearance of this find.

In the autumn of 1919 (23rd September) the "Maud" reached the Ajon island, and here entered the ice off the west coast in order to overwinter here.

The Ajon island is situated off the north coast of eastern Siberia at 70°N and between 168° and 169°E, at the entrance of Tsjaunbukten (Fig. 1). The island is

[1] Zool. Mus. Univ. Copenh.

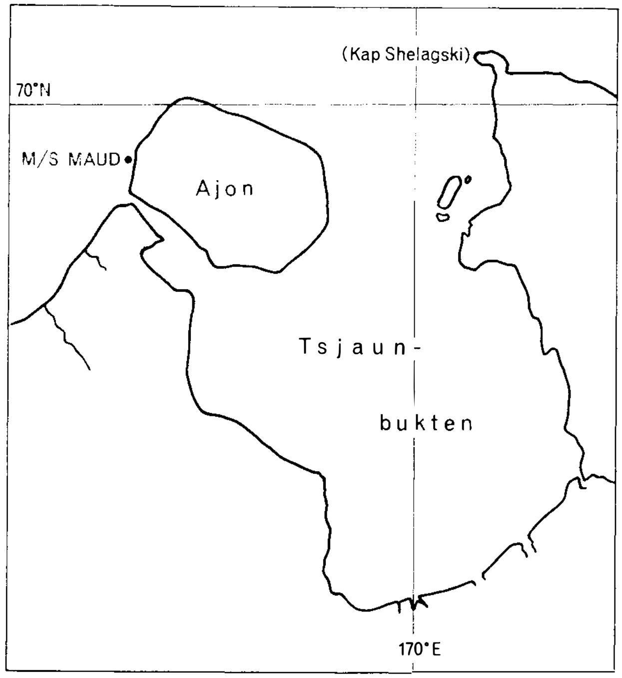

Fig. 1. *The Ajon island and its nearest surroundings (after part of Amundsen's map).*

50×30 km across, and according to AMUNDSEN (1921, p. 215), a plateauland. A few bones were found on the low slopes on the east side of the island. Certain data in Amundsen's book "Nordøstpassagen" may be connected with these finds and should therefore be cited here: "10th November (1919). Yesterday Wisting found a heavy mammoth bone, which was sticking out of one of the steep slopes on the island. There are more bones in the same place, but we cannot dig there until spring." And later: "27th November. One of the Russians who was with us told, that the bone which Wisting found here had not belonged to a mammoth, as we believed, but to a giant ox which occurred simultaneously with the mammoth." On 28th December Amundsen wrote: "Today Rønne and Sundbeck during a trip ashore found several bones of the afore-mentioned prehistoric ox." As a vague geological greeting could finally be stated on 7th April: "...At 2 p.m. –16°C. There is no more snow drifting, but sand. The wind is scattering the sand dunes, throwing them over the ice. No wonder there is shallow water round this island."

This scanty information is all that Amundsen writes in his diary about the primary finds on Ajon. Since then the material has been kept at the museum in Oslo, with the inscription on the bones: Bison. Ajon (68°52′). East side of the island. R. Amundsen exp.

The so-called "secondary" appearance is based upon a find from 1968 in a gravel-pit at Kvam in Gudbrandsdalen, southern Norway, where a fragment of a smaller but rather heavy bone was discovered (HEINTZ 1969a, pp. 337–342; 1969b, pp. 437–438). This piece agreed so well with one of the bones from Ajon that it could also be supposed to derive from a bison.

Prof. Heintz knew that certain bison finds from the interglacial period (DEGER-

BØL 1945) were kept at the Zool. Mus. of Copenhagen together with other material for comparison. He therefore sent the bone from Kvam to Copenhagen, and it proved to be part of the diaphysis of the left *ulna* of a small juvenile mammoth (the corresponding bone fragment from Ajon, which was sent later, proved to be almost identical with the fragment from Kvam, and thus also was a part of the left *ulna* of a juvenile mammoth).

Since we have single interglacial finds of bison from different gravel-pits in Denmark kept at the Copenhagen Museum, I was anxious to see the other bones from Ajon in order to compare them with these.

With his usual courtesy Prof. Heintz sent me the find. An investigation of the bones showed that the bison finds consisted of nine rather well preserved limb bones and seven fragments of ribs. In addition to the already mentioned juvenile *ulna*, there was a piece of a rib (*costa*) from a mammoth, and a fragment of a small reindeer's antler.

Of this material only the bison bones will be discussed in the following. By way of orientation as to the background at the Ajon find, some reflections on the origin, distribution, and races of bison in the later and last part of the Quaternary Period in Europe, Asia, and America are here discussed. These views are on all essential points extracts from C. C. Flerow's treatment of this subject in the chapter "On the Origin of the Mammalian Fauna of Canada" (FLEROW 1967, pp. 271–280) in "The Bering Land Bridge" (HOPKINS 1967).

The earliest stages of the history of the bison are still obscure, but there can be no doubt of its Asiatic origin. The hitherto oldest finds derive from Late Pliocene (SIWALIK) deposits in India, from where *Bison sivalensis* (FALCONER) derives. In addition, the form *Bison palaeosinensis* (CHARDIN and PIVETEAU) is known from China in deposits with the Nihowan fauna (which corresponds to the European Villafranchium stage or Tegelen interglacial).

From the Riss-Ice Age we have the oldest finds of bisons in Europe, which no doubt immigrated from Asia. The long-horned steppe bison, *Bison priscus crassicornis* (RICHARDSONI) in the same period migrated from Asia to America across the Bering Bridge and, thus appeared throughout Europe, Asia, and North America.

During the Riss-period the southern part of the American population was separated from the northern stock by the advancing inland ice. In the U.S.A. of today the bison developed into the giant form *Bison latifrons* (HARLAN); from this, *Bison alleni* (MARCH) evolved, which later on, during the Würm-glaciation, changed into the steppe bison, *Bison bison antiquus* (LEIDY), from which the recent plain bison, *Bison bison bison* (LINNAEUS) derives.

Bison priscus crassicornis remained in its northern area of distribution, Alaska and Siberia, during a considerable part of Late Pleistocene; but towards the end of the Würm-glaciation this bison gradually decreased in size; the long-horned *B. priscus crassicornis* changed into a more short-horned form, *Bison priscus priscus* (BOJANUS).

During the Würm-glaciation the bison had a very extensive continuous distribution throughout the greater part of the northern subarctic area of the globe (Europe, Asia, and America); this area however rapidly decreased – from a geological point of view – towards the end of the Würm-glaciation, as the changed climatic conditions restricted the grazing areas of the bison. When the ice melted, other, more northern areas gradually arose in parts of Europe, eastern Siberia, Alaska, Canada, and the U.S.A.

These populations which were separated from each other, developed differently due to isolation under different conditions of life, into forms as *Bison bonasus* in Europe, *Bison priscus athabascae* in East-Siberia, Alaska and Canada, and, as mentioned above, into *Bison bison bison* in the U.S.A.

The European bison is further divided into certain geographical races, which are however without interest in this connection. (As to the interpretation of these races and their origin, opinion differs (KURTÉN 1968, p. 186). On the other hand, a certain significance is attached to the above-mentioned very small, short-horned, endemic race of *Bison priscus*, mentioned by FLEROW (1967, p. 278) which lived in the extreme northern areas of eastern Siberia isolated from the rest of its area by mountain ranges. This race occurred in the lowland areas near the Arctic Ocean, round the rivers Lena, Indigirka and Kolyma. It became extinct during the warm maximum of the Postglacial period.

As to bison forms in the Ajon area, it can briefly be said that from Mid-Pleistocene up to the end of the Würm-glaciation we had the long-horned *B. priscus crassicornis*, which from the end of the Würm-glaciation and into the Post-glacial period changed into the short-horned, smaller *B. priscus athabascae*, which – as mentioned by FLEROW – had local races.

The Ajon island consists of quaternary melt-water-sediments resting on post-orogenic basin deposits of Upper Mesozoic and Lower Kaenozoic ages, deposited between a Triassic-Jurassic range of fold-mountains (to the north and the west) and an alpine (Tertiary) range of fold-mountains (to the south and the east).

Ajon was not always an island. During the Riss and Würm-glaciation the north coast of Siberia was situated several hundred kilometres north of the present Ajon (due to the great quantities of water which were bound in the permanent ice). This extensive area was a subarctic steppe with tundra vegetation (FRENZEL 1968, Pls. 9–10.)

After the Würm-glaciation the sea transgressed the area; Ajon became a flat island with low slopes hollowed by the sea, and here some of the bones were found.

The area seems to contain several remains of more or less scattered skeletons. An indication of this is the reference to gifts or exchange of mammoth teeth etc. among the local population and the crew of the "Maud".

Without having a closer knowledge of the Ajon island and its sediments (i. e. that large animals may have perished locally and remained within the area) it seems more probable that the above-mentioned Bison carcass may have been transported by water for shorter or longer distances, before it was finally deposited in the sediments of the island. It is therefore not certain that this bison lived and died on the present Ajon island.

As mentioned above, Amundsen states that one of the bones "stuck out from the steep slopes of the island"; judging from their appearance, however, these bones look as if they had been found at the surface: they are white, cracked, hard, rather heavy, and nearly resonant, as is often the case with fossil bones. They are very similar to the bones which are found at the surface in dry arctic regions.

Such finds, e.g. from North Greenland, are surprisingly heavy, so heavy that there is no doubt that their weight has increased considerably. This phenomenon may be explained by the fact that bones lying at the surface in areas where the precipitation is minimal and the evaporation great, do not lose weight because the inorganic substances are not washed out. On the other hand, they will accumulate the substances contained in the percolating water which by capillary action rises from the substratum. This increase in weight is particularly noticeable in whale bones, particularly in the vertebrae, as the spongy tissue here gives an enormous internal surface for depositing the substances dissolved in the water.

It can be mentioned that a subfossil whale bone (a caudal vertebra of a young baleen whale) found in 1964 on the beach at Cap Tobin, NE Greenland (70°25′N), weighed 2020 g, while a corresponding recent vertebra (degreased and of equal size and ontogenetic age) weighs only 740 g. The subfossil vertebra thus weighs almost three times as much as the recent one.

This is so striking that a more exact investigation is called for, in order to supplement the hypothetical reflections mentioned above.

The bison bones from Ajon are not exactly dated geologically (apart from the fact that they were found in quaternary melt water deposits); it must be admitted that an identification to one of the above-mentioned races is not possible at present, since these races are based on skulls or parts of these. Whole skeletons occur very rarely in which the proportions between the skull and the postcranial parts can be compared and be of guidance in analysing the numerous finds of single bones.

It is tempting to consider the small endemic form of *Bison priscus*, which lived postglacially in these regions; this, however, is doubted by Flerow as seen from what is said below.

From an extract of a correspondence between prof. Heintz and prof. Flerow regarding the Ajon find, I have permission to quote the following: "I (Flerow) possess a good collection of skulls from NE Siberia and skulls of a "Wood Bison" (*Bison bison athabascae*; the recent Canadian wood bison). In addition, I possess a fairly complete skeleton of "Wood Bison". I was therefore fully convinced that the recent "Wood Bison", according to its morphological characters, is identical with *B. priscus* which lived in East Siberia, it is however clearly distinguished from "Plain Bison" (*B. bison bison*) and from *B. bonasus*.

I have therefore called this form *B. priscus athabascae*. The recent "Wood Bison" is, however, considerably larger, judging from its metacarpalia, than your bison from Ajon.

Unfortunately, I have not yet received a satisfactory skeleton material of the small form which I described from Upper Pleistocene from NE Siberia (from the Würm-Wiscontian period). I only possess skulls, I am however convinced that the metacarpalia which Amundsen found, do not belong to this endemic race. Amundsen's find is most probably remains of the last *B. priscus* which lived in NE Siberia till the middle of Holocene. We have remains of such small "degenerated" specimens in our collections".

Later on, as a comment on a drawing with measurements of the mentioned metacarpus, I received the following communication from prof. Flerow: "As far as I remember, the appearance of the metacarpus from Ajon, of which you sent me a drawing, shows that this bone belonged to an adult male (♂). I find that it is not particularly large as compared with the last bisons which we have found in NE Siberia."

If Flerow is right in his supposition, the bones from Ajon indicate a final phase in the Asiatic history of the bison which closely corresponds to the conditions in Greenland, where both muskox and reindeer, during climatically adverse periods, show a decrease in the size of individuals. Prior to the extinction of the species small-sized individuals are of such common occurrence that the form could rightly be designated as a "kummerform".

When the bison from Ajon and adjacent areas became extinct during the warm maximum of the Postglacial period (which lasted more than 4000–5000 years, but within this interval had several smaller fluctuations), the cause probably is that unstable weather conditions set in during climatic changes which, among other things, also involved a rapid change between warm and cold periods; these result in a recurrent freezing over of the coastal areas, which may easily have fatal consequences for the grass-eating animals.

Under the extreme conditions of life, prevailing in Siberia as well as on the NE coast of Greenland, to which these large hoofed animals are exposed, even a small change in the climatic conditions may cause a deterioration of the biotope to such an extent that they will decrease in size, and, in the case of extremely unfavourable conditions, will perish – if an emigration to regions with better conditions of life is not possible. This happened to the East Greenland reindeer just before 1900; this year was a climatic threshold to a warmer period.

Also the opposite change, the transition from a warmer to a colder period, creates unstable climatic conditions. It seems probable that the extinction of the bison in NE Siberia is due to such a transition period within the warm maximum of the Postglacial period.

The bones

Plates I–II show the total find of bison bones in the correct mutual relation of their dimensions. The measurements of the respective bones are found in Tables 1 and 2.

A34226. *Scapula*, dextra, somewhat fragmented, upper margin and central part of the upper half part are weathered away, like *spina scapulae*, and the outer layer of *proc. coracoides* is missing. The *fossa articularis* measures 80 mm × 66 mm in diameter, and the width of the *collum scapulae* (ant.-post) is 86 mm.

This bone shows such a pronounced difference in the degree of weathering of the two sides that there can be no doubt that it was found at the surface. The outer side which was turned upwards is strongly weathered and cracked. It has been exposed to direct sun, frost, rain, and drying by the wind (Fig. 2A), while the inner side (the lower side) has a smooth surface, having been protected from the influence of the weather by resting in the ground (Fig. 2B).

The *humerus*, sinistra, is rather weathered and cracked. The surface of the

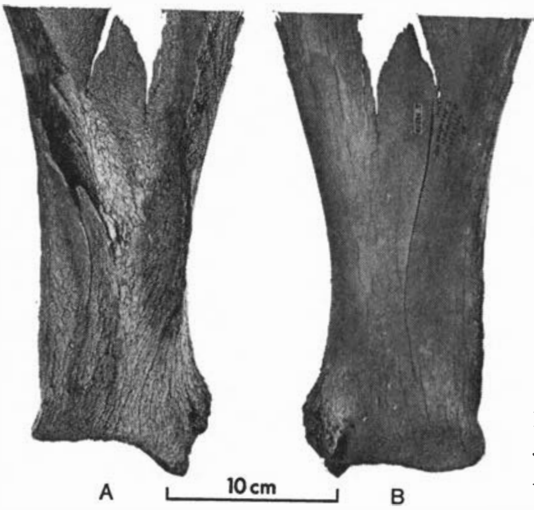

Fig. 2. *Bison, Ajon. Lower part of the* s c a p u l a. *A – the "upper side", B – the well preserved "under side".*

Table 1

	B. priscus Ajon	*B. Bison b.* CN1396
Humerus		
Greatest length	(420)	405
Length, cap. humeri-cond. medialis	355	345
Prox. breadth, transversal	131+ ?	135
— — ant.-post.	130	145
Least breadth of diaphysis, transv.	57	53
Dist. breath, transv.	99	91
— — ant.-post.	59	57
Radius		
Greatest length	366	351
Prox. breath, transv,	102	105
— — ant.-post.	51	52
Middle breadth, transv.	58	58
— — ant.-post.	35	36
Dist. breadth, transv.	95	95
— — ant.-post.	58	58
Femur		
Length, cap. femoris-cond. tibialis	448	413
Prox. breadth, transv.	(150)+ ?	155
Middle breadth, ant.-post.	58	58
Distal breadth, transv. (greatest)	113	120
Tibia		
Greatest length	443	420
Length of outside	395	375
Prox. breadth, transv.	122	126
— — ant.-post.	110	115
Middle breath, transv.	55	58
Distal breath, transv.	80	75
— — ant.-post.	56	55

upper end is so damaged that the interior spongy tissue is laid bare, the upper end of the *trochanter major* is missing, and therefore the greatest length of this bone cannot be measured exactly. Apart from this and the cracks supposedly due to desiccation (which here as in the other bones appear to be primary – not secondary) – by being kept in the museum, the bone is intact.

A33327. The *radius* sinistra, rather well preserved, however, shows considerable ruptures due to desiccation. At the lower end the ossification zone is discernible between the diaphysis and the epiphysis, and thereby indicates the ontogenetic age of this bone. It is stated that the lower epiphysis of the radius in recent oxen grows until an age of $3^1/_2$–4 years; this growth occurs simultaneously with the ossification of the upper epiphysis of the *humerus* and the *ulna*, the lower epiphysis of the femura and the upper epiphysis of the *tibia* (Cornwall 1956, p. 229). The stage of the fusion of the epiphyses with the diaphysis is the same for the Ajon bones and is so advanced that the longitudinal growth can be regarded as terminated; the ontogenetic age can therefore be estimated at about four years.

A34227. The *ulna*, sinistra, cracked and weathered. The articulation surfaces fit exactly into the above-mentioned *radius*, and the ossification zone of the upper epiphysis is distinct.

The *metacarpus*, sinistra, is very well preserved (apart from small cracks due to desiccation), and it is one of the most important bones of the find, since – more than the other bones – it gives information on sex, habits and conditions of life during growth, see later.

A34224–5. The *femura*, dextra and sinistra; both bones are on the whole intact, apart from weathering and single deep cracks in the diaphysis. At the upper end the *trochanter major* is weathered away in both femura. These bones too have an ontogenetic age corresponding to that of the other ones; the lower ossification zone of the epiphyses is distinct.

A34223. The *tibia*, sinistra is intact, apart from weathering, and cracks which caused that a piece of the caudal side of the diaphysis is missing. The ossification zone of the upper end is distinct.

A34228. The *calcaneus*, dextra, intact, crumbly and cracked. Greatest length: 171 mm.

Costae:

A34230. c. no. 11, sinistra, middle part, length 450 mm (straight line).

A34231, c. no. 3, dextra, middle part, outer side, length 325 mm. Outer side (situated on the ground, the upper side) cracked and weathered, inner side (lower side) markedly better preserved, almost without cracks.

A34232, c. no. 2, sinistra, middle part, length 325 mm, cracked and weathered; in this state of preservation no distinct difference between the two sides.

A34233, c. no. 4, dextra, middle part, split longitudinally, hindmost part preserved, length 305 mm. Outer side cracked and weathered, inner side smooth and well preserved.

A34234, c. no. 3, sinistra, upper part, split longitudinally (anterior and inner side) length 230 mm, outer side cracked and weathered, inner side well preserved, smooth.

Without number, c. no. 6, sinistra, upper part without upper end, length 134 mm, outer side cracked and weathered, inner side well preserved, smooth.

Without number, lower part without lower end, length 165 mm (cannot be placed to number or side), outer side well preserved, inner side cracked and weathered.

A common feature found in all the bones is that everything tends to show that they belonged to the same individual; both colour, state of preservation and their common dimensions agree. There is nothing in the constellation of the bones which indicates more than one individual; the most essential point is however that the bones are of the same ontogenetical age (about four years).

The difference in the degree of weathering of the "upper- and underside" of several of the bones indicates that most of them have been lying on the surface of the ground (when they were found), however, the skeleton may originally have been lying in situ, more or less buried in a deposit which in the course of the years, by wind erosion etc. has subsided to such an extent that some bones have been exposed (cf. Amundsen's remark about sand drifting from the surface of this island).

If we take it for granted that the bones derive from the same individual it is tempting – and justified – to calculate a shoulder height for the Ajon bison on the basis of the length of the limb bones supported by a recent skeleton of a Plain Bison, *Bison bison bison* ♂ (CN1396) which as a well-known "type" has also been used for comparison in the tables of the measurements. The length of the long bones indicates that the Ajon bison was somewhat taller than the recent Plain Bison, although many measurements are surprisingly concordant. Judging from its skeleton, the Plain Bison had a shoulder height of 187 cm. The Ajon bison presumably measured 190 cm or slightly more. Judging from the measurements of the single bones, it is in particular the hindquarters which were higher in the Ajon ox. The *femur* and the *tibia* together are longer by almost 6 cm, while the forelimb (the *humerus*, the *radius*, and the *metacarpus*) is only 3–4 cm longer than in the Plain Bison. Thus it can be imagined that the Ajon bison is a slightly larger, more long-legged, ox than the Plain Bison. In its proportions presumably intermediate between the Plain Bison and the Canadian wood bison (*Bison bison athabascae*).

Of the single limb bones only the *metacarpus* should be further discussed; its exact and relative measurements are compared with those of other bovine species in Table 2; its great conformity with the recent American Plain Bison is striking, and stands out clearly, among other things by the full agreement of the breadth-length index. The same column of measurements (8, D.E.) reveals the sexual dimorphism of the Plain Bison bone, features which could reasonably be applied to the Ajon bison.

Plate III shows a number of *metacarpi* of different bison oxen compared to the *metacarpus* of aurochs (No. 1) in order to give an idea of sizes and proportions. The *metacarpus* of the subfossil (preboreal) aurochs is so to say identical with that of the interglacial steppe bison (No. 2) (apart from certain morphological characters at the upper end, which are not visible in the figure). The *metacarpus*

Table 2

Metacarpus	Great. length	Measurements of breadth: Proximal Transv.	Proximal Ant.-post.	Middle Transv.	Middle Ant.-post.	Distal Transv.	Distal Ant.-post.	Relative measurements: No.4×100 / No.1	No.5×100 / No.1	No.6×100 / No.1	No.7×100 / No.1
	1	2	3	4	5	6	7	8	9	10	11
A *Bison priscus (♂)* Ajon, N. E. Siberia 1919 (Oslo)	209	82	47	55	29	83	41	26.3	13.8	39.2	19.6
B *Bison priscus* Kolding, Denmark 1950 (interglacial)	248	88	51	51	34	86	45	20.5	13.2	34.5	18.1
C *Bison bison athabascae* ♀ Alberta, Canada 1928 (Ottawa CN10405)	208	67	41	37	26.5	83	41	17.8	12.7	39.9	19.7
D *Bison bison bison* ♀ ad. Alberta, Canada 1926 (Ottawa CN6009)	197	65	38.5	36.5	24	64	35.5	18.5	12.1	32.4	18.0
E *Bison bison bison* ♂ ad. Zoo. Gard., Københ. 1926 (CN1396)	205	78	45	54	27	76	40	26.3	13.1	37.6	19.5
F *Bison bonasus* ♂ ad. Zoo. Gard,. Københ. 1961 (CN3378)	209	73	42	41	24	71	39	19.1	11.4	34.4	13.8
G *Bos primigenius* ♂ ad. Grænge, Lolland 1942 (Praeboreal, Z.IV)	251	87	50	51	34	87	46	20.3	13.1	34.6	18.3
H *Bos grunniens* ♂ ad. Zoo. Gard., Københ. 1902 (CN866)	151	(70)	(43)	47	24	67	37	31.1	15.2	44.3	24.5
I *Ovibos moschatus* ♂ ad. N, E. Greenland 1956 (CN3036)	153	52	35	35	18	62	32	22.8	11.7	40.4	20.9

of the Ajon bison (No. 3) and that of the recent Plain Bison (No. 4) correspondingly agree, as mentioned above.

A short, broad metacarpus is generally regarded as an adaptation to the life in mountain regions. If the metacarpus of aurochs and that of the steppe bison are compared with that of the two postglacial bisons, it is the difference in length which is noticeable; this leads to the hypothesis that the "short-legged" bison in NE Siberia as well as in America has undergone a long evolution in mountain regions.

Such a type of landscape, with its more or less "vertical" forms, may in several ways neutralize the climatic influence, or rather it implies so varying ecologic conditions that there are several chances of survival in periods with a changing climate than in the extensive "horizontal" steppes where periods of drought have fatal consequences for the whole vegetation and thereby for the animals subsisting on it.

On the other hand, in favourable periods with optimal conditions for the vegetation, the steppe offers much better possibilities than the mountainous regions.

It is thought that climatically unfavourable conditions are responsible for the extinction of the long-legged and long-horned steppe bisons which were distributed over vast areas, while the remote populations in the mountainous regions – the smaller and short-horned forms – subsisted.

The *metacarpus* from Ajon is short. Flerow writes in his correspondence, quoted above, that it is considerably smaller than that of the recent Canadian wood bisons (these are larger than the Plain bison), and that he "has some remains of similar small "degenerated" specimens in the collections." It is important that the word "degenerated" is placed within inverted commas; it is true that this bone is short, but its relative measurements, notably the breadth of the middle of the bone in relation to the length (Plate IIA), indicates a vigorous animal which had favourable food conditions during growth. Conversely, unfavourable conditions in this period would have resulted in a more hourglass-shaped metacarpus with a slender diaphysis (small middle breadth) in relation to the upper and lower ends.

Such bones are well-known from our prehistoric – often underfed – domestic oxen, while the well fed cattle of our days again have obtained the bone shape natural for oxen. It can be mentioned by way of an example that a metacarpus of a cow of red Danish dairy breed fully agrees in its proportions with the metacarpus of a cow of aurochs (Møhl 1957, p. 309).

Apart from the fact that the greater or smaller relative breadth of the diaphysis gives some indication of the conditions of life during growth, it also indicates a sexual dimorphism, since the bulls have a shorter and broader *metacarpus* than the cows (cf. Table 2, measurement 4, for C, D, and E), which should be considered in relation to the weight of the animals. As is normal in bovine species, and clearly pronounced in bison oxen, the bulls have a considerably greater weight than the cows.

In Table 2 is further included more distantly related forms, such as the yak-ox, *Bos grunniens* and musk-ox, *Ovibos moschatus*, in order to show the pronouncedly short metacarpus of these species, and to point out similarities and differences in their distribution and survival.

Both species came from Asia to America across Beringia during the Pleistocene. The yak-ox (or a nearly related form) however only reached Alaska (Frick 1937, pp. 568–69) where it became extinct before historical time (only few finds with unreliable age determination are known), but it still lives in Asia in the highland of Tibet.

The musk-ox, on the other hand, succeeded in migrating from Asia across Beringia right to the east coast of Canada, and as the last stage (like the reindeer) to the north and east coast of Greenland where great numbers of vigorous animals are still found as in Canada.

In contrast to the yak-ox, the musk-ox however became extinct in Asia –

although at a very late date. Several limb bones and considerable parts of about ten skulls have been found in a settlement near Mesin (about 51°N, 31°E) at the river Desna in the province Tschernigow; and from another settlement in south-western Russia, Kostenki I (north of the eastern part of the Black Sea at 51°N), in the province Woronezh, bones of musk-ox are known (GROMOVA 1935, p. 113).

GROMOVA refers these settlements to a palaeolithic culture similar to the French Orignac and Solutré; but new age determinations (C14 datings, not published) seem to show that these Russian cultures are much younger, and that the musk-ox lived in the Old World only a few thousand years ago.

Finally, to revert to Amundsen's find from Ajon, more subfossil material (of whole skeletons) must be procured before it is possible to consider this bison against the background of the above-mentioned geographic, climatic, and ecological conditions related to the fluctuations of the Würm-glaciation.

The great morphological agreement which is shown between bones (especially the *metacarpus*) of the Ajon bison and the American Plain Bison (Table 2 and Plate III) suggests a parallel development under equal conditions which resulted in a common appearance. Whether the Ajon bison, as suggested by Flerow in his letter, is one of the last *Bison priscus* in NE Siberia, or whether it belongs to the said small endemic race mentioned by him, cannot be decided at present.

Резюме

В статье описывается 9 хорошо сохранившихся костей конечностей и 7 обломков ребер бизона (*Bison priscus*), найденных зимой 1919–20 года членами экспедиции Амундсена на острове Айон, в северо-восточной Сибири.

В поздне-плейстоценовую эпоху длиннорогий бизон (*B. priscus crassicornis* (REICH.)) был распространен циркумполярно, но к концу вюрма он был замещен более мелкой, короткорогой формой (*Bison priscus priscus* (BOJAN)). Ныне живущих бизонов Европы и Америки нужно рассматривать как периферические группы основного азиатского, вымершего племени, остатки которого известны из арктических областей северных берегов Сибири. Это племя жило, следовательно, в северной Сибири сравнительно недавно — в послеледниковый период.

Флеров (1967) упоминает небольшую эндемическую породу *Bison priscus* из областей рек Лены, Индигирки и Колымы.

Во времена рисса и вюрма северный берег Сибири лежал на много сотен километров севернее чем сейчас. Айон сделелся островом лишь в послеледниковый период. Море начало тогда постепенно размываь его берега, в отложениях которых и были найдены субфоссильные кости. Кости эти белые, твердые и довольно тажелые, с многочисленными трещинами от высыхания (Таб. (Plates) I и II). Вопрос об увеличении веса субфоссильных костей дискутируется на примерах костей найденных при таких же условиях в Гренландии.

Все кости с Айона принадлежат одному и тому же, приблизительно четырехлетнему животному. Что касается размеров костей, то они приблизительно отвечают размерам костей *Bison bison bison*, но немного длиннее их. Высота животного на уровне плеч была по всей вероятности около 90 см (Таб. III).

В таблице III воспроизведены длинные пястные кости у 1) добореального первобыка (тура) и 2) межледникового степного бизона (оба из Дании), а также короткие пястные кости, характерные для горных пород у 3) бизона с Айона и 4) американского прерийного бизона. Так как степи экологически очень однообразны, то они особенно чувствительны к климатическим изменениям, что в свою очередь отражается на фауне. Но животные, живущие в горах, всегда имеют возможность найти более подходящие для себя экологические »ниши«, и поэтому могут легче пережить климатические изменения. На некоторых примерах из Гренландии показано, как чувствительны животные к климатическим изменениям, особенно когда они живут в исключительно тяжелых условиях.

В таблице II даны фактические и относительные размеры костей плюсны у различных быкообразных, что дает понятие о морфологии и образе жизни Айонского бизона. Кости плюсны Айонского бизона сравнительно короткие и широкие, и в своих пропорциях гармонические — они не напоминают кости »чахлых« форм. Все индесы точно соответствуют индексам самцов американского бизона.

Флеров подчеркивает в личном сообщении автору, что находки с Айона вряд ли можно причислить к мелкой эндемической породе бизонов, известных из Сибири; они должно быть принадлежат к одним из последних представителей *Bison priscus*, живших в северо-восточной Сибири до середины голоцена.

По мнению автора трудно решить вопрос к какой породе нужно причислить бизона с Айона, пока не будут найдены новые материалы. Но бизон этот жил во всяком случае в конце азиатской истории бизонов, и его размеры и пропорции были промежуточными между размерами и пропорциями современного бизона прерий и канадского лесного бизона.

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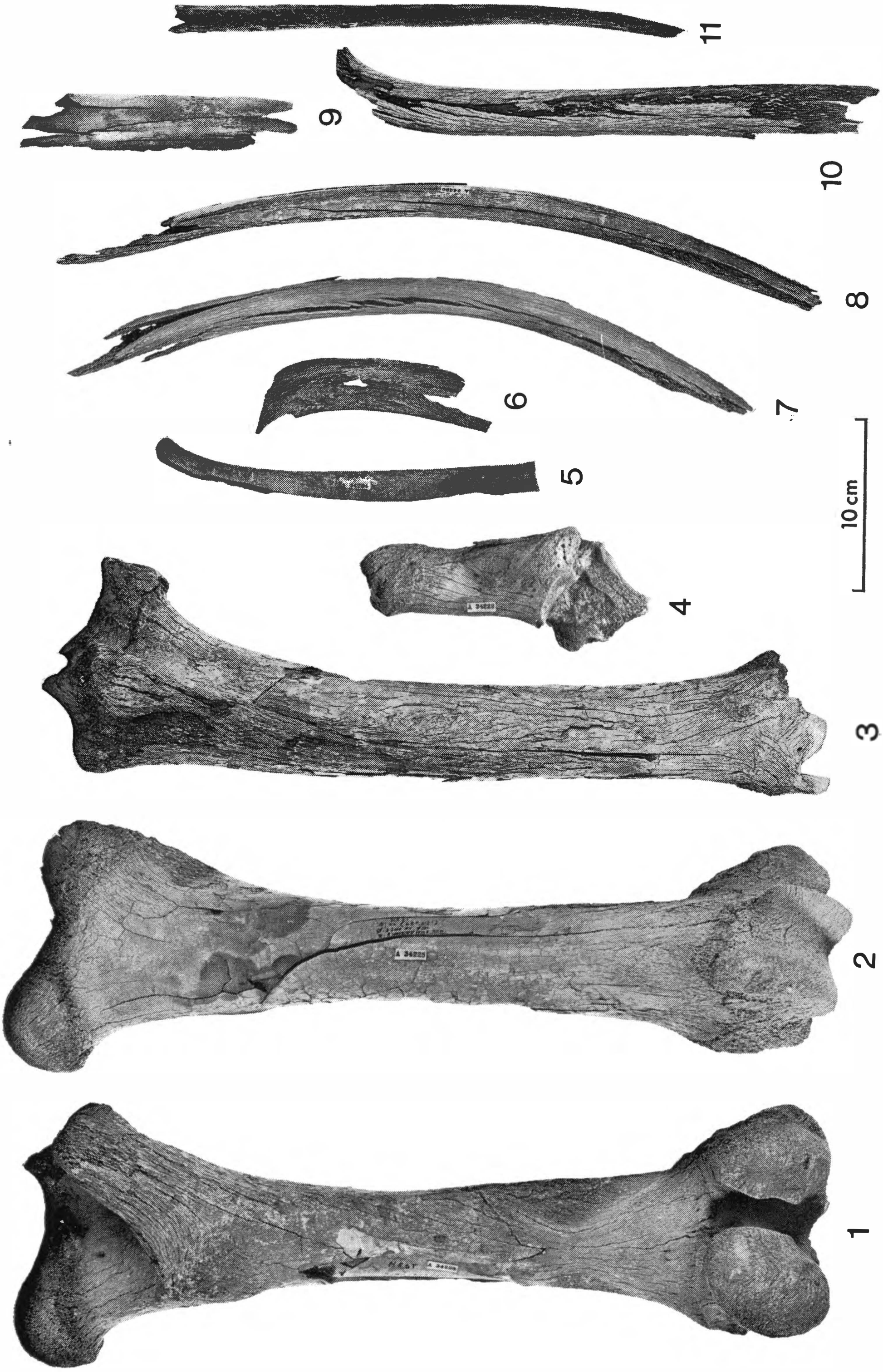
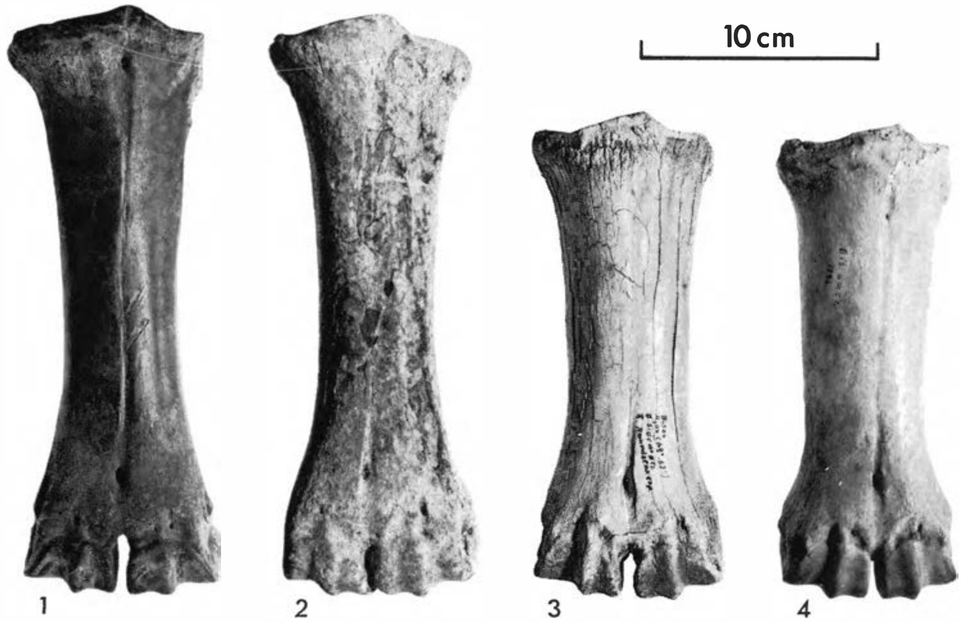
Bison, Ajon. Bones of the forelimb. 1 – *scapula*, 2 – *humerus*, 3 – *radius*, 4 – *ulna*, 5 – *metacarpus*.



Bison, Ajon. Bones of the hindlimb. 1 *femur* (dex.), 2 *femur* (sin.), 3 *tibia*, 4 *calcaneus*, 5–11 *costae*. 5:34234, 6:without no., 7:34232, 8:34230, 9:without no., 10:34231, 11:34233 (see text).



Cannon-bones, *metacarpi*. 1 – Urus, *Bos primigenius*, Denmark, praeboreal. 2 – Steppebison, *Bison priscus*, Denmark, interglacial. 3 - "Ajon-bison", *Bison priscus*, Holocene.
4 - Plainbison, *Bison b. bison*, U.S.A. recent.

Zur Flora des Van Mijenfjorden-Gebietes (Spitsbergen) und Hopens

VON

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Inhaltsverzeichnis

Abstract

This preliminary account deals with botanical results of a joint expedition from the German Federal Republic and Norway to Spitsbergen in 1970. Important finds from the Van Mijenfjorden area, West Spitsbergen, are *Honckenya peploides, Ranunculus pallasii, R. auricomus* agsp. *pedatifidus, Potentilla crantzii, P. nivea, Arnica alpina, Taraxacum brachyceras, Luzula wahlenbergii,* and *Carex stans.*

Accessions to the flora of the isolated island of Hopen, south-eastern Svalbard, were *Poa pratensis* agsp. *alpigena, Poa alpina* var. *vivipara,* and *Festuca vivipara.* Presently, the island's vascular flora is known to comprise 22 species.

I. Van Mijenfjorden

Im Sommer 1970 führten wir eine botanische Expedition in das Van Mijenfjorden-Gebiet (Spitsbergen) durch. An ihr nahmen teil: LUDGER DILLA, Köln; TORSTEIN ENGELSKJØN, Oslo; FRIEDRICH HÖRL, München; KLAUS KRAMER, Dr. INGRID KRAMER-MÜSKES, beide Bonn; ARNE PEDERSEN, Oslo; und Prof. Dr. HANS-JOACHIM SCHWEITZER, Bonn (Leiter).

Im einzelnen war geplant, das in Abb. 1 schraffiert dargestellte Gebiet unter Einschluss von Makromyceten, Flechten, Moosen und Gefässpflanzen floristisch und pflanzensoziologisch zu erforschen. Darüber hinaus sollten aber auch cytotaxonomische und ökologische Untersuchungen vorgenommen werden. Die Ziele wurden im wesentlichen erreicht. Nur die ökologischen Untersuchungen wurden

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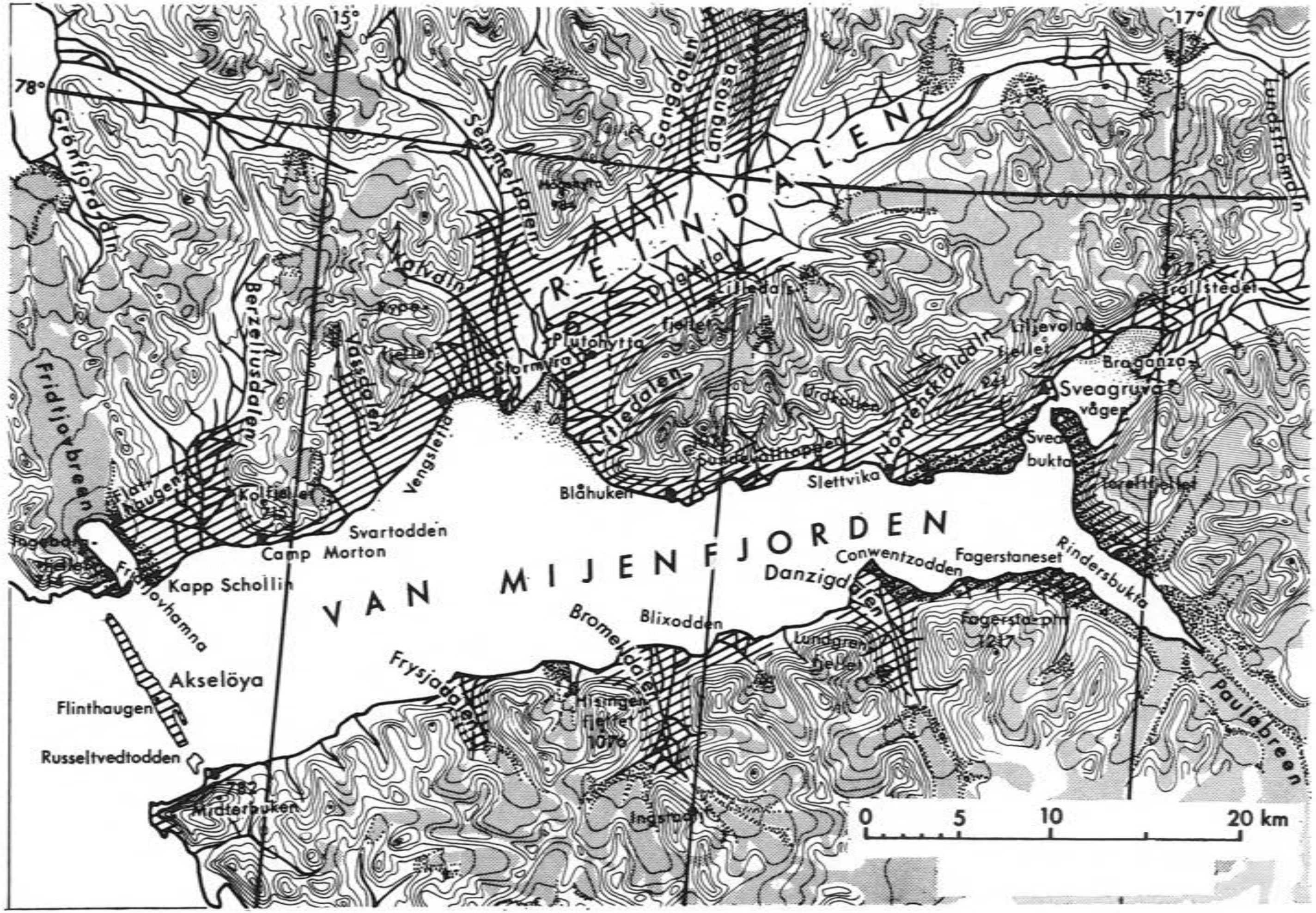

Abb. 1. *Übersichtskarte des Van Mijenfjorden-Gebietes. Schraffiert: untersuchtes Gebiet.*

durch das schlechte Wetter stark beeinträchtigt. Ausführlicher werden wir über die Ergebnisse der Expedition später an anderer Stelle berichten.

Obwohl wir es nicht als unsere Aufgabe betrachteten, nach Raritäten zu suchen, sondern mehr die allgemeine Zusammensetzung und die Lebensverhältnisse der Flora zu studieren, stellten wir doch eine Anzahl in Svalbard verhältnismässig seltener Arten fest. Die Bestimmungen der Pilze, Flechten und Moose sind ebenso wie die Chromosomenzählungen ausgewählter kritischer Gruppen (*Dupontia, Festuca, Draba* und *Potentilla*) noch nicht fertiggestellt.

Von den selteneren Gefässpflanzen sei im folgenden ein Fundortsverzeichnis gegeben. Die Fundorte sind dem Nordufer des Van Mijenfjordens von Westen nach Osten, östlich um Braganzavågen herum und dem Südufer von Osten nach Westen folgend und als letztes die Akseløya einschliessend, aufgezählt.

Es gibt nur wenige Fundorteangaben höherer Pflanzen aus dem Van Mijenfjorden-Gebiet. Der norwegische Lichenologe BERNT LYNGE sammelte 1926 Flechten sowie andere Pflanzen in Bellsund und Van Mijenfjorden (LYNGE 1936, 1938, Belegexemplare in Herb. O). Tromsø Museums Spitsbergenexpeditionen 1958 und 1960 (teilnehmende Botaniker: OLAF I. RØNNING, OLA SKIFTE, NIELS FOGED) untersuchten Midterhuken, Kapp Schollin, Berzeliusdalen und die Gegend um Braganzavågen (Belegexemplare in Herb. TROM). Dr. GEOFFREY HALLIDAY (Lancaster University) und Mitarbeiter führten 1965 eine Expedition nach Reindalen durch (Duplikatbelege in Herb. TROM). Die zum Teil interessanten Neuangaben dieser Expedition sind zur Zeit (Mai 1971) noch nicht veröffentlicht worden.

Allgemeines über das untersuchte Gebiet

Die Flora im Van Mijenfjorden-Gebiet ist artenärmer und die Vegetation karger als im benachbarten Isfjorden-Gebiet. Dies dürfte in erster Linie auf das einförmige oligotrophe Gestein (fast ausschliesslich tertiäre Sandsteine und Tonschiefer) zurückzuführen sein. Nur der Midterhuken und die Akseløya bestehen vorwiegend aus permokarbonischen verkieseltem Kalk und Mergel. Auch die lang andauernde Vereisung des Fjordes (fast stets bis Mitte Juli) dürfte sich ungünstig auf die Vegetation auswirken.

Reindalen hat jedoch ein günstigeres Lokalklima, was durch das Auftreten gut entwickelter *Dryas/Cassiope/Hierochloë-Heiden* kontinentalen Typs zum Ausdruck kommet. Sonst fehlt *Cassiope tetragona* im Fjordgebiet.

Verzeichnis seltenerer Arten im Van Mijenfjorden-Gebiet

Lycopodiaceae

Lycopodium selago L. – Flathaugen, Berzeliusdalen Westseite (Osthang des Sefströmkammen) häufig, Berzeliusdalen Ostseite, Kolfjellet (bis 500 m), zwischen Camp Morton und Vassdalen, Vassdalen (beide Talseiten), zerstreut entlang der

Bergfüsse (50 bis 100 m) von Vengsletta bis Høgsnyta, Talausgang von Gangdalen, Südosthang der Langnosa, Endmoräne vor dem Litledalen, Torellfjellet Westseite.

Equisetaceae

Equisetum scirpoides MICHX. – Litledalsfjellet Westseite häufig, Litledalen, Nordenskiölddalen, Trollstedet, Danzigdalen, Blixodden und Bromelldalen.

Salicaceae

Salix reticulata L. – Flathaugen 150 m, Bromelldalen Ostseite, Frysjadalen Ostseite, Akseløya Westseite nahe Flinthaugen.

Polygonaceae

Koenigia islandica L. – Slettvika im Sumpf nördlich der Hütte, Conventzodden im Moränengebiet.

Caryophyllaceae

Honckenya peploides (L.) EHRH. – Nur eine einzige, junge Pflanze am Strande bei Slettvika.

Melandrium affine (J. VAHL) HARTM. – Bei Gangdalshytta 60 m, Moräne vor dem Torellfjellet, Danzigdalen.

Ranunculaceae

Ranunculus pallasii SCHLECHT. – Reindalen im Sumpf südlich der Høgsnyta 30 m.

Ranunculus spitsbergensis (NATH.) HADAČ – Mündung und Zentrum des Berzeliusdalen, Vassdalen unterhalb Rypefjellet, Stormyra und unteres Reindalen in sehr grossen Beständen, Slettvika im Sumpf nördlich der Hütte, Terrasse zwischen Slettvika und Liljevalchfjellet, Akseløya an zwei Stellen zwischen Silberbukta und Russeltvedtodden.

Ranunculus lapponicus L. – Reindalen Nordseite, zerstreut, bei Gangdalshytta 60 m, Litledalen, unterhalb Sundevalltoppen, Terrasse zwischen Slettvika und Liljevalchfjellet, Bromelldalen Ostseite.

Ranunculus auricomus L. agsp. *pedatifidus* (SM.) – Kolfjellet am östlichen Vogelfelsen, Midterhuken an verschiedenen Stellen und ziemlich häufig.

Cruciferae

Braya purpurascens (R. BR.) BGE. – Moränengebiet zwischen Fridtjovhamna und Flathaugen, unterhalb des Blåhuken, in den Bachbetten im Danzigdalen, Bromelldalen, Frysjadalen.

Eutrema edwardsii R. BR. – Danzigdalen Ostseite, Bromelldalen Ostseite, Frysjadalen Ostseite.

Draba gredinii EKMAN – Zwischen Berzeliusdalen und Camp Morton, Høgsnyta 60 m, Blåhuken, Sveagruva, Danzigdalen, Blixodden, Bromelldalen.

Draba bellii HOLM – Moränengebiet zwischen Fridtjovhamna und Flathaugen, Ausgang des Nordenskiölddalen, Moräne vor Torellfjellet, Danzigdalen, Blixodden, Frysjadalen.

Saxifragaceae

Saxifraga aizoides L. – Zwischen Kolfjellet und Vassdalen, Høgsnyta Südosthang 60 m, Litledalsfjellet Nordwesthang, Litledalen, Bromelldalen, Frysjadalen, Midterhuken Westfuss.

Saxifraga hyperborea R. BR. – Flathaugen, Berzeliusdalen Ostseite, Camp Morton, Vassdalen (bis 400 m), Nordseite des Reindalen mehrfach, Gangdalen (bis 400 m) mehrfach, Litledalen, Blåhukdalen, Blåhuken Südhang, Sundevalltoppen Südhang, Nordenskiölddalen mehrfach, Sveagruva, Trollstedet, Moräne vor Torellfjellet, Danzigdalen Ostseite, Bromelldalen Ostseite, Frysjadalen. *S. rivularis* ist etwas häufiger und im ganzen Gebiet verbreitet, vor allem im Tiefland und am Strande.

Chrysosplenium tetrandrum (N. LUND) TH. FR. – Stormyra an vielen Stellen, wenn auch nicht häufig, Blåhuken Südseite, Midterhuken in feucht-schattigen Rinnen massenhaft und bis zu 15 cm hoch werdend, Akseløya an zwei Stellen westlich des Flinthaugen.

Rosaceae

Potentilla nivea L. ssp. *subquinata* (LGE.) HULTÉN – In wenigen Exemplaren auf einem Moränenhügel im Bromelldalen.

Potentilla crantzii (CR.) BECK – Camp Morton, an zwei Stellen an der Südostseite des Blåhuken, zahlreich am Südhang eines Moränenhügels im Bromelldalen.

Ericaceae

Cassiope tetragona (L.) D. DON – Vengsletta, vereinzelt, aber häufiger werdend im Reindalen, häufig zwischen Høgsnyta und Gangdalen, und am Südosthang der Langnosa 50 bis 150 m, Reindalen Südseite erst bei der Plutohytta beginnend.

Empetraceae

Empetrum hermaphroditum HAGERUP – Flathaugen, Berzeliusdalen am Westhang des Kolfjellet, zwischen Camp Morton und Vassdalen, vereinzelt am Südhang der Langnosa, in grosser Menge am Fuss der Endmoräne vor dem Litledalen, Liljevalchfjellet Südostseite.

Asteraceae

Erigeron humilis GRAH. – Flathaugen, Vassdalen (Osthang), Vengsletta, massenhaft im Canon am Ausgang des Litledalen, Litledalen mehrfach, Blåhukdalen, Blåhuken Südhang, Sundevalltoppen Südhang, Torellfjellet Westseite und Moräne davor, Danzigdalen, Moränenhügel im Bromelldalen.

Petasites frigidus (L.) Fr. – Vassdalen, Übergang Vengsletta – Stormyra, Reindalen Nordseite mehrfach, Talausgang des Gangdalen, Litledalen, Blåhuken Südseite, drei Stellen zwischen Sundevalltoppen und Slettvika, Nordenskiölddalen, Danzigdalen, Bromelldalen, Frysjadalen, Midterhuken Westseite.

Arnica alpina (L.) Olin – Canon am Ausgang des Litledalen, Ostseite des Nordenskiölddalen – hier von Frau H. Grøndahl, Wien, in 1957 entdeckt, Moränenhügel im Bromelldalen.

Cichoriaceae

Taraxacum brachyceras Dahlstedt – Kolfjellet am östlichen Vogelberg zusammen mit *Ranunculus auricomus* agsp. *pedatifidus*.

Juncaceae

Luzula wahlenbergii Rupr. – Berzeliusdalen westlich des Nordwestfusses des Kolfjellet, Reindalen südlich der Høgsnyta 30 m, Reindalen Westseite nahe der Mündung des Flusses.

Cyperaceae

Carex parallela (Laest.) Sommerf. – Danzigdalen Ostseite, hinteres Bromelldalen, hinteres Frysjadalen.

Carex rupestris All. – Zwischen Berzeliusdalen und Camp Morton, Kolfjellnasa Südseite, Høgsnyta Südosthang, bei Gangdalshytta 60 m.

Carex glareosa Wg. – Mündung des Berzeliusdalen, Mündung des Reindalen, 1 Exemplar im Moränengebiet am Conventzodden.

Carex stans Drej. – Ein grosser Bestand auf einer postglazialen Meeresterrasse zwischen Slettvika und Liljevalchfjellet. Zusammen mit *Ranunculus spitsbergensis* und *R. lapponicus*. Die Taxonomie der *Carex aquatilis*-Gruppe im nördlichen Zirkumpolargebiet ist problematisch. Die Bestimmung der betreffenden 20–30 cm grossen *Carex* ist deshalb vorläufig.

Carex misandra R. Br. – Flathaugen, Litledalen, unterhalb Urdkollen, Nordenskiölddalen, Trollstedet, Danzigdalen, Bromelldalen Ostseite, Frysjadalen, Midterhuken Westfuss.

Gramineae

Hierochloë alpina (Sw.) R. Br. – Reindalen Nordseite, zerstreut zwischen Høgsnyta und Gangdalen, Terrassen bei der Gangdalshytta häufig, Endmoräne vor dem Litledalen, Endmoräne vor dem Nordenskiölddalen.

Phippsia concinna (Th. Fr.) Lindeb. – Fangsthütte am Fridtjovhamna, Gangdalen 400 m, Sveagruva, Moränengebiet am Conventzodden.

Calamagrostis neglecta (Ehrh.) G. M. S. – Midterhuken Westfuss, Akseløya zwischen Reirmarka und Russeltvedtodden.

Deschampsia brevifolia R. BR. – Sven Nilssonfjellet Nordseite, Midterhuken Westfuss, Akseløya nahe Russeltvedtodden.

Arctophila fulva (TRIN.) RUPR. – Berzeliusdalen östlich der Flussmündung, Stormyra westlich Plutohytta.

Colpodium vahlianum (LIEBM.) NEVSKI – Blixodden, Akseløya.

II. Hopen

Im Anschluss an den Aufenthalt auf Spitsbergen hatte SCHWEITZER Gelegenheit, Bjørnøya und Hopen aufzusuchen. Auf Bjørnøya ist zwischen den älteren Gebäuden der Funkstation nach 1967 (cf. ENGELSKJØN & SCHWEITZER 1970) *Stellaria media* (L.) VILL. in 11 üppigen Exemplaren eingeschleppt worden.

Über die Flora Hopens sind unsere Kenntnisse äusserst dürftig. Deshalb sind bei den verschiedenen Pflanzen Häufigkeitsangaben hinzugefügt worden. Bedauerlicherweise währte der Aufenthalt auf Hopen so kurze Zeit, dass nur der südliche Teil der Insel von der Funkstation an besucht werden konnte. Wegen des einförmigen Gesteines – mesozoische Tonschiefer, Mergel und Sandsteine – und des durch starke Solifluktion bewegten Bodens ist der Pflanzenbewuchs, selbst der von Flechten und Moosen, ziemlich spärlich.

Die Flora Hopens zählt nunmehr (cf. EATON 1876, LID 1929) 22 Arten. Nicht beobachtet wurden von SCHWEITZER *Luzula arcuata*, *Deschampsia alpina*, *Puccinellia phryganodes* und *Potentilla hyparctica*.

Caryophyllaceae

Cerastium regelii OSTENF. – Zerstreut zwischen Funkstation und Iversenfjellet. Vor allem in Bachläufen und Taleinschnitten.

Cerastium arcticum LGE. – Etwas seltener als vor.

Ranunculaceae

Ranunculus sulphureus SOL. – Hier und da in Taleinschnitten und an Felsen.

Ranunculus pygmaeus WG. – Selten, zwischen Werenskioldfjellet und Kvasstoppen und im Bekkeskardet.

Papaveraceae

Papaver dahlianum NORDHAGEN – Zerstreut.

Cruciferae

Cochlearia groenlandica L. – Zerstreut, stellenweise häufiger an der Küste.

Draba alpina L. – Selten, vorwiegend an felsigen Stellen in Taleinschnitten.

Saxifragaceae

Saxifraga oppositifolia L. – Häufig.

Saxifraga nivalis L. – Selten, nur 1 Exemplar hinter der Funkstation beobachtet.

Saxifraga tenuis (WG.) H. SM. – Häufig. Wahrscheinlich von EATON (1876) als *S. nivalis* bestimmt.

Saxifraga cernua L. – Häufig.

Saxifraga rivularis L. – Häufig.

Saxifraga groenlandica L. – Häufig.

Gramineae

Alopecurus alpinus SM. – An drei Stellen gefunden: Funkstation bei der Sauna, Werenskioldfjellet Südostseite, Bekkeskardet.

Phippsia algida (SOL.) R. BR. – Häufig.

Poa pratensis L. agsp. *alpigena* (FR.) – Neben *Phippsia algida* häufigstes Gras der Insel, aber immer nur flächenweise auftretend und fast stets steril und mit rötlich überlaufenen Blättern. Besonders an Nistplätzen von *Stercorarius parasiticus*. Vermutlich handelt es sich bei dem von EATON als *Poa arctica* R. BR. bestimmten Gras um diese Spezies (cf. LID 1929). Sonst neu für Hopen.

Poa alpina L. var. *vivipara* – Ziemlich selten in Taleinschnitten. Neu für Hopen.

Festuca vivipara (L.) SM. – Nur in Bekkeskardet gefunden. Neu für Hopen.

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The catch of walrus *(Odobenus rosmarus)* in the areas of Svalbard, Novaja Zemlja, and Franz Josef Land

(Промысел моржа (*Odobenus rosmarus*) в областях Свальбарда, Новой Земли и Земли Франйа-Иосифа)

BY

ODD LØNØ[1]

Contents

Abstract

Statistics of the catching of walrus have been compiled. The catch in the Svalbard area started in 1604. The population of walrus in Svalbard waters has gradually been reduced since then, and now only a couple of hundred exist.

Аннотация

Составлена статистика по норвежской добыче моржа на Свалбьарде, начавшейся в 1604 г. Во время начала добычи популяция моржей насчитывалаголов 10 тысяч. Неразумной охотой она теперь сокращена примерно до двухсот голов, обитающих в северо-восточных частях архипелага. Промысел этих зверей был запрещен в 1952 г.

The walrus catch at Bjørnøya

The Dutch explorer WILLEM BARENTS discovered the island of Bjørnøya and gave it its name in 1596 (DE VEER in *Purchas* 1906). The next person to come to the island was the Englishman FRANCIS CHERRIE in 1603 (GORDON in PURCHAS 1906).

FORSTER (1788) and BARROW (1818) have a good outline of the catch at Bjørnøya

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in the first years after the discovery. According to their reports the first catch of walrus was taken by an English ship in 1604. On July 10 the crew discovered a flock of more than 1000 walrus which were on land. The English had no previous experience of this kind of hunting and caught only about 50 animals. BARROW (1818) relates: "They shot at them in vain till their muskets were spoiled and their powder was spent, when wee would blow their eyes out with a little pease-shot, and then come on the blind side of them, and with our carpenter's axe cleave their heads: but for all that we could doe, of above a thousand wee killed but fifteene". At another place on the island, they saw another flock of about 1000 walrus on land. In 1605, a ship accompanied by a little pinnace caught 700–800 walrus. We have no information about ships at Bjørnøya in 1607, but in 1608, one ship caught more than 900 walrus there. Two walrus calves were also caught and taken back alive to England. One of them lived for two weeks. It is mentioned that there was another boat there that summer, but there are no details of any catch. In 1609, there were five ships at Bjørnøya, with a total crew of 182, but there are no details of their catch and it is possible that it was not a big one that summer, because "The whole of which vessels, being caught in a cove by the drift-ice, had nearly been crushed to atoms".

In 1611, one ship caught 200 walrus (POOLE b in *Purchas* 1906).

In 1612, there were three ships at Bjørnøya, but there is no information about their catch (BARROW 1818).

The large catches of bowhead whale in Spitsbergen in 1611 and in the following years seem to have provided the reason for the cessation of all interest in walrus hunting at Bjørnøya after 1612. We have no reports of hunting on the island, but we must presume that whalers on their way north and south to Spitsbergen visited the island now and again.

The Russians began to visit Bjørnøya in the eighteenth century, but we do not know how many hunting expeditions they have had there. Graves and remains of four houses (ISACHSEN 1921) have been found, which indicates that there have been Russian hunters who spent the winter there. They must have been hunting walrus, as, apart from a small number of foxes, there was nothing else to hunt. There have been no Russian hunters on Bjørnøya since 1817 (LÖWENIGH 1830).

The first time a Norwegian ship hunted at Bjørnøya, apart from a couple of unsuccessful attempts in 1790 (HAGEMANN 1888) and 1819 (KEILHAU 1831), was in 1820. More than 100 walrus were caught, but the ship was blown ashore, and remained at Bjørnøya (BROOKE 1827). Norwegians spent the winter on Bjørnøya for the first time in 1823–24, a group of nine (KEILHAU 1831). That winter they made a catch of 680 large and 70 small walrus (Finnmarksposten 1874). The next winter, 1824–25, a group of eight men caught 677 walrus, and eight men again spent the winter there in 1825–26, but the results were poorer and the number of their catch is not recorded (KEILHAU 1831). We know furthermore that expeditions spent the winter on Bjørnøya in 1829–30 (HENKING 1901), 1834–35, when all the seven men died, and 1841–42 (ISACHSEN 1921), but nothing is known about the catches. In 1851–52, eight men were forced to spend the winter on Bjørnøya; they saw a number of walrus around the island, but dit not have the necessary equipment with which to catch them (Menigmands Ven 1852). In 1865–66 a hunting expedition, which spent the winter there, caught only one walrus on February 16 and at the same time thew saw two others (ISACHSEN 1921). Walrus has not been hunted since then at Bjørnøya, and further observations are not known.

The walrus catch in Spitsbergen waters

In 1596, after a stay of some days on Bjørnøya, WILLEM BARENTS travelled northwards and discovered Spitsbergen also. The islands were later visited by HENRY HUDSON (in PURCHAS 1906) in 1607, and by JONAS POOLE (a in PURCHAS 1906) in 1610. Reports of these journeys gave rise to extensive whaling after 1611.

We know very little about the whalers' catch of walrus but, as during the years from 1611 until approximately 1650 whaling took place inside the fjords, we must presume that they caught a good many as there was a great number of walrus in this newly discovered hunting ground. From 1650 onwards, more and more whales were caught out in the pack ice, and after 1710 whaling became completely pelagic (HOEL 1966). After 1650 the whalers caught very little walrus as they did not have time to hunt walrus on land. ZORGDRAGER (1750) says of the whalers' catches of walrus: "Jedoch dies bringet der Reederei so wenig Vortheil, dass man, wenn man noch in der guten und zur Fischerei bequemen Zeit ist, es kaum wert achtet, darnach zu fahren, und die Zeit zu versplittern, damit es an dem Wallfischfang keine Hindernis haben möge. Wann aber die gemeldete Jahres-Zeit verlaufen ist, und man um Östen wieder zurück kommet, oder keine Hoffnung ist, Wallfische zu bekommen, so darf man in dem Aufsegeln, wenn sich Wallrussen sehen lassen, noch wohl einige Mühe und Zeit daran wenden. Nun kan man leicht begreifen, dass es nicht leicht möglich sey, auf diese Weise einen grossen Fang zu thun". OESAU (1937), who has written in detail of the early whaling activity from Schleswig-Holstein, says: "Wenn auch die Jagd auf Wale und Robben vor der auf Walrosse den wertaus grössten Vorrang hatte, so ist doch auf den Grönlandfahrten Walrossfang gelegentlich getrieben worden, ja, zeitweise wurden lediglich Walross-Fangexpeditionen unternommen, auch von Schleswig-Holstein aus". Casually, when the whalers hunted for whale near land they found large numbers of walrus. ZORGDRAGER (1750) tells of RYKE YSE, the whaler who in 1640 or 1645 saw an unbelieveable number of walrus in the Ryke Yseøyane (the islands have been named after him). He killed several hundreds of them.

The Russians came to Spitsbergen in the years between 1715 and 1720 (HOEL 1966). They came first and foremost to hunt walrus, but also hunted the white whale, seal, reindeer, fox, and polar bear, and they collected eggs and down. Hunting activity during the summer was carried out from sailing vessels, but hunting activity during the winter was based on huts. They certainly caught many walrus, but we know very little about their catches.

According to Norsk Handels-Tidende (1827), there were six to eight Russian vessels at Svalbard each year before 1808. During the Anglo-Russian War, 1808–1812, Russian hunting activity came to a complete halt because the English destroyed the Russians' hunting vessels. After the war there were one to two Russian vessels per year at Svalbard. A few results of the Russian catches are known. In Magdalenefjorden a group of hunters, who spent the winter there in 1783–84, caught 300 walrus (VIZE 1935). KEILHAU (1831) tells of the two groups of Russian hunters – about 40 men altogether – who made a catch of 1200 walrus at Sørkapp in the winter of 1818–19, or the year after. In 1821 the crew of a ship caught about 400 walrus at Spitsbergen (GRÜNER 1823). Twenty Russians caught 1100 walrus in Bellsund in 1822–23 (Norsk Handels-Tidende, 1827), but their hunting activity ceased completely in 1853 (HOEL 1966).

Norwegians visited Spitsbergen for the first time in 1795; this expedition spent the winter there, but the result is unknown. Spitsbergen was visited by a boat again in 1819, and from 1821 Norwegian hunting activity developed quickly in the Arctic, based on both summer and winter hunting. During this period the Russians' activity decreased while the Norwegians' hunting increased (KEILHAU 1831). The Norwegians learnt their hunting methods from the Russians, and carried on where they left off. The hunting of walrus was the most important of their activities. During the years 1822–1834, five parties were sent to spend the winter in Spitsbergen, but as few of them had any success, winter activity ceased for a long time. Summer hunting increased, however, and after 1821 Norwegians had vessels at Spitsbergen each year.

Some time after Norwegians had begun hunting walrus, other nationalities came into the picture too. In Norsk Handels-Tidende (1832) the following figures of walrus catches made by boats fitted out from Copenhagen are to be found: in 1830, 1 boat caught 134 walrus; in 1831, 3 boats caught 340 walrus; and in 1832, 5 boats caught 701 walrus – three of these boats had first been to Jan Mayen and hunted seal. We also know that there was a boat from Hamburg engaged in walrus hunting in Spitsbergen in 1835 and 1836 (Norsk Handels-Tidende 1837).

It has not been possible to discover any more information about the walrus catches of other nationalities in Spitsbergen after the 1820's. RODE (1842) has only one line about this: ". . . . even boats from Denmark and Hamburg have been on hunting expeditions in the Arctic in latter years while they have been waiting for their return cargo", that is, return cargo from Hammerfest, Vardø, and Vadsø. It is very unlikely that there have been many boats other than those which have been mentioned, and their catches have probably been very small in comparison with those of the Russians and Norwegians.

Norwegian walrus catching in the Arctic

Fig. 1 gives the catch of walrus during the period 1821–1834 from both sailing vessels and expeditions which spent the winter on Bjørnøya and in Spitsbergen. The figures for 1821–1829 are taken from RODE (1842) and YTREBERG (1946). All the catches were made by sailing vessels from Hammerfest, except for those from the two Tromsø vessels which caught 45 walrus in 1822. In 1826, too, there

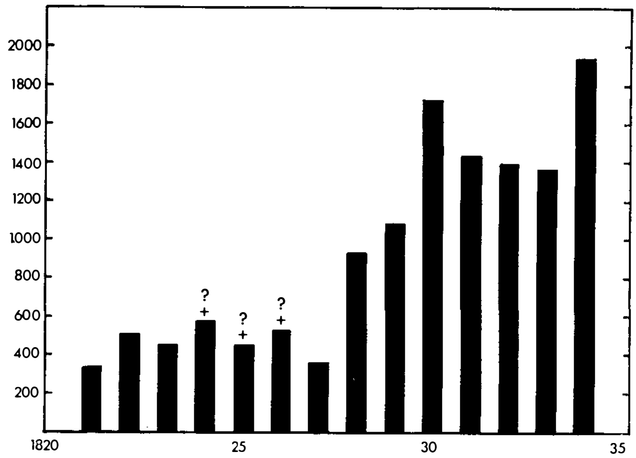


Fig. 1. *Norwegian walrus catch 1821–34. For the years 1824, 1825, and 1826 only a part of the catch from the wintering crew is in the figures. Consult text.*

Норвежский моржовый промысел в 1821-34 гг. Для 1824, 1825 и 1826 гг. только часть числа добытых зимовщиками зверей включена в фигуру. Добыты все звери около о. Медвежьего и Шпицбергена.

was a boat from Tromsø at Spitsbergen, but the catch is unknown. The figures for 1824, 25, and 26 are stated by RODE to be too small to be considered as the catches from parties which spent the winter on Bjørnøya during these years (see overleaf) and have only partially been included. It is not possible to calculate the total catch for these three years, but it must be at least 200 to 300 more than the figures in Fig. 1 show for the years 1824 and 1825. RODE further states that a boat with a considerable catch was shipwrecked in 1822. The catches for 1830–35 are according to Amtmennenes femårs-beretninger. In 1835, five vessels from Tromsø caught 135 walrus. The catches from Hammerfest and Vardø are not known.

Our knowledge of walrus catches during the period 1836–1873 is fragmentary.

1836–40: According to Amtmennenes femårs-beretninger, the catch from Hammerfest and Alta in 1836 and 37 is stated to have been mediocre, in 1838 and 39 to have been good, and in 1840 to have been poor. We have information from newspapers for two of these years. Norsk Handels-Tidende (1837) states that seven boats went hunting from Hammerfest in 1836 and caught 50 walrus, and Adressecontoirs-Efterretninger (1839) states that in 1838, five boats from Hammerfest and one from Tromsø caught 107 and 50 walrus respectively. The boat from Tromsø had been hunting seal at Jan Mayen before it went to Spitsbergen and caught walrus. Tromsø Tidende (1839) states that one of the boats from Hammerfest caught 252 walrus in 1839.

1840–45: Amtmennenes femårs-beretninger states that the average annual walrus catch for Hammerfest and Tromsø during the years 1841–45 was 222. Tromsø Tidende (1845) says there were no boats from Tromsø operating in the Arctic in 1844, but that there were 10 boats from Hammerfest.

1846–50: Amtmennenes femårs-beretninger refers to special figures for Arctic catches during these years, but it has not been possible to find them, and they have probably been lost. NICOLAYSEN (1894) states that six boats from Tromsø caught 214 walrus in 1847, and eight boats from Hammerfest caught 819. YTREBERG (1946) says that in 1849 two boats from Tromsø caught 72 walrus.

1851–55: Amtmennenes femårs-beretninger gives detailed information about the Arctic catch, but unfortunately there are no figures for the number of walrus which were caught. In all, 75 journeys were made by sailing vessels to Spitsbergen from Tromsø and Hammerfest during these years.

1856–60: In Amtmennenes femårs-beretninger we find the following information about Arctic hunting: "five or six vessels have been fitted out in Tromsø, with an average crew of seven – satisfactory results. In 1856–59 an average of 12 boats has been fitted out from Hammerfest, and in 1860, 14 boats. Good returns". MOBERG (1960) gives the following catches for Hammerfest: in 1857, 820; in 1858, 915; and in 1859, 860 walrus.

1861–70: Beretninger om Norges Fiskerier (1870) and YTREBERG (1946) give information only from certain years in this period about how many boats that took part and the total value of the Arctic catch. But Adresse-Kalender (1876) gives information of the export of walrus hides from Tromsø and Hammerfest for seven of these years. The number of hides is not given, but the weight. In Fig. 2 the number of hides is calculated by using 150 kg as an average weight for a salted walrus hide. It is difficult to say if this information and the calculation of the number of walrus used in Fig. 2 give the right value of the catch for the given years. Some of the hides could have been sold inland, and hides from one year could have been sold the year after. Most probably the calculated numbers are too small.

1871–83: The catch of walrus is represented in Figs. 2 and 3. The figures for 1871–75 are from Beretning om Norges Fiskerier. The catch for Hammerfest is unknown in 1871. The figures for 1876–78 are from Statistikk over Norges Fiskerier, and those for 1882–83 are from Norsk Fiskeritidende. From 1868 there is an increase in the participation in Arctic hunting which can be accounted for by the fact that Norwegians began hunting in the new hunting grounds in Novaja Zemlja and in the Kara Sea.

1884–1909: We have very satisfactory information for this period in Norsk Fiskeritidende. The information is given in such a way that it is possible, roughly, to divide the catches between the hunting grounds shown in Figs. 3 and 4. Many of the catches were made in the new hunting grounds of Novaja Zemlja and the Kara Sea. In 1887 there was a record catch of 2,261 walrus – the largest year's catch that we know of. In the years 1903–08, 77 walrus are said to have been caught in North-East Greenland.

1910–39: As is evident from Figs. 4 and 5, walrus catches from 1910 up until World War I were small and insignificant. During the war there was a tremendous increase in Norway's participation in Arctic hunting (HOEL 1949), but the figures are very incomplete, and for certain years completely missing. The figures for 1915 and 1920 are from IVERSEN (1928). After 1924, however, the catch figures in

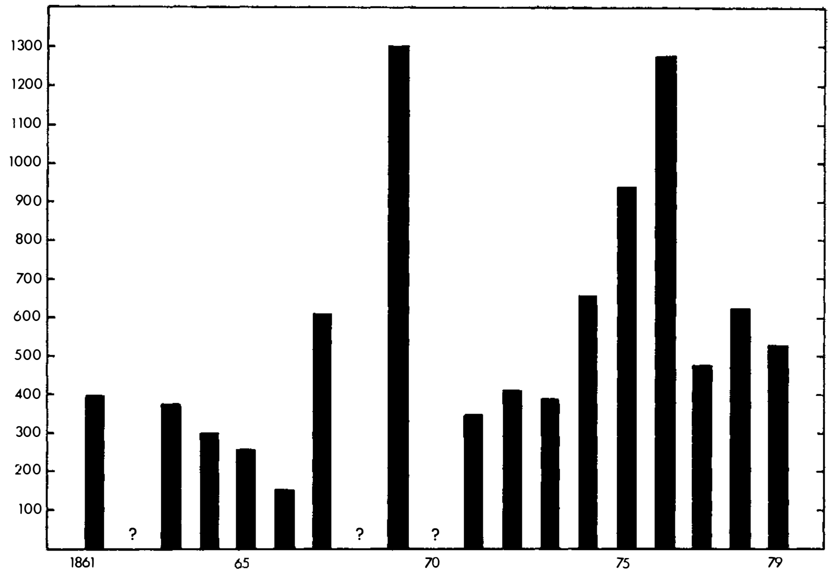


Fig. 2. *Norwegian catch of walrus 1861–79. The figures for the catches for 1862, 1868, and 1870 are missing, likewise the catch for 1871 from the boats from Hammerfest. Consult text. For the period 1836 to 1860 only a few fragmentary records are known.*

Норвежский моржовый промысел в 1861-79 гг. Отсутствуют сведения о добыче в 1862, 1868 и 1870 гг., также как о добыче произведенной зверобоями г. Гаммерфест в 1871 г. Для периода 1836-60 гг. известны только неполные сведения.

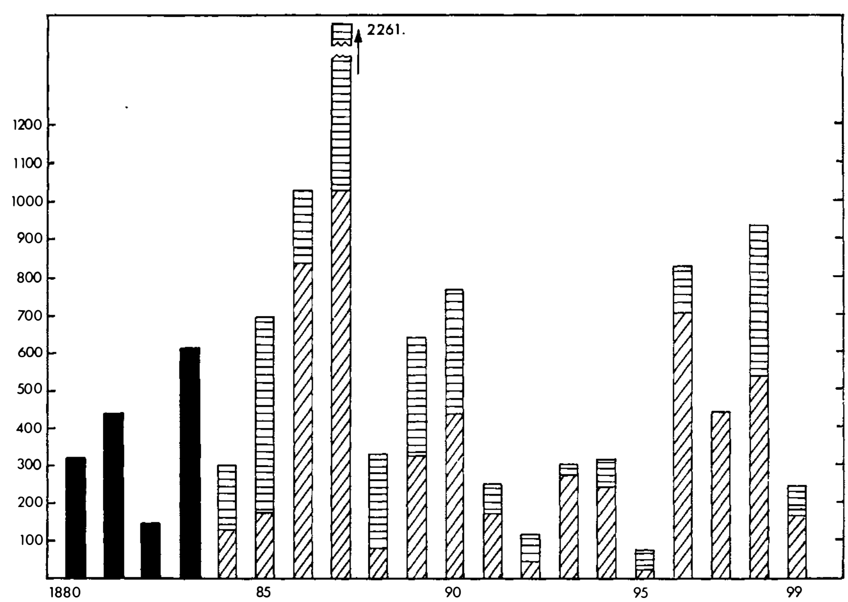


Fig. 3. *Norwegian catch of walrus 1880–99. For the years 1884 to 1909 it is possible to find the approximate figures for the catch taken on the various hunting grounds. ////// catch taken at Spitsbergen (Nordisen), ≡≡≡ catch taken at Novaja Zemlja and in the Kara Sea.*

Норвежский моржовый промысел в 1880-99 гг. Для периода 1884-1909 гг. можно дать приблизительные цифры добытых в разных районах зверей. ////// обозначает добычу, происходившую около Свальбарда, ≡≡≡ – около Новой Земли и в Карском море.

Norges Fiskerier were again complete. After 1923 there was a 10-year period of good walrus catches. This was because the engine-powered vessels could now get through to Franz Josef Land, and hunt between the islands or in the pack ice south of these islands (HORN 1930).

Walrus catches after 1931 have been insignificant. This is due mainly to the fact that the Russians banned the Norwegians from hunting in Franz Josef Land after they annexed the islands in 1929.

1940–52: During the war years 1940–45, no vessels were fitted out for Arctic hunting from Norway, and we know that only two walruses were caught in 1940 and one in 1945. The catches after 1945 (Årsberetning vedkommende Norges

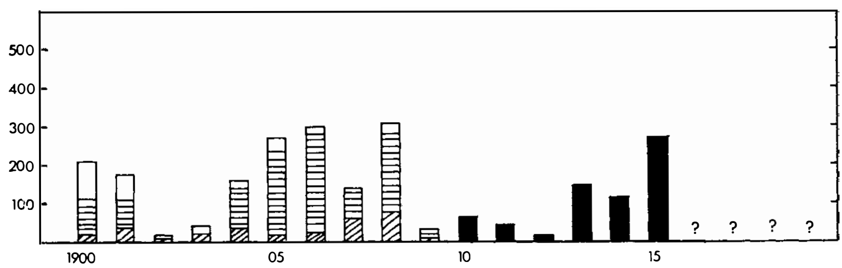
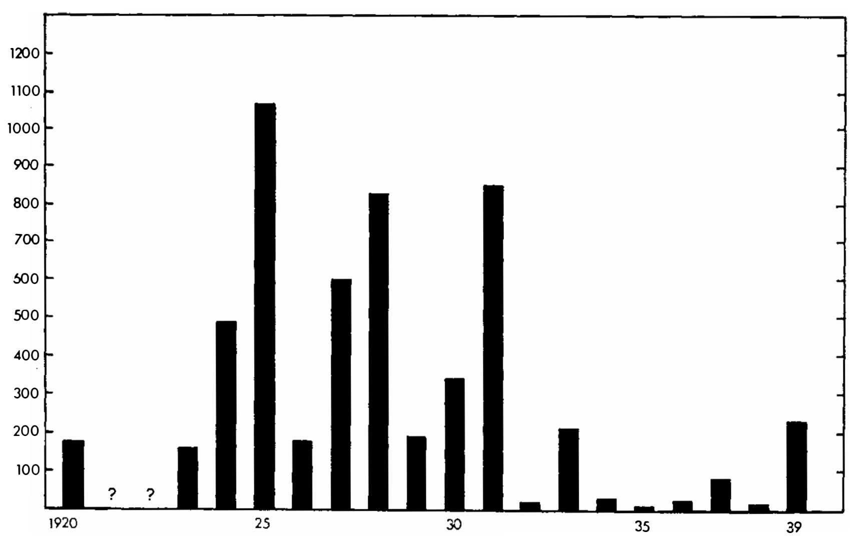


Fig. 4. *Norwegian catch of walrus 1900–19. For explanation of symbols see Fig. 3.* ☐ *indicates catches on unknown hunting grounds or catches taken in North-East Greenland.*

Норвежский моржовый промысел в 1900-19 гг. Объяснения символов – теже, что на рис. 3. ☐ обозначает добычу в неизвестном районе или около северо-восточной Гренландии.



Figs. 5. *Norwegian catch of walrus 1920–39. Most of the catches from 1923–31 are taken at Franz Josef Land.*

Норвежский моржовый промысел в 1920-39 гг. Большинство зверей в 1923-1931 гг. добыто около Земли Франца-Иосифа.

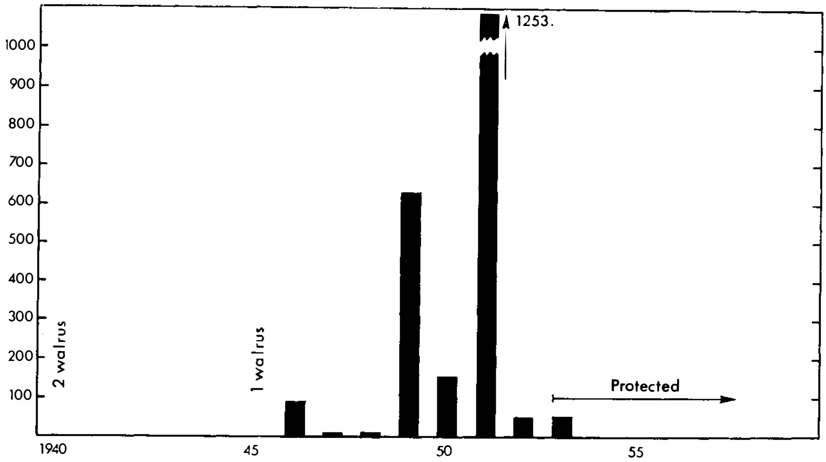


Fig. 6. *Norwegian catch of walrus 1940–53; 624 walrus of the catch in 1949 and 1175 walrus of the catch in 1951 were taken in the Davis Strait.*

Норвежский моржовый промысел в 1940-53 гг. Из общей добычи 624 голов в 1949 г. и 1175 голов в 1951 г. приходятся на Девисов пролив.

Fiskerier) are given in Fig. 6. The catch in 1946 was made at Franz Josef Land. Out of the catch of 630 walrus in 1949, 624 were caught by one vessel in the Davis Strait. Of the big catch of 1253 walrus in 1951, 1175 were caught in the Davis Strait and one in the Jan Mayen area; about one half of the rest (77 walrus) were taken at Kvitøya (S. SNARBY and J. OLSEN, pers. com.) and the other half probably in the ice south of Franz Josef Land. As far as one knows there have been no hunting in the Davis Strait by Norwegians, except for the years 1949 and 1951. Captains S. SNARBY and J. OLSEN report that they caught 55 walrus east of Kvitøya and at Victoria Island at the end of August, 1950.

Since the law passed on June 20, 1952, the walrus has been a protected animal – even so, approximately 50 walrus were caught in the pack ice south of Franz Josef Land in the summer of 1953 (the informant wishes to remain anonymous).

Discussion

There were many walrus at Bjørnøya both in summer and winter when the first hunters came there, but considerable inroads were made upon the stock by the English during the years 1604–11, as described earlier. Even so, when the Norwegians started hunting at Bjørnøya in the 1820's, there was still a considerable number there. This was due to the fact that people had lost interest in Bjørnøya because of the richer hunting grounds in Spitsbergen. It is possible that the Russians' catches did not greatly affect the stock of walrus, for the crew of the Norwegian boat which visited Bjørnøya in 1820 told BROOKE (1827): "The crew before mentioned represented the numbers of the walrus, particularly on the northern side of the island to be immense . . . .".

The walrus quickly disappeared from Bjørnøya after 1830. This was hardly due to hunting on the island alone, for there was very little, but it is clear that the decline in the stock of walrus coincided with the reduction of the stock on the west coast of Spitsbergen.

It was easy to catch walrus on Bjørnøya as, because of the nature of the country, there were only two places where the walrus came up onto land. The best place was Herwighamna in the north of the island, where most of the walrus were killed. The other was Kvalrossbukta, though this was of less importance.

Like Bjørnøya, the Spitsbergen islands, when they were discovered, were found to have a very large stock comprised of ten-thousands of walrus. During the first years, walrus catches were made in connection with whaling in the areas which were most free of ice, on the west coast of Spitsbergen and at Edgeøya. As the walrus is easy to catch and its reproduction is slow, a large proportion of the stock was quickly destroyed. ZORGDRAGER wrote in 1750: "Es scheinet, die Engelander haben zu Anfang der Fischery in der Horizont Bay, Klock-Bay und mehr anderen Bayen .... In diesen Bayen hielten sich dazumal auch viele Wallrussen und Robben auf: jetzo aber wenig".

When the Norwegians began hunting regularly in 1821, they hunted in the same areas as the Russians had done. KEILHAU wrote in 1831 about the hunting grounds: "It is above all the west coast of Spitsbergen, from Sørkapp to Amsterdamøya, where hunting has taken place. Hopen and Tusenøyane are also visited a good deal by Norwegians. The remaining areas are hunted only by the Russians". Even though the stock had already been noticeably reduced in 1750, as ZORGDRAGER (1750) points out, there was still a large stock of walrus on the west coast of Spitsbergen in the 1820's. Norsk Handels-Tidende (1827) says about Bellsund: "Walrus hunting in this fjord is very regular. As one piece of proof of the numbers of walrus which are to be found in one single fjord, one small schooner caught a complete catch in one hour there on August 12th, 1826. A group of 20 Russians spent the winter here in 1822–23 and caught 1100 walrus".

The Norwegians, who, after a while, were the only ones to hunt in Spitsbergen, hunted the same grounds right up to the 1860's. KARL PETTERSEN (1864) says: "For a long time, the Norwegian hunting vessels kept almost exclusively to the west coast, but have gradually withdrawn further north and east. Until latter years, few have ventured east of Sjuøyane". The regular hunting activity by the Norwegian vessels reduced the stock of walrus so much, that in the 1860's it was no longer possible to hunt in these areas.

The north-eastern areas along Hinlopenstretet, Nordaustlandet, Storøya, Kvitøya, and Kong Karls Land had been left in peace by the hunters in the small vessels. But it was now necessary to attempt to reach these difficult areas, which were almost inaccessible because of ice, in order to catch walrus. Geographical knowledge increased. In 1863, Nordaustlandet was sailed around for the first time (HORN 1930) and in July–August of the same year, good catches were taken in the northern part of Nordaustlandet and eastwards towards Storøya. The following year, a large catch was taken by three vessels at Storøya, but the catches were lost as all three vessels were wrecked. During the subsequent inquiry, one of the captains said that there were so many walrus at Storøya, that they had been able to kill as many as they had wanted to. Many dead walrus had been left behind because they had not been able to take them with them. Just how many walrus were caught is unknown, but one of the vessels had 212 walrus on board (ISACHSEN 1921). The walrus managed to exist for some years to come in these north-easterly areas which were effectively protected by ice in years when the pack ice was close. But if one managed to get there, one was assured of good catches. In 1876, some sailing vessels from Tromsø again managed to get as far east as Storøya and found walrus on land. (This was the year in which Kvitøya was discovered (YTREBERG 1946). In 1886, another record catch was made at Storøya – one boat caught 206 walrus (YTREBERG 1946). There were many walrus to be seen east of Nordaustlandet during the years 1886 and 87 (ISACHSEN 1921).

In 1868, Norwegians began to hunt at Novaja Zemlja and in the Kara Sea (YTREBERG 1946). The waters around Franz Josef Land were visited for the first time by seal hunters in the summer of 1886. These islands were not visited again until 1896 because of the ice conditions, but from then onwards, they and the pack ice on the southern side were frequently visited by vessels which were hunting for walrus (HORN 1930). Norwegians were the first to come to the walrus hunting grounds in the ice in the northern part of Novaja Zemlja, the Kara Sea, and Franz Josef Land, and they hunted here without competition from other nationalities (ISAKSEN), exploiting these areas in addition to the hunting grounds in Svalbard. But at the same time, the walrus began to mean much less to the Arctic hunting industry as a whole, since this was concentrating much more on seals. The hunting of harp seal in the White Sea began at about the same time as that of the walrus in Novaja Zemlja. The years 1868–70 were the last in which walrus catches were of the greatest importance for the North-Norwegian sealing fleet (HOEL 1949). The sailing vessels, which had gradually become large and more powerful, were replaced by steam and motor vessels after 1905 (HOEL 1949). With engine-powered vessels one could penetrate into areas which had previously been inaccessible or rarely visited because of difficult ice conditions.

The walıus stock at Svalbard was given its final blow by the large fleet of sealing vessels which hunted during World War I. After that time, walrus catches made at Svalbard have been of little importance for Arctic hunting activity, and people only caught walrus when they happened to come across them.

The large catches which were made after 1923 are mostly due the fact that boats which had motors were able to get through to the hunting grounds in Franz Josef Land.

Information about when and how the catches have been made at Svalbard gives us the possibility of assessing the walrus' movements.

Around Bjørnøya there was a stock of many thousands of animals both in summer and winter when walrus hunting began. Here we must suppose that the walrus was part of a local stock which did not move very far in the course of the year. Even so, we must allow for the possible connection between the walrus on Bjørnøya and Spitsbergen, especially in winters where there was much ice, and animals from the north have migrated south.

The stock of walrus, which was to be found in various areas in the Spitsbergen group of islands, must have been composed of partially stationary groups which, because of short distances, must have had some contact with each other. It is unlikely that the walrus in this area has migrated regularly over long distances summer and winter. If there had been regular migration from the west coast to the north-eastern areas in autumn and in spring, then the walrus over the whole group of islands would have been wiped out at the same time. We now know that for many decades the west coast had been hunted so thoroughly that there were no more walrus left (there were no more catches to be made either in winter or in summer), and the area did not become populated from the north-easterly areas where there was a stock of several thousand walrus.

The walrus does not make holes in the ice and thus it must withdraw from areas where the pack ice freezes or is very close. Pictures taken from satellites show that even at a time when maximum ice is to be found in winter, there are still open leads around Nordaustlandet and Hinlopenstretet (VINJE 1970). Therefore, the walrus which have lived in the north-easterly region have not had to move very far in order to exist during the winter. Observations from hunters suggest that in late autumn or in early winter there is a migration by the walrus from the north southwards towards Edgeøya and Tusenøyane, though it is very unlikely that all the animals move so far south. But it is certain that walrus are to be found all summer at Edgeøya, too.

There is nothing to suggest that there is an annual migration between the north-easterly parts of Svalbard and Franz Josef Land. Here, one can again refer to the fact that only insignificant catches were made in Nordaustlandet during the period 1920–34, while several thousand walrus were caught in Franz Josef Land during the same period.

The present status of the walrus in Svalbard

Observations of walrus in Svalbard made by NORDERHAUG (1969, 1970, 1971) (for the years 1960–70), and TOLLÉN (1960), and supplemented by personal observations by KNUT BJÅEN, KNUT JOHANNESSEN, captains SIGMUND SNARBY, JENS OLSEN, HÅKON GODTLIEBSEN, LORENTZ ALBERTSEN, and ERNST EILERTSEN, and the author during the years 1946–70 give a good picture of the distribution and occurrence of the walrus in Svalbard today.

There are no observations from Bjørnøya. An occasional walrus may be found there, but for the most part the island remains unvisited.

On the west coast of Spitsbergen, which is the most frequented part of the group of islands, nine walrus were seen during the period 1960–68. In the summer of 1969, three walrus were seen – a male, a female and a calf – at Kvadehuken in Kongsfjorden.

In the areas around Edgeøya, Barentsøya, Hinlopenstretet, the northern part of Spitsbergen, and Nordaustlandet occasional walrus and small flocks have been observed almost every year from 1950 until 1968. The largest flock – ten walrus –

was seen in Tjuvfjorden in November 1954. In the summers of 1969 and 70, many more walrus were seen than before. On the northern side of Spitsbergen and in the areas around Lågøya, near Nordaustlandet, flocks of walrus have been seen, although the size of the flocks has not, unfortunately, been mentioned.

We have only one observation from the areas around Storøya, Kvitøya, and Victoria Island after 1952, where in 1951 and 1952 two hundred or so walrus were seen, and that was made in August 1970, although it is to be remembered that this area is now rarely visited. This observation is from Kvitøya, where several flocks of about 50 walrus altogether were seen. We can presume that here there are still some hundreds of walrus – the remains of the large stock which was earlier to be found in Svalbard.

Observations of many more walrus seen during the last two years than before indicate that the protection of walrus since 1952 is now beginning to give results. We can suppose that if the walrus continues to be left in peace, it will eventually spread and repopulate the whole of the Svalbard area.

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Norsk Polarinstitutts virksomhet på sokkelen[1]

(The activity of Norsk Polarinstitutt relating to the continental shelf)

AV

TORE GJELSVIK

Abstract

Most of the work of Norsk Polarinstitutt has taken place in the Svalbard archipelago and the surrounding waters, i.e. the north-west part of the Barents shelf.

Onshore, geodetic and topographic work, including aerial photography, have been carried out since 1910, to establish the coastal base for the hydrographic surveying of the fiords and offshore sounding. Thanks to acquisition of a mobile electronic navigation system in 1963, the accuracy and progress in hydrographic work in later years have been notable.

A great amount of geological information has been collected on the islands themselves, relating in part to the "basement" of the sedimentary basin supposed to underlie most of the shelf, in part to the sediments themselves.

In 1970 the institute, in co-operation with the Continental Shelf Division of the Royal Norwegian Council for Scientific and Industrial Research and other Norwegian institutions, initiated the "Barents Shelf Project" which consists of magnetic, gravimetric, and seismic measurements, acoustic surveying, photography, biological and geological sampling of bottom layers, as well as of an increased programme of oceanographic measurements for sea ice studies. Consideration is also given to the pollution problem.

In 1970 aerial and marine magnetic surveying of the archipelago and the waters to the south was carried out, the detailed sounding of the Spitsbergen Bank concluded. Two oceanographic buoys with automatic instrumentation for measuring current direction and speed, temperature and salinity were anchored at a depth of 50 m below surface.

Før sin rekonstruksjon i 1948 het Norsk Polarinstitutt Norges Svalbard- og Ishavs-undersøkelser. Allerede dette navnet forteller at instituttets oppgave var en kombinert oppgave, en undersøkelse av Svalbardøyene og det omgivende hav, som er den nordligste del av det grunne shelfhav, Barentshavet, og dekker den nordligste og bredeste del av den norske kontinentalsokkel.

Geologisk, til dels også geografisk, er det naturlig å oppfatte øyene som en integrerende del av Barentsshelfen, og en kan si at nesten all den virksomhet som instituttet har drevet i dette området angår sokkelproblemene. Denne virksomhet dekker et bredt naturvitenskapelig fagspektrum. Imidlertid skal jeg innskrenke

[1] Foredrag holdt på Industriseminaret, Universitetet, Blindern, 9/12, 1970.

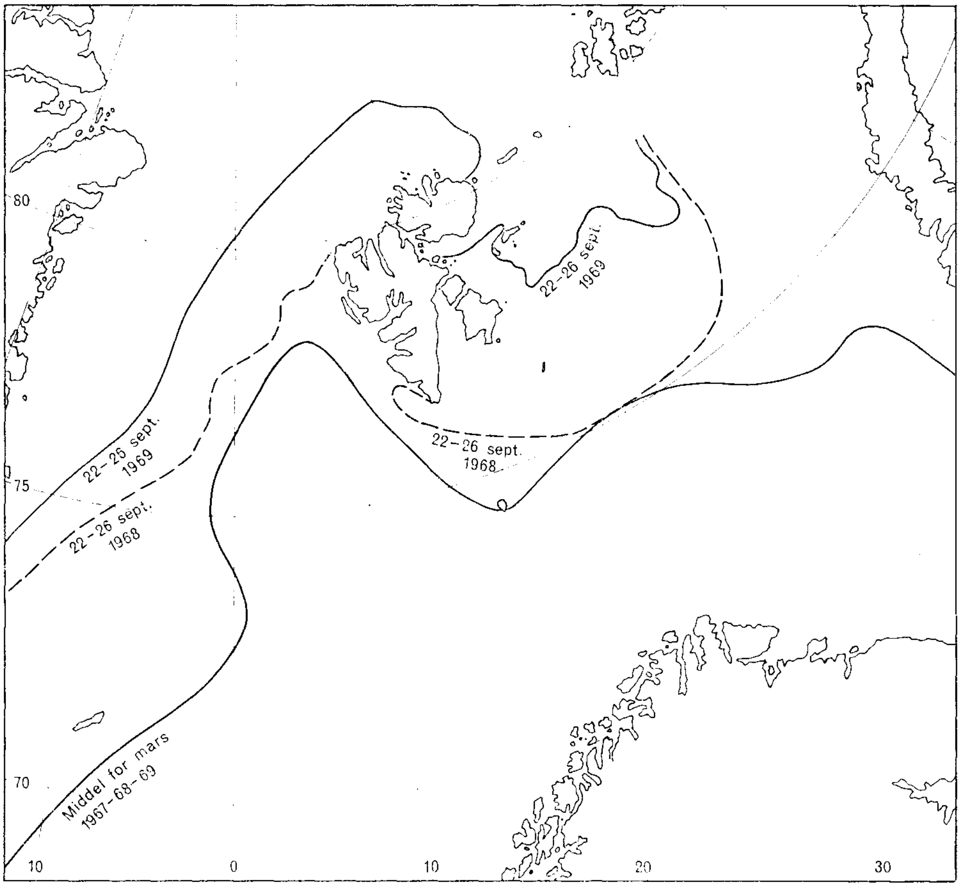

Fig. 1. *Isgrenser for «beste» ismåned (september) i 1968 og 1969 i forhold til gjennomsnittet for «værste» ismåned (mars, 1967–1969).*

meg til å berøre den virksomhet som har mest direkte betydning for den aktuelle målsetting for undersøkelsene av kontinentalsokkelen.

Da instituttet begynte sin virksomhet omkring 1910 under navnet De norske statsunderstøttede Spitsbergen-ekspeditioner, eksisterte bare et primitivt kartverk, som hva landkart angår var ubrukbart for enhver økonomisk målrettet virksomhet, og pålitelige sjøkart manglet. Det ble derfor en påtrengende oppgave å utarbeide et adekvat kartverk, og det er fortsatt en av instituttets hovedoppgaver. All virksomhet i feltsesongen, månedene juli og august, var basert på båt-transport, og mangelen på brukbare sjøkart vanskeliggjorde arbeidet i dette farlige farvann, som ved siden av å være meget grunt også har sterke tidevannsstrømmer og når som helst kan bli isfylt (Fig. 1). Sikten er ofte dårlig, det var ikke for ingenting Nansen kalte sin bok om disse farvann «Nord i tåkeheimen».

Men det topografiske og geodetiske arbeidet for *landkartleggingen* måtte gå foran, sjøkartleggingen er avhengig av en kystkontur og faste punkter på land. Dette var et slitsomt og langsommelig arbeid i disse veiløse områder, hvor topografene måtte klatre opp fra kysten til de utvalgte toppene med sitt tunge utstyr

Fig. 2. *En av Norsk Polar-institutts topografer i arbeid.*
Foto: O. Steine

(Fig. 2) i et bratt og ulendt fjellterreng, oppdelt av tallrike isbreer med stygge sprekkefall. Det trigonometriske nett var ført opp langs vestkysten og rundt nordkysten så langt som til Wijdefjorden, men i det indre fjellområde på Spitsbergen og over de østlige øyene var det bare spredte målinger uten ordentlig kontroll og sammenheng. I de indre fjellområdene kunne man ikke komme lenger med de mangelfulle fremkomstmidlene, og i de østlige farvann slapp man sjelden til p.g.a. isen. Et pionérarbeid fra denne tid fortjener å nevnes, instituttets topografiske avdeling var den første i Norge til å ta i bruk flyfotografering for kartleggingsformål, og nesten hele øygruppen ble dekket med skråfotografier i 1936 (Fig. 3), og instituttet anskaffet sammen med Norges geografiske oppmåling den første planigraf til landet.

Sjøkartleggingen var ført fram i skipsleia fra Bjørnøya til Ny-Ålesund, og alle de større fjordene på vestsiden av Spitsbergen var opploddet. I de østlige områder fantes sjøkart i liten målestokk og med få loddskudd. Det gikk uhyre smått fremover, dels fordi man var avhengig av klar sikt til fastpunkter på fjelltopper i land, dels fordi hydrograferingsarbeidet måtte utføres med det vanlige ekspedisjonsfartøyet som hadde utallige andre oppdrag i den korte feltsesongen. Når skuta

Fig. 3. *Skråbilde fra flyfotografering i 1936. Strandflaten nord for Lågneset, Bellsund, Spitsbergen.*

omsider var ledig for sjøkartleggingen, var det sjelden det klaffet med vær og sikt. Målinger av tidevann og magnetisk misvisning er blitt utført som ledd i den hydrografiske aktivitet.

En viktig oppgave fra tidlig tid var også *geologiske undersøkelser*. Den internasjonale konkurranse om kullfeltene og andre råstoffer, som gips-, fosfatleier og malmforekomster, satte preg på undersøkelsene. Den knappe geologstab, to-tre mann, gjorde at systematisk kartlegging ikke kunne settes i gang samtidig. Det bør nevnes at instituttets geologer tidlig interesserte seg for oljespørsmålet og allerede i 1926 gjorde en spesialundersøkelse med henblikk på problemet. Imidlertid har jo Spitsbergens geologi fristet noen få andre norske geologer og tallrike utenlandske, slik at det alt i alt var utført et betydelig geologisk arbeid. Takket være dette forarbeidet og med utnyttelse av skråfotografiene kunne dr. A. K. ORVIN i 1940 publisere et geologisk kart (målestokk 1:1 000 000) med beskrivelse, som betydde en milepæl i den geologiske utforskning av øygruppen. Dette arbeid ga en oversikt både over de viktigste trekk i stratigrafien og i de tektoniske forhold, og senere tids undersøkelser har bare i mindre grad kunnet endre de hovedkonklusjoner ORVIN kom fram til. Som man ser på Fig. 4 er alle de geologiske systemer fra Prekambrium til Kvartær representert, bare i noen relativt korte og spredte perioder har området ligget over havets overflate. På denne måte skiller forholdene seg sterkt ut fra de tilsvarende på fastlands-Norge, hvor de postkaledonske forma-

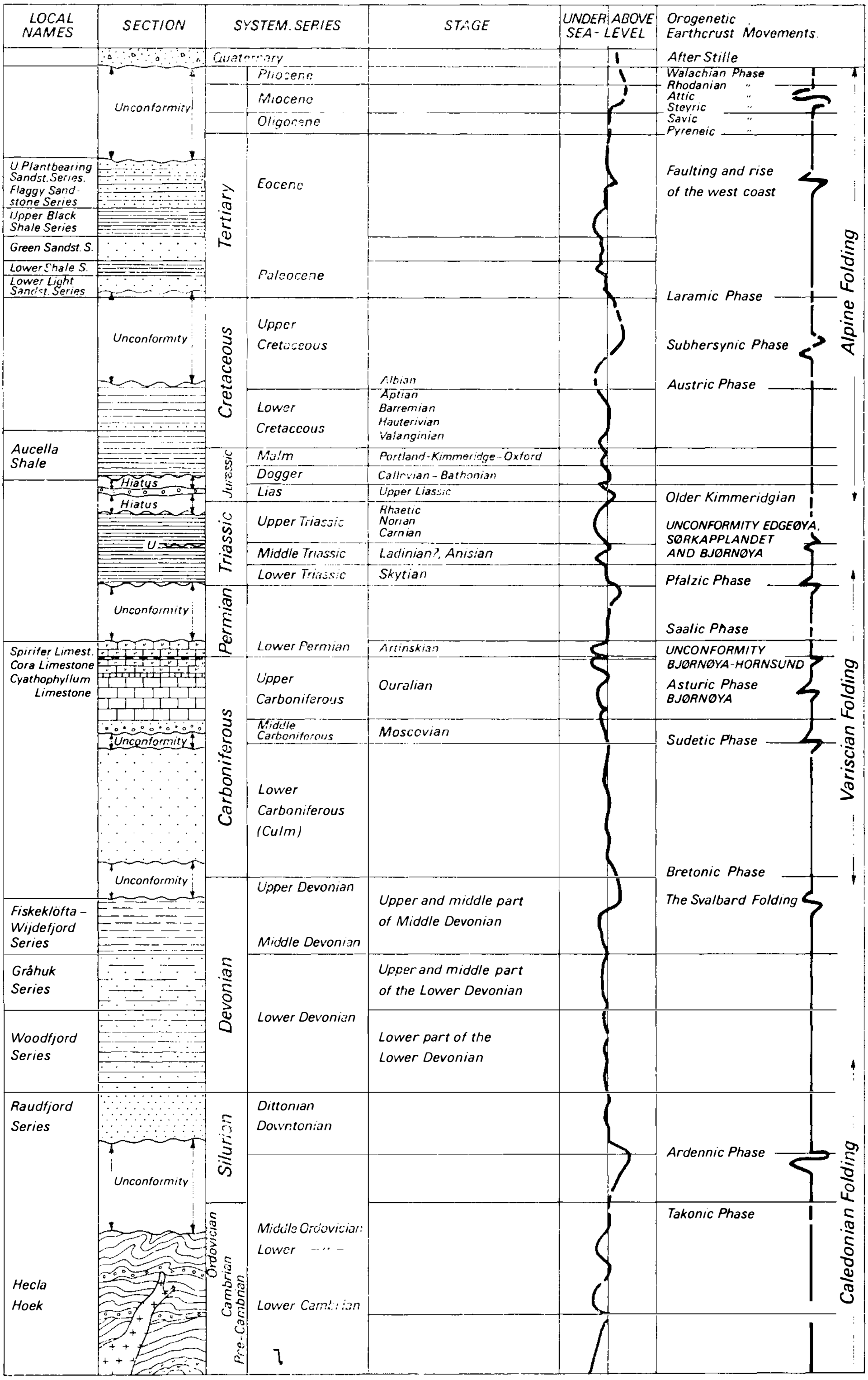

Fig. 4. *Skjematisk stratigrafisk kolonne som viser de geologiske systemer på Spitsbergen.* (Fra A. K. ORVIN: *Outline of the geological history of Spitsbergen.*)

sjoner praktisk talt er fraværende. Bjørnøya var tidlig gjenstand for meget detaljerte undersøkelser. Et kart i målestokk 1:50 000 ble utarbeidet av instituttets geologer allerede i 1920-årene. Denne øya som ligger så isolert halvveis mellom Spitsbergen og Finnmark, inntar i likhet med Hopen lenger øst en nøkkelposisjon for tolkningen av geofysiske og geologiske data fra Barentsshelfen. De geologiske undersøkelser på Svalbard hadde, i likhet med den topografiske kartlegging, stort sett innskrenket seg til de lettere tilgjengelige områder. Fremdriften av så vel de geologiske undersøkelser som sjø- og landkartleggingen var dessuten hindret av et mangelfullt kjennskap til isforholdene.

I 1961 la instituttet fram en 3-årsplan for effektivisering av instituttets feltvirksomhet. Hovedpunkter var helikopterstøtte for topografer og geologer, eget fartøy og moderne elektronisk navigasjonsutstyr for sjøkartleggingen, en utvidelse av den geologiske avdeling til 5 mann og igangsetting av systematiske sjøisundersøkelser ved hjelp av en fast ansatt geofysiker. Myndighetene stillet seg stort sett positive til forslaget, og fra sesongen 1963 av lyktes det å komme i gang etter de nye planer. Det har dog i de fleste år vært vanskelig å få en effektiv helikopterordning innenfor den økonomiske ramme instituttet er blitt tildelt.

Det skal ikke her gis noen detaljert fremstilling av de enkelte års virksomhet, bare en oversikt over resultatene.

Landkartlegging: Vertikalflyfotografering er fullført over Spitsbergen, Kong Karls Land, Barentsøya og den vestlige halvpart av Nordaustlandet. Det trigonometriske nett er fullført på Spitsbergen, også med kontrollmålinger over høydepassene. Distansemålinger med tellurometer er blitt stadig utvidet. Et betydelig arbeid er også utført for å knytte Edgeøya og Barentsøya til Spitsbergennettet og fremskaffe fastpunkter for ny konstruksjon av kystkonturene der. Dette har vært prioritert de siste sesonger for å kunne få trukket opp grensene mellom Svalbards 4 sjømil brede sjøterritorium og den helnorske sokkel som omgir det. Det er imidlertid ikke mulig å knytte de østligste øyer til Spitsbergennettet ad optisk vei, og da det ved elektroniske avstandsmålinger har vist seg at Bjørnøyas kartmessige beliggenhet i forhold til Spitsbergen, tross astronomiske stedsbestemmelser, synes å være beheftet med betydelige feil, har instituttet i samarbeid med Norges geografiske oppmåling og utenlandske spesialister vinteren 1970/71 satt i gang et satelittfotograferingsprogram i Ny-Ålesund, som vil knytte Spitsbergen til det europeiske datum i Tromsø. Til sommeren vil vi gjennomføre et dopplerprosjekt, slik at Kvitøya, Kong Karls Land, Bjørnøya og Hopen geodetisk kan knyttes til denne nye kjede fra Tromsø til Ny-Ålesund.

Fremgangen i *sjøkartleggingen* siden 1963, da vi anskaffet det elektroniske navigasjonssystemet Decca Hi-Fix og fikk leie et fartøy av Marinen til opploddingsvirksomheten, har vært betydelig (Fig. 5). Farvannene i sørøst har vært prioritert, vi må benytte de gode isår til å lodde der. Ny lodding på vestkysten har vært utført når vi ikke kunne slippe til andre steder. Det fra et oljesynspunkt så interessante område mellom Sørkapp, Hopen og Bjørnøya — Spitsbergenbanken og Storfjordrenna er blitt ferdig opploddet i og med sommerens målinger. Nye sjøkart kan imidlertid ikke konstrueres før satellittprogrammet har gitt den nødvendige geodetiske kontroll.

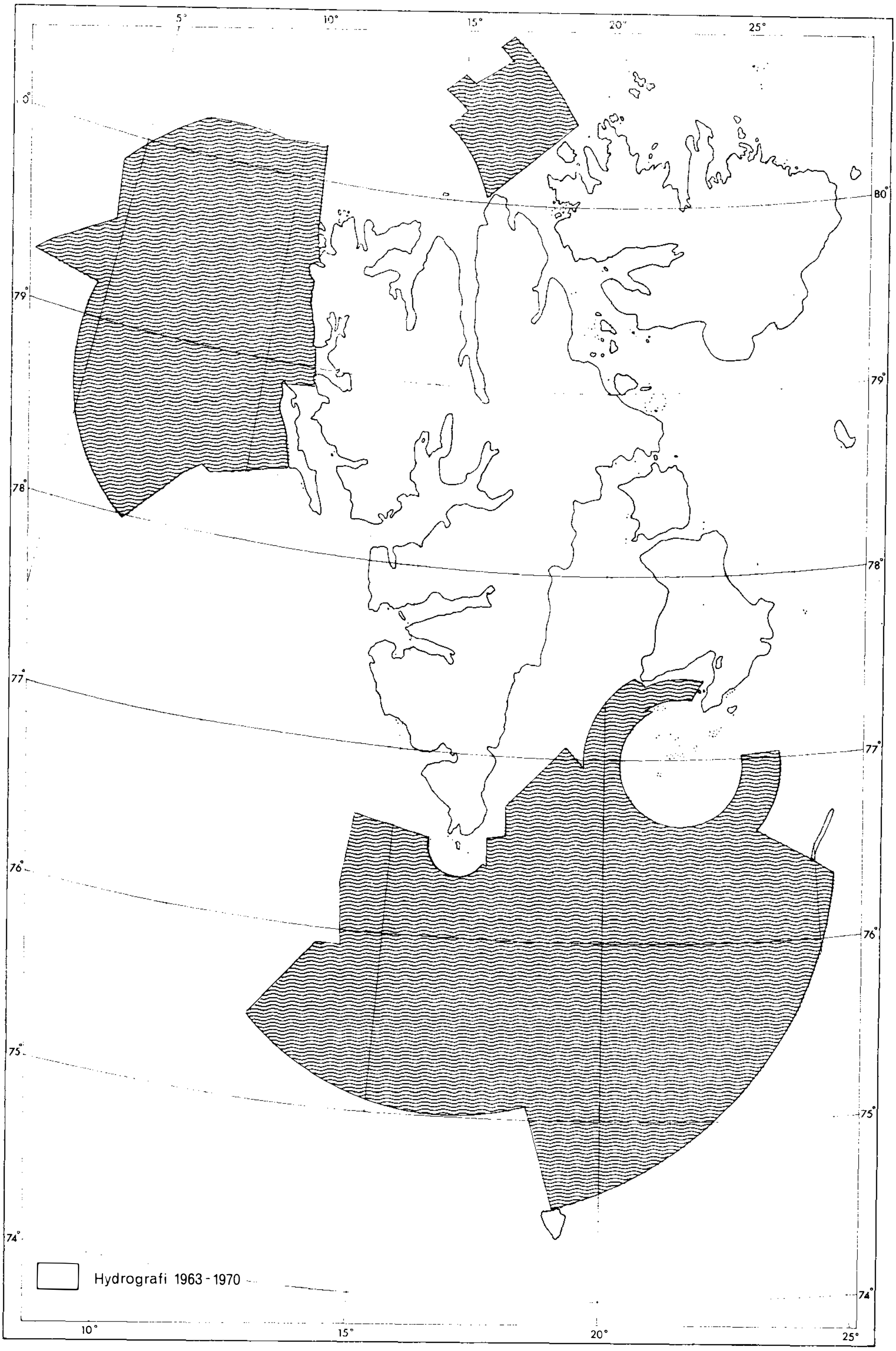

Fig. 5. *Områder som er opploddet i tiden 1963–1970 med elektronisk navigasjonsmiddel.*

På den *geologiske front* har arbeidet i disse år i første rekke måttet bestå i å dekke tidligere ukjente områder, som det indre av nordvest-Spitsbergen og Nordaustlandet. I 1969 kunne vi således publisere en ny oversikt over geologien i de isfrie deler av Nordaustlandet, sammen med et geologisk kart i målestokk 1: 200 000. Det er basert på en sommers teamwork av fire-fem geologer understøttet av helikopter og et ishavsfartøy – for øvrig en sommer da isforholdene var særdeles vanskelige (Fig. 6). Disse områder er for så vidt ikke oljepotensielle, men kjennskapet til dem er likevel av stor betydning for bedømmelsen av «basement»-problemet i Barentshavet. Både på Nordaustlandet, Spitsbergen og Bjørnøya har det vist seg at de øvre formasjoner av de metamorfe bergarter i stor grad består av karbonatbergarter eller andre sedimentære lag med lite innhold av magnetitt, og en bør nok tolke de magnetiske data fra fly og fartøyer med forsiktighet.

Undersøkelser m. h. p. oljemulighetene i de yngre, umetamorfe sedimentserier som dekker den sørøstlige og østlige del av øygruppen, og som antas å dekke større deler av Barentssokkelen, har måttet gå hånd i hånd med kullundersøkelsene og geologisk kartlegging.

Etter at den topografiske serie i 4 blad i 1: 500 000 kom ut, er disse gitt prioritet i geologisk kartlegging foran 1:100 000-kartene. Det første av dem, Søre Spitsbergen, ble utgitt i mai 1971, det andre, Edgeøya, vil utkomme i en foreløpig svart-hvitt utgave. Også dette kart er et eksempel på resultatet av et godt teamwork i *en* feltsesong, utført av tre-fire geologer, godt understøttet av ekspedisjonsfartøyet med helikopter, under ledelse av operasjonssjef THOR SIGGERUD.

Undersøkelser av de umetamorfe formasjoner på Svalbards landområder har gitt en rekke opplysninger av betydning for vurderingen av oljemulighetene på sokkelen.

Instituttet innledet i 1963 sine *sjøisundersøkelser* ved organisering av observasjoner ved ishavsstasjonene og overvintrende fangstfolk, samt data fra ishavsskuter, senere ved flytokter av Luftforsvarets Albatrossving på Andøya. Instituttet kunne deretter utarbeide regelmessige iskart for sommersesongen. En betydelig støtte for undersøkelsene kom med de daglige satellittfotos som instituttet fikk oversendt, først fra København, senere fra Meteorologisk Institutt på Blindern. De gjorde kartene sikrere og mer detaljerte, og instituttet begynte å sende ut ukentlige iskart i sommerhalvåret til rederier og andre interesserte. Meteorologisk Institutt har nå overtatt den rutinemessige iskarttjeneste, slik at Polarinstituttets isforsker kan konsentrere seg om andre oppgaver. Strålingsmålinger av ymse slag er kommet i gang ved den faste vitenskapelige stasjon i Ny-Ålesund, som instituttet administrerer.

Det er Meteorologisk Institutt, gjennom Vervarslinga for Nord-Norge, som har ansvaret for værvarslingen for Svalbard og Ishavet, og som derfor driver ishavsstasjonene på Spitsbergen, Bjørnøya og Hopen. Norsk Polarinstitutt har en meteorolog for forskningsoppgaver, som bl. a. for hvert år publiserer oversikter over værutviklingen i instituttets årbok (se s. 252–255).

Den opptrapping og tekniske modernisering som ble gjennomført ifølge 3-årsplanen av 1961, har brakt kartleggingen på sjø og land ut av dødvannet og satt fart i de geologiske undersøkelsene. Men det var klart at det var en lite tilfreds-

Fig. 6. *Fra den geologiske kartlegging av Nordaustlandet, utført med støtte av helikopter og ishavsfartøy.*

Foto: T. S. WINSNES

stillende situasjon å ha et skip med et kostbart navigasjonsutstyr, men ellers bare med et ekkolodd som instrumentering. Virksomheten i den norske sektor i Nordsjøen var kommet i gang, og dimensjonene av våre sokkelinteresser begynte å avtegne seg. Instituttet ville gjerne ta fatt på sin del av oppgaven og la i 1966 fram et forslag om noen nye stillinger for å kunne ta opp et geofysisk og maringeologisk arbeid på sokkelen. Denne gang hadde det ikke myndighetenes øre, det ble avslag med henvisning til at det ennå ikke var avgjort hvordan de norske sokkelundersøkelsene skulle organiseres. Det var først etter at arbeidet ved NTNF's kontinentalsokkelkontor for alvor kom i gang at det ble realistiske muligheter for instituttet til å komme i gang med et utvidet arbeid på sokkelen. I mellomtiden hadde oljefunnet på Prudhoe Bay på Alaskas nordkyst og gass/oljefunn på den russiske ishavskyst igjen fokusert oljeselskapenes interesse på Svalbardområdet etter at interessen hadde dabbet noe av da Caltex' 3 500 m dype borhull på Spitsbergen bare hadde påvist økonomisk uinteressante spor av gass.

Høsten 1969 la Norsk Polarinstitutt fram for prosjektstyret i NTNF en *rammeplan* for vitenskapelige undersøkelser av Barentssokkelen. Instituttets forutsetninger for å fremme forslag om en slik undersøkelse kan sammenfattes slik:

1. Den geologiske stab har en god innsikt i de øvre paleozoiske, mesozoiske og tertiære bergarter og strukturer på Svalbard, likeledes når det gjelder bergarter og tektonikk i «basement». Den har innsamlet et omfattende materiale fra øyene som kan anvendes i sokkelundersøkelsene.
2. Staben omfatter en rekke faggrupper av betydning for sokkelundersøkelsene, og den tekniske utvikling har medført et stadig større tverrfaglig samarbeid i

felt. Instituttets struktur, fastlagt av hensyn til de spesielle forhold i polartraktene, viser seg å være godt anvendbar på dagens sokkelundersøkelser i samme strøk.

3. Instituttet har lang erfaring i operasjoner i disse vanskelige og til dels farlige havområder. Ved hjelp av et mobilt og nøyaktig elektronisk navigasjonsutstyr og et leiet fartøy utfører det hvert år batymetriske målinger i sokkelområdet. En faglig ekspansjon ville være billig og lett å gjennomføre når bare de dertil nødvendige midler og fagfolk kunne tilføres.
4. Instituttets sjøisundersøkelser kunne med beskjedne midler utvides og innstilles på de nye tekniske problemer som oljemuligheter på sokkelen skapte.

Et femte moment kan tilføyes. Det foregår en betydelig virksomhet ved utenlandske ekspedisjoner. Med sine gode kontakter til de fleste av disse og ikke minst de russiske, kan instituttet som også har en egen oversetter av russisk polarlitteratur i sin stab, nyttiggjøre resultatene til de utenlandske ekspedisjonene for det norske Barentshavprosjekt.

Men instituttet måtte ha assistanse fra andre i fagområder det ikke selv dekker, og den fremlagte plan forutsetter et vidtgående samarbeid.

Rammeplanen ble raskt akseptert og satt ut i livet. JENÖ NAGY som var prosjektets geologiske leder, utarbeidet først et strukturkart som grunnlag for planleggingen av geofysiske undersøkelser. Området Sørkapp (Spitsbergen)–Hopen –Bjørnøya som omfatter Spitsbergenbanken, det største området med dybder under 100 m som finnes på den norske sokkel, ble gitt førsteprioritet.

Feltundersøkelsene startet i april måned 1970 med flybårne magnetiske målinger ved geofysisk avdeling, Norges geologiske undersøkelse. Målingene skulle etter planen først utføres over de kjente geologiske formasjoner over land, slik at man kunne gjøre en sikrest mulig korrelasjon med senere geofysiske data fra havområdet. P.g.a. navigasjonsmessige vanskeligheter fikk man stort sett bare fløyet de profiler som gikk over land eller øyer. (Senere på sommeren har Norges geologiske undersøkelse også dekket området mellom Bjørnøya og Finnmark.)

Under toktet 1970 ble Norsk Polarinstitutts hydrograferingsfartøy i tillegg til vanlig ekkolodd også utstyrt med et penetrasjons-ekkolodd og et magnetometer. Den siste del av det prioriterte område ble dekket, og likeledes ble det kjørt en del ekstra profiler med magnetometer og penetrasjonsekkolodd over den tidligere opploddete del av dette. Dermed har vi fått en preliminær magnetisk dekning av hele Svalbardområdet og Barentshavet.

Jordskjelvstasjonen i Bergen utførte på slutten av sesongen et seismisk tokt i Barentshavet. Den grunne Barentsshelfen har vist seg å by på tekniske problemer, og Jordskjelvstasjonen ønsket derfor å utføre mesteparten av målingene i det dypere området mellom Bjørnøya og Finnmark. Det ble imidlertid gjort et snitt og et par refraksjonsmålinger i den vestlige del av Spitsbergenbanken.

Ved siden av de feltmessige målinger har Polarinstituttets geologer fortsatt sine kart- og litteraturstudier og bl. a. utarbeidet et kart over bunnforhold og sedimenttyper. Kartet vil supplere dataene fra penetrasjonsekkoloddet og gi veiledning for det prøvetakingstokt som planlegges for neste sesong. Vi regner med i neste sesong å få videreført de geofysiske og batymetriske målinger. Det store problem for så vel undersøkelser som eventuell drift i Barentshavet er selvsagt polarisen. Ved siden av isdekket er strømforholdene av stor betydning. I Svalbardområdet møtes strømmer av forskjellig temperatur og retning, og den store tidevannsforskjell medvirker til å skape store variasjoner. Under Barentshavprosjektet har Polarinstituttet kunnet øke sine isundersøkelser i vesentlig grad, særlig m.h.p. å klarlegge strømforholdene. Sommeren 1970 ble det således satt ut to oseanografiske bøyer. De registrerer strømstyrke og -retning, temperatur og saltholdighet hver time i ett år. Flere bøyer vil bli satt ut i neste sesong. I samarbeid med NTNF's kontinentalsokkelkontor har instituttet arbeidet med å finne en hensiktsmessig metode for direkte måling av isens fart og retning. Denne del av isprogrammet håper vi at vi kommer i gang med fra neste sesong. Resultatene vil bl. a. bli nyttiggjort av Havnelaboratoriet ved NTH, som arbeider med spørsmålet om polarisens virkning på konstruksjoner i havet. De strømmålinger som gjøres har også betydning for naturvernproblematikken. Instituttet har følt et ansvar for den ømtålige økologiske balanse på Svalbard. I polarområdene dekomponerer olje meget langsommere enn i varmere strøk, og en eventuell oljelekkasje kunne få katastrofale følger for det rike dyre- og fuglelivet. Et biologisk program utarbeidet av instituttets biolog vil bli inkludert i prosjektet fra neste sesong. Instituttet takker NTNF's kontinentalsokkelkontor, Marinen, Jordskjelvstasjonen og Norges geologiske undersøkelses geofysiske avdeling for god assistanse og godt samarbeid om utforskningen av vårt nordligste sokkelområde.

The Norwegian Antarctic Expedition 1970-71

BY

THORE S. WINSNES

After the Norwegian Antarctic Expedition 1968–69 it was decided to have a similar expedition to H. U. Sverdrupfjella in Dronning Maud Land in the season 1970–71. The area had previously been visited by a field group from the Maudheim (of the Norwegian-British-Swedish Antarctic Expedition) in 1951 and later by Russian geologists in 1960. The westernmost area was visited by the Belgian Antarctic Expedition in 1968.

The plan for the expedition was to make a more detailed geological mapping of the area together with a study of the biology. The glaciology of the area would also be studied, and one would try to get measurements of the big Jutulstraumen glacier. Finally, the microclimate above the snow surface would be studied.

Only the scientific and some radio equipment were brought from Norway. The field equipment and the transportation to the working area were contributed by the National Science Foundation in Washington. The members of the expedition consisted of six men: T. S. WINSNES, leader, and A. HJELLE, both geologists; T. VINJE, meteorologist; Y. GJESSING, glaciologist; J. ANGARD, biologist; and E. NETELAND, radio operator.

The expedition left Oslo 21 October and arrived in Christchurch, New Zealand, some days later. Here the expedition members were fitted out with polar clothing and then flown south to McMurdo, the main American base in Antarctica, from where all American land operations in the continent are arranged.

In McMurdo an intense activity prevailed, with a great number of field expeditions making ready for the season's work. The Norwegian group started to collect equipment for their work. This took some time, and as the toboggans were in a bad shape from last season, they had to go through major repairs. In the meantime the expedition members had opportunity to do some physical training and to join a course in snow and ice craft, led by New Zealand experts.

After trying out the Polaris toboggans, the expedition was loaded aboard a Hercules airplane on 20 November. To be able to reach H. U. Sverdrupfjella with a total load of 14,000 pounds, it was necessary to refuel at the Pole, and later at the English base, Halley Bay, at the east coast of the Weddel Sea. This made it necessary to bring along another Hercules with a load of fuel from which sufficient fuel for the rest of the trip could be had. The first trip had to turn back as low clouds coming in over Halley Bay just before the aircrafts arrived there prevented landing.

For a period bad weather and also bad radio conditions prevented another try, but finally on 30 November it was decided to make another try.

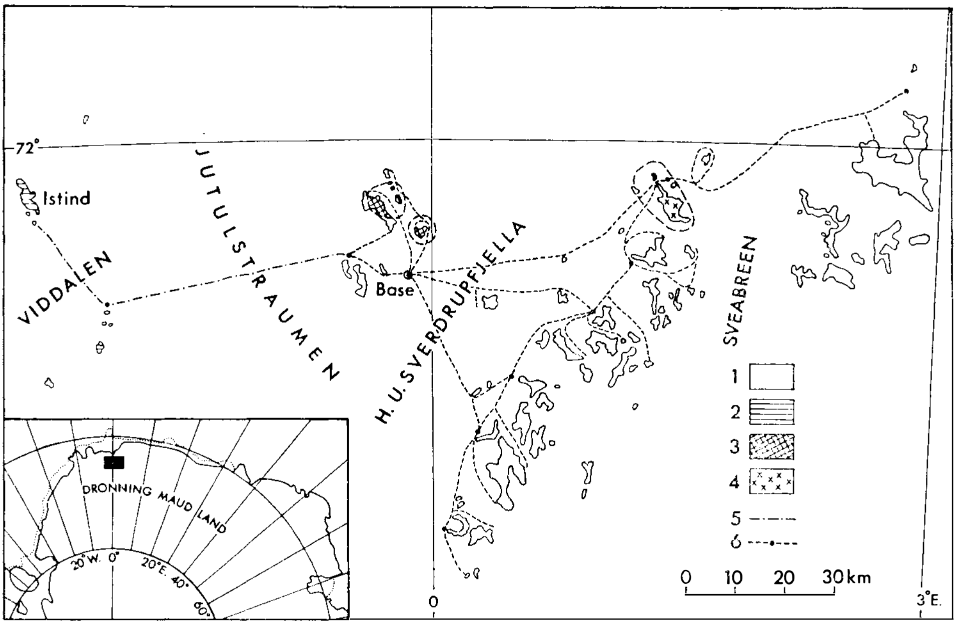

Fig. 1. *Area covered by the Norwegian Antarctic Expedition 1970–71. Legend: 1 – amphibolite gneisses and meta-sediments, 2 – sedimentary rocks in the west. 3 – nepheline-syenite, 4 – granite, 5 – gravimeter traverse, 6 – sledge journeys with field camps.*

After eight hours' flight a landing was made in Halley Bay after a brief stop at the Pole. In Halley Bay the snow was too soft to allow starting with the total load, and two trips to H. U. Sverdrupfjella were found necessary. The landing area was covered by clouds but by radar navigation it was possible to find the area and to land through a small rift in the clouds. Before the next trip the weather had improved somewhat, and twelve hours after the start from McMurdo the expedition could begin to build their main base. It was situated some 40 km west of the spot planned, but proved to be just as good for the work to be done. (See Fig. 2.)

After building the camp, the next task was to erect the instruments for meteorological observations and observe the nearest mountains for nesting birds. As soon as possible a row of 15 marks were erected across the 50 km wide Jutulstraumen glacier. These were sighted in with a theodolite for accuracy. At the end of the season they were remeasured and the movement of the glacier surface will be evaluated. Some poles put up in 1968 were refound and remeasured too. Thus it was possible by comparing their height then and now to find the accumulation of snow in the interval.

During the crossing of the glacier a gravimetric traverse was done. The Worden gravimeter was used at some gravimeter bases in McMurdo, and the values in Dronning Maud Land will therefore be connected with the American net. This is of great value for further gravity work in eastern Antarctica.

At the base micrometeorological measurements were registered on tape every five minutes, comprising temperature, wind speed, air moisture, snow temperature, and radiations. Some 200 measurements of the wind profile in the lower one metre

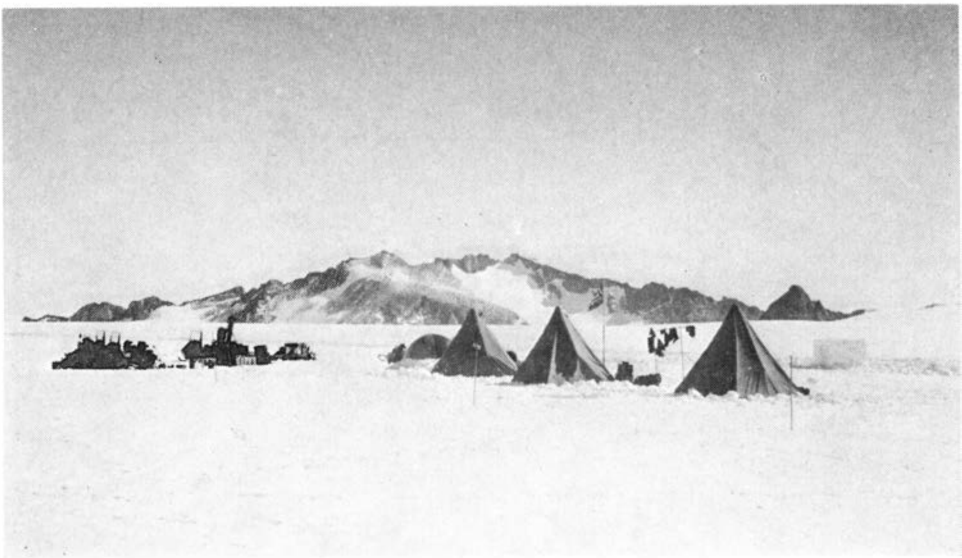

Fig. 2. *The main base, Camp Norway 2.*

were done by hot wire anemometer and the temperature profile by thermocouples. The sencors were placed on a movable arm. Ordinary meteorological observations were taken every three hour from 0900 to 2100.

As no nesting birds were observed in the neighbourhood of the base, work was more centered on the study and collecting of plants and insect material. Studies of temperature variations of the rocks during day and night gave indications of the climatic conditions. Collections were made from all over the mountain area.

During more than 1,000 km of sledge journeys by two cooperating field groups, consisting of two men each, the H. U. Sverdrupfjella was geologically mapped and a collection of rock samples was made (see the map, Fig. 1).

The weather conditions were very good. Little wind and temperatures above what was expected made camping very easy. The temperature varied from –2° to –20°C. Most of the area also had a good snow surface for travel, but near the mountains very coarse sastrugi were common.

Apart from a visit to the base during Christmas time, the field groups spent most of their time in the mountains. A daily contact was maintained with the base through small field radio sets. The base was in daily communication with the South African base, SANAE. Through them a contact with the McMurdo base and with Norway was maintained.

By 20 January the field work was completed, and during ten days of waiting for return transport work was done near the base. Finally, on 3 February conditions were favourable and the expedition was picked up by a Hercules airplane, and brought back to McMurdo. After a couple of days here with packing material for shipping, the members were flown to Christchurch where some summer days were spent before the next transport brought the expedition members back to America and Norway.

Mass transport of Jutulstraumen ice stream in Dronning Maud Land

BY

YNGVAR T. GJESSING[1]

Contents

Abstract

An estimate is given of the mass transport of a 50 km wide ice stream in Dronning Maud Land. The cross section of the glacier is determined by a chain of 16 gravimeter stations, using an approximate ice-rock density difference on the calculated residual gravity anomalies. The velocities were determined by theodolite observations between the different gravimeter stations. The maximum ice thickness and velocity were found to be 1560 m and 390 m/year respectively. The mass transport of the ice stream was estimated at $76 \cdot 10^8$ ton/year.

Introduction

Jutulstraumen ice stream is located in Dronning Maud Land, near the zero meridian. It leads from the Antarctic plateau about 3000 m above sea level to Kronprinsesse Märtha Kyst, and is bounded by the mountain massifs Sverdrupfjella to the east, and Borga and Ahlmannryggen to the west. The ice stream is about 250 km long and its narrowest part is 50 km wide (Fig. 1).

The Norwegian Antarctic Expedition 1970–71 operated in this area. The field work on Jutulstraumen was carried out in the interval 10 Dec. 1970–20 Jan. 1971.

Observations and calculation methods

In order to calculate the mass transport of a glacier, a cross section and the velocity distribution in this cross section have to be known.

Although the gravity method is less accurate for glacier thickness studies than

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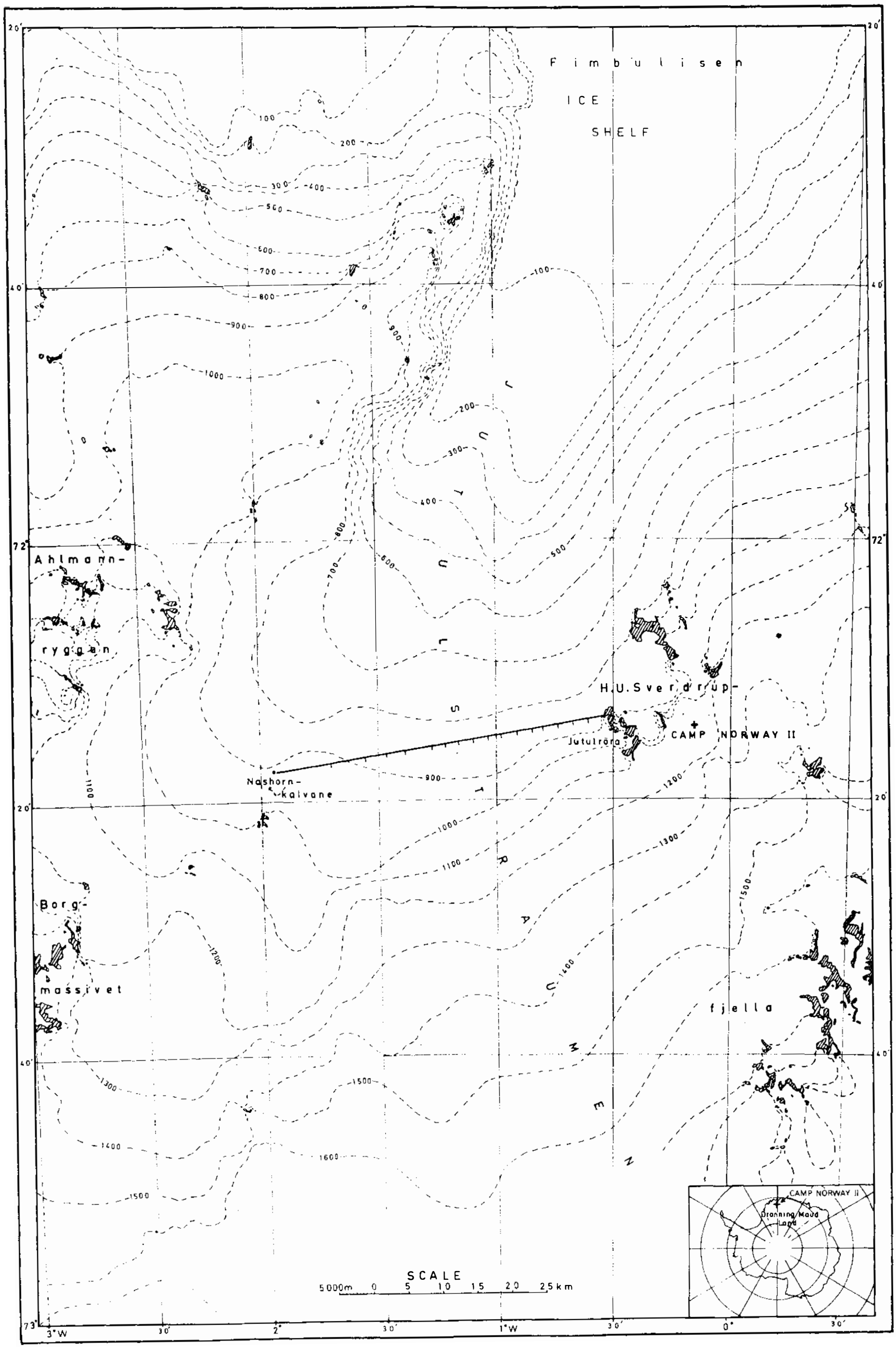

Fig. 1. *Map of Jutulstraumen ice stream and the surroundings.*

seismic measurements, radioecho-sounding, or drilling, it has the advantage of simplicity and rapidity in the field. The instrument used for our gravity measurements was a Master Worden Gravimeter (Model 121), generously lent to us by the Seismological Observatory at the University of Bergen. Absolute gravity measurements were carried out in the area using the gravity station McMurdo D as reference. However, relative measurements are more relevant for calculations of ice thickness. The gravity stations on the glacier were established by a running line of sight traverse with snow toboggans between two reference stations on firm ground, Jutulrøra and Nashornkalvane. The distances between the stations were determined by means of a distance meter mounted on a Nansen sledge. This method was checked by repeated measurements, and by comparison with the total distance from Jutulrøra to Nashornkalvane, which was known from previous mapping. The accuracy should be at least within $\pm$ 100 m. The altitudes of the stations were determined by repeated altimeter measurements and were related to the reference stations. The relative elevation is presumably accurate to $\pm$ 5 m. Each station was marked with empty oil drums.

For practical reasons all observed gravity values were referred to the reference station at Jutulrøra. Next, the so-called Bouguer anomalies (B) for the gravity stations on the glacier and for Nashornkalvane were calculated. This relative Bouguer anomaly is supposed to be caused mainly by the mass deficit due to the substitution of ice for rock. However, the effect of the regional trend of B, unrelated to the ice thickness, is also included in the anomaly. If no such trend exists, there should be no relative Bouguer anomaly at Nashornkalvane. The relative Bouguer anomaly at the latter station was, however, –17.1 mgal.

The geology at the two reference stations is quite different. At Jutulrøra the surface consists of gneiss with a density of 2.7 g cm^{-3}, while at Nashornkalvane sandstone with density of 2.5 is exposed. Consequently, at some place between these two stations there exists a geological boundary which cannot be located exactly. We have here assumed that the trend of the Bouguer anomaly unrelated to ice thickness is approximately linear.

The residual anomaly was corrected for topography and elevation (HAMMER 1939). The first rough determination of the ice thicknesses was made by applying the infinite slab Bouguer correction:

$$g - G = K \cdot h\,(q_1 - q_2) \quad \text{or} \quad h = \frac{g - G}{K \cdot (q_1 - q_2)}$$

where g and G are the theoretical and observed gravity respectively, h is the ice thickness, K is a proportionality factor, and q_1 and q_2 are the densities of rock and ice respectively. In the present survey the density difference was 2.60 (rock) minus 0.90 (ice) equal to 1.70 g cm^{-3}, or 14.05 m ice thickness per mgal.

With a bedrock configuration determined in this manner, it is possible to apply more refined methods to eliminate the assumption of infinite extent inherent in the Bouguer correction. A line integral method for calculating the gravity effect for bodies of arbitrary cross section but infinite extent in the third dimension, was used to obtain a cross section which approximately fits the Bouguer anomaly curve. The ice thickness calculated by this method is somewhat greater than that calculated from the Bouguer correction.

The relative positions of the gravimeter stations were determined by two-way theodolite observations between the ice stations and stations on firm ground. The observations were carried out 10–12 Dec. 1970, and 16–19 Jan. 1971, and the movement in this period of 37 days was calculated. These calculations also involve the distances between the reference stations and the intermediate gravity stations, which were, as mentioned above, measured directly with a distance meter.

A Belgian expedition made a gravimeter traverse across Jutulstraumen in the same area in Jan.–Febr. 1968 (AUTENBOER and DECLEIR 1969). Their gravimeter stations were marked with poles. We were able to find some of these stations and they were attached to our station chain.

Results and discussion

The cross section of the glacier (Fig. 2) shows a groove in the western part with a maximum depth of 1560 m. It is reasonable to assume that this groove coincides with the border zone between gneiss and sandstone. It is worth mentioning that at the locations where the Belgian and our stations coincided, the calculated ice thickness never differed by more than 4%. This comparison is of course complicated by the fact that the Belgian stations have moved several hundred metres since Jan. 1968.

Inaccuracies in the calculations of thicknesses are mainly caused by the choice of mean rock density, errors in the measurements of the elevation, and by the choice of the zero value for the evaluation of the residual anomalies. If the rock density is wrong by as much as 0.05 g cm^{-3}, this will introduce an error of 0.33 m per mgal into the whole cross section. The error is consequently proportional to the ice thickness and with the density error assumed above would amount to about $\pm$ 43 m. An error in the elevation measurements of, say, 5 m corresponds to about 1.5 mgal, or an ice thickness of approximately 20 m, independent of the total ice thickness. Finally, inaccuracies in rock density and elevation measurements at Nashornkalvane relative to Jutulrøra will involve a difference in the residual anomaly, which in turn will introduce an error in the interpretations proportional to the distance from Jutulrøra. If for example the rock density is 0.1 g cm^{-3} too low and the elevation 5 m too high, an error of about 15 metres will be produced for the thickness of the western part of the ice stream. As a whole, the errors in the calculated ice thickness may reasonably be considered to be less than 70 m for the deepest parts, and 40 m as a maximum for depths of about 300 m, corresponding to inaccuracies of 5–12%.

Errors in the velocity determinations may be caused by inaccuracies in the distance measurements and in the theodolite survey. In both cases the result was based on repeated measurements. The inaccuracies in the distance determinations are, as previously mentioned, probably within $\pm$ 100 m, and in the case of the-

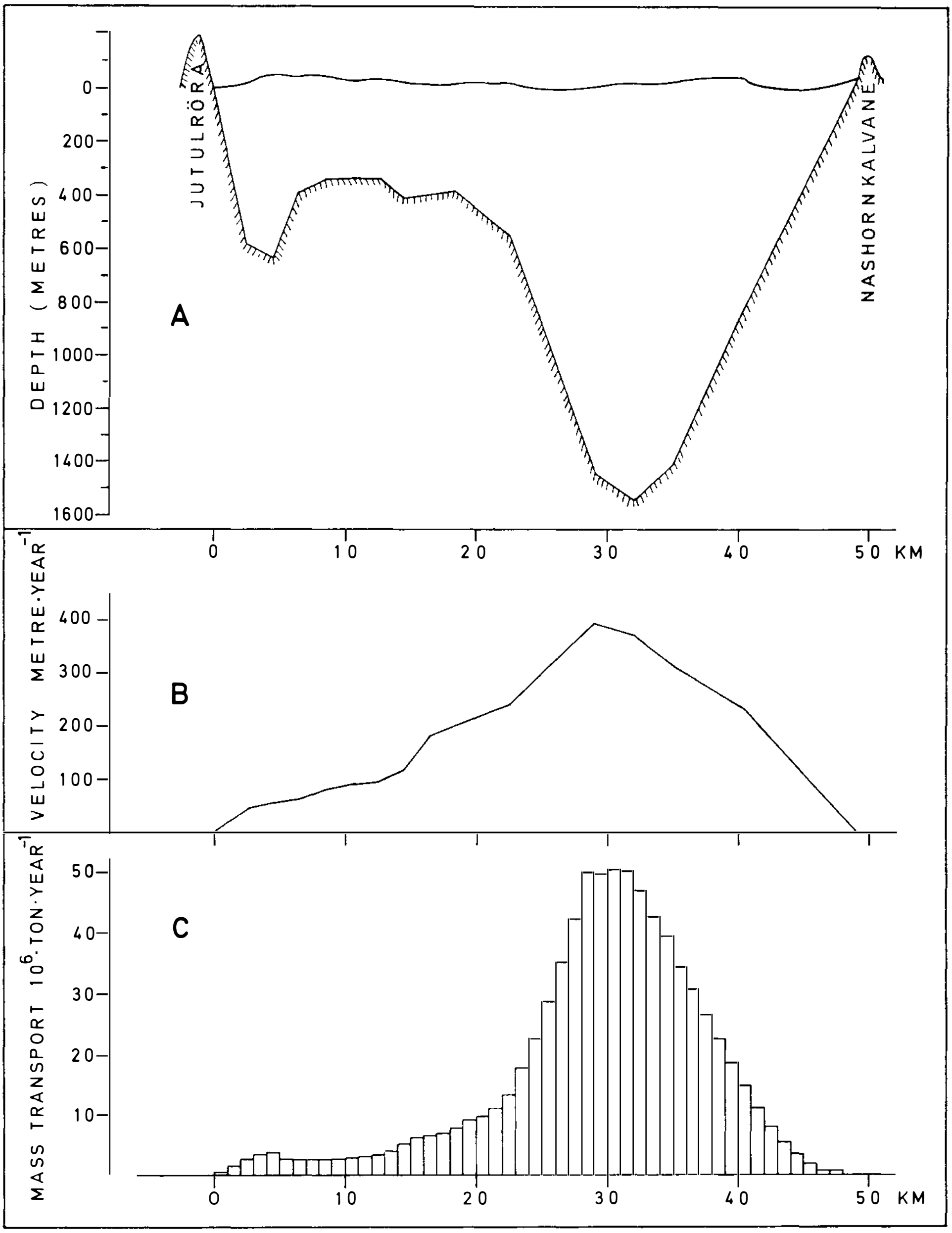

Fig. 2. *Distribution of ice thickness (A), velocity (B), and mass transport (C) of Jutulstraumen.*

odolite observations within $\pm$ 0.001^g. This means that the accuracy of the calculated movement during 38 days should be within $\pm$1 m for the central part of the glacier, and $\pm$ 0.3 m for the eastern part. The maximum velocity is estimated at 390 m/year.

The velocity decreases with depth, but we do not know the form of the vertical velocity profile. In the present case we have assumed a mean velocity of 95% of the surface velocity to be a reasonable estimate.

In the calculation of the mass transport it is assumed that both the ice thickness and velocity vary linearly between the observation points (Fig. 2). On the basis of these two curves, velocity and ice thickness for each 1000 m are used for calculation of mass transport. The distribution of mass transport (Fig. 2) demonstrates that approximately 75% of the mass transport takes place within a 15 km wide area around the position where the maximum ice thickness is found. The estimate of the total mass transport is $76 \cdot 10^8$ ton per year. We have supposed the annual change in velocity to be small; this seems to be a realistic assumption as far as Antarctic ice streams are concerned (cf. SWITHINBANK 1963).

Acknowledgements

The author wishes to acknowledge the assistance of all the members of the Norwegian Antarctic Expedition 1970–71, and especially the help of both the leader THORE WINSNES and of JENS ANGARD.

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Søren Richter

AV

VIDAR HISDAL

Den 20. oktober 1970 døde SØREN RICHTER, ishavsveteranen og den fremragende kjenner av polarstrøkenes geografi og historie.

Han ble født i Lier i 1903, men vokste opp i Narvik og fikk sin gymnasieutdannelse i Tromsø. Etter bifagseksamen i geografi og historie ved Universitetet i Oslo tok han fatt på arkeologien, som skulle bli hans spesialfelt.

Det var også først og fremst arkeologiske interesser som fikk ham til å delta i den toårige overvintringsekspedisjon, som det nystartede foretagende Arktisk

SØREN RICHTER *ombord på «Veslekari» under ekspedisjonen i 1929.*
Foto: SVERRE SØRENSEN

Næringsdrift sendte over til Øst-Grønland i 1929. Ved siden av å være fangstmann ville han studere restene etter gamle, utdødde eskimokulturer. Han var også med på to sommerekspedisjoner til Nordøst-Grønland for Norges Svalbard- og Ishavs-undersøkelser i 1932 og 1933. Høsten 1934 tok han så magistergraden i arkeologi, og resultatene av hans undersøkelser ble publisert samme år under tittelen: "A contribution to the archaeology of North-east Greenland".

Fangstmannslivet var imidlertid etter hvert blitt noe mer enn en hobby ved siden av de arkeologiske studier. Dette frie livet i ødemarken var i sannhet en tilværelse etter hans hjerte. Det var nok derfor ikke bare vitenskapelige interesser som gjorde at han overvintret igjen for Arktisk Næringsdrift i de samme strøk i 1935–36, og med egne ekspedisjoner i 1937–38 og 1939–40.

Under den siste overvintringen kom krigen til Norge. RICHTER sluttet seg da til det norske skiløperkompani på Island, og han var med på besettelsen av Jan Mayen i 1941. Året etter var han en kort tid stasjonert på Svalbard for å kjøre inn amerikanske hundespann etter norsk mønster. Høsten 1943 kom han igjen til Jan Mayen og var der til krigens slutt, de siste måneder som sjef for garnisonen.

Fra 1946 var han bibliotekar ved Norges Svalbard- og Ishavs-undersøkelser – i 1948 omdannet til Norsk Polarinstitutt – en stilling han hadde like til han sluttet av helbredshensyn våren 1970. Også i disse etterkrigsårene fikk han anledning til å besøke Grønland, seks ganger i alt, i de fleste tilfeller som leder av utskiftningsekspedisjonene til de norske stasjonene. I 1959 hadde han det tunge verv å fire det norske flagg i Myggbukta, et flagg han hadde vært med å heise 28 år tidligere, ved okkupasjonen av Nordøst-Grønland for Norge.

Allerede disse tørre fakta antyder at SØREN RICHTER's liv må ha vært uvanlig omskiftende og rikt på opplevelser.

Rent fysisk hadde han dimensjoner og styrke som få. Dette, kombinert med en ualminnelig nøysomhet og hardførhet, gjorde at han var sjelden godt egnet til et liv i polarstrøkene. Han ble da også fort akseptert av de fangstfolk han kom i kontakt med, ja til og med sett opp til med respekt, til tross for at det i dette miljø nok ofte måtte betraktes som et handikap å være «lærd mann». Han trengte seg da heller aldri på med sine kunnskaper.

JOHN GIÆVER, som en tid var sammen med ham på Grønland, har i boken «Hardbalne polarkarer» gitt noen glimt av sin venn i kapitlet «Fangstmann, villmann, krigsmann og arkeolog». Han nevner de betenkeligheter enkelte til å begynne med hadde, og fortsetter: «La gå at Søren var dobbelt så sterk som noen av oss, men han var så grublende livsfjern tillike at det måtte være mord å slippe ham aleine laus i villmarka. Vi tok feil. – Men det var likevel grunnlag for vår mistru. For en alminnelig dødelig torde det være lite anbefalelsesverdig å begi seg på langferd i førti kuldegrader og djupsnø uten å snøre støvlene, til eksempel. Eller å simpelthen glemme å ta på de nødtørftigste klær. – Eller en glemmer svolt i den tru at en har ett tre kilo svidd havregrøt ganske nylig, hvilket skjedde dagen før. Søren presterte å tasse om på viotta i mer enn døgnet med skoa så fulle av snø, at han nærmest gikk på tå, – alt mens han grublet på om en steinflis fra sommeren før kunne være bruddstykke av en pilespiss eller en kniv.»

Etter krigen vendte han tilbake til bøkenes verden, en omstilling han med sitt

RICHTER *fotografert i 1964 bak sitt skrivebord i Norsk Polarinstitutts bibliotek (Observatoriegaten).*

Foto: THOR SIGGERUD

likevektige gemytt klarte merkverdig godt. Ved siden av arbeidet som bibliotekar, fungerte han som levende leksikon i polarhistorie. Hans hjelpsomhet på dette området var enestående. Enten det var en skoleelev eller en vitenskapsmann som trengte opplysninger, øste han velvillig av sitt enorme kunnskapsforråd. Dette stjal svært mye av hans tid, tid som han hadde utmerket god bruk for til eget, ofte viktigere arbeide. Skjønt han hadde en utrolig hukommelse, måtte han selvsagt ofte konsultere litteraturen. Det hendte at et raskt telefonspørsmål kunne koste ham timers arbeide. Ble han bebreidet for dette, at han kastet bort tiden på problemer som spørreren selv burde ha tatt seg av, myste han gjerne spøkefullt med øynene og sa: «Men vi kan da ikke være bekjent av ikke å kunne svare på et slikt spørsmål.»

Ikke sjelden fikk han på biblioteket også besøk av venner fra tiden som fangstmann, eller fra krigens dager. Enkelte var nok falt mer eller mindre av lasset og hadde ikke klart å tilpasse seg et «normalt liv». Når det trengtes, ga han da gjerne en økonomisk håndsrekning, skjønt ingen kan påstå at han selv hadde noen overflod av denne verdens gods. «Der gikk mine siste tiere,» kunne han si etter et slikt besøk. Så måtte han telle over om han hadde nok til bussen hjem. Men det hendte han fikk pengene og et takkebrev tilbake. Da var han opprømt, nærmest triumferende: «Jeg visste det var godt to i den mannen!»

Den økonomiske side ved tilværelsen heftet han seg lite ved. Selvangivelsen syntes således hvert år å være ham et like nytt og overraskende mysterium. En gang han hadde påtatt seg å skrive en særlig arbeidskrevende artikkel for et minimalt honorar, ble han foreholdt det ruinerende i foretagendet. «Jo–jo,» svarte han besindig, «jeg kom meg da heller ikke til å forlange noe.» – «Men,» føyde han til litt etter, «det skulle nå være artig å se om jeg kunne få det til.» Tanken på oppgaven opptok ham mer enn pengene. Hans inntekter kom da heller aldri til å stå i noe rimelig forhold til det arbeide han utførte i kraft av sine kunnskaper.

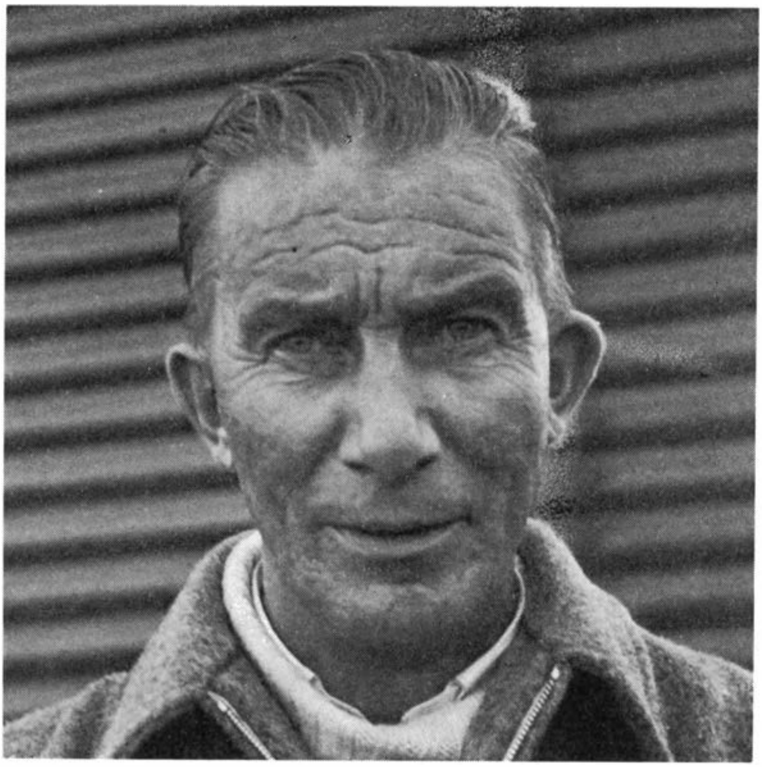
Et bilde av SØREN RICHTER ville være meget ufullstendig om hans talent som spøkefugl og særpreget historieforteller ble uteglemt. For mange som bare kjente ham flyktig, forble dette ukjente trekk ved hans person. Hans ordknapphet kunne jo til tider minne betenkelig om den fullkomne taushet. Ikke så når han var i det rette lune og henfalt til sin mangfoldighet av erindringer, helst om underlige tildragelser i polarstrøkene og selsomme mennesketyper han hadde støtt på der. Ingen kunne betvile at han da var i sitt ess: bred og godslig i stolen og med et glimt i øyet, som vitnet om at han selv var levende med i beretningen. Han fortalte alltid med våken sans for en barokk humor, som kledte dette spesielle stoff fortreffelig, – dertil var han ikke uten fabulerende evne. Flere av disse historier fortjente en bedre skjebne enn å havne i glemmeboken. Ofte ble han da også oppfordret til å skrive dem ned. Men på dette punkt var han ganske urokkelig. «Nei, skrive kan jeg ikke.» Og dog var han ingen dårlig skribent. Det viser ikke bare hans bok «Store norske ekspedisjoner» og de mange polarartikler han forfattet i årenes løp, men også beretningen «En sannferdig historie om «Mosquito-Bob» og Myggbukta», som han i sin tid skrev for Norsk Polar-Tidende, meg bekjent den eneste gang han lot seg bevege ut på det mer skjønnlitterære plan.

Kan hende er det disse rent personlige egenskaper som best har festet seg i erindringen: hans oppmuntrende munterhet og lune vesen, hans tålmodige hjelpsomhet. I en tid da utviklingen leder til økende standardisering, også av menneskenes sinn, blir særpregede personligheter som SØREN RICHTER stadig sjeldnere. Jeg tror alle som lærte ham å kjenne, føler at tilværelsen mistet noe av sin fargerikdom ved hans bortgang.

John Schjelderup Giæver

AV

NILS JØRGEN SCHUMACHER[1]



Polarmannen og forfatteren JOHN GIÆVER døde plutselig i sitt hjem 11. november 1970.

Han var født i Tromsø i 1901. Hans barne- og ungdomsår kom således til å falle i en periode da utstrakt virksomhet i polartraktene på mange måter satte sitt preg på ishavsbyen. Det miljø som der ble skapt kom for alltid til å sette sitt preg på JOHN GIÆVER.

Egentlig hadde han valgt handelen som sitt virkefelt, men kom snart over i journalistikken. I tyveårene var han dels journalist, dels redaktør i lokalaviser

[1] Det Norske Meteorologiske Institutt, Oslo 3.

nordpå, og man finner ham da som en aktiv debattant i den lokale presse. I disse årene sendte han også ut sin debutbok.

Men heller ikke som skribent kunne han slå seg til ro. Dragningen mot polartraktene som var skapt i de tidlige ungdomsår, førte til at han i 1929 brøt over tvert og sluttet seg til en gruppe på ti fangstmenn som det nystartede selskap Arktisk Næringsdrift A/S sendte til Øst-Grønland for å bygge ut et nett av fangststasjoner. GIÆVER kom derfor til å starte sin løpebane som polarmann med et større nyreisingsarbeide med de muligheter det ga til å høste verdifull erfaring.

Etter to år på Grønland kom GIÆVER tilbake til Norge sommeren 1931. Året efter la han ut fra fødebyen som leder av sin egen ekspedisjon til de samme trakter. I tillegg til fangstvirksomhet skulle det denne gang også tas meteorologiske observasjoner som et ledd i norsk virksomhet i polaråret.

Også denne ekspedisjonen kom til å vare i to år, så da GIÆVER i 1935 ble ansatt som sekretær ved Norges Svalbard- og Ishavsundersøkelser (senere Norsk Polarinstitutt), hadde han fire overvintringer på Grønland bak seg. Arktisk Næringsdrifts virksomhet ble ledet herfra, og det falt da naturlig at GIÆVER ble leder for dets ekspedisjoner til Øst-Grønland.

Også i 1940 ble det sendt ut en ekspedisjon for å hente hjem fangstfolkene fra Øst-Grønland, men denne vendte ikke tilbake til Norge. Etter en tid i London kom GIÆVER over til Amerika hvor han fikk en rekke oppdrag, blant annet ble han leirsjef for «Vesle Skaugum» i Canada. Under frigjøringen organiserte han forsyningstjenesten fra Sverige til Finnmark, og han var med på å opprette den sivile administrasjonen i fylket.

Etter frigjøringen var GIÆVER knyttet til Luftforsvaret, og i 1947 var han en tid stabsjef ved L.K.N.

Da det i 1948 skulle tas ut en norsk overvintringssjef for «Den norsk-britisk-svenske vitenskapelige ekspedisjon til Antarktis, 1949–52», falt valget naturlig på JOHN GIÆVER. I ham var et grundig kjennskap til polartraktene kombinert med administrativ erfaring og trening i å omgås og lede mennesker av forskjellig nasjonalitet. Men viktigere enn de rent ytre kvalifikasjoner skulle hans menneskelige egenskaper vise seg å være. På det området kom nok ekspedisjonen til å stille spesielle krav til sin sjef. Han skulle være den daglige leder av en gruppe menn som uten unntagelse var ham totalt underlegne i polar erfaring. På den annen side var de spesialister innenfor sine felt, og skulle utføre et forskningsarbeide som han kjente lite til og som ville være utslagsgivende for ekspedisjonens endelige resultat. Selv innså han vel klarest både sin styrke og sin begrensning. Derfor valgte han rådgiverens rolle, aldri den autoritære sjefs. At han også kunne være den myndige leder viste han kanskje best da ulykken var ute. Da avskar han hurtig enhver diskusjon og tok bestemmelsen.

Ekspedisjonens resultater er det beste bevis på at JOHN GIÆVER var en effektiv leder. Vi som deltok vil verdsette høyest det kameratskap og samhold han skapte og som gjør at vi ennå søker kontakt med hverandre så ofte anledning bys.

Efter hjemkomsten i 1952 ledet GIÆVER Polarinstituttets sommerekspedisjoner til Øst-Grønland ennå i noen år, men sviktende helse la efterhvert en demper på hans polare aktivitet.

Men desto større ble hans aktivitet på det litterære felt. Nå hadde han den ro over seg som skulle til for å fortsette der han en mannsalder tidligere hadde brutt over tvert. Og nå kunne han øse av det hav av inntrykk som hadde festnet seg gjennom et kvart århundres aktivitet i polartraktene. I første rekke var det livet der han interesserte seg for og skildret. Naturkreftenes golde spill opptok ham nok i mindre grad. Derfor kom også det sterile Antarktis til å virke mindre tiltrekkende på ham enn det langt frodigere Arktis. Og når vi ser bort fra Maudheimboka er hans forfatterskap nesten utelukkende viet de nordlige egne. Med sine glimrende skildringer fikk hans bøker en stor lesekrets.

JOHN GIÆVERS virksomhet i polartraktene fant sted før teknikken for alvor gjorde sitt inntog i disse fjerne strøk av vår klode. De mennesketyper han skildret er i ferd med å forsvinne. Vi hedrer hans minne og takker for det han har lært oss om polarlandet og dets menn.

Glaciological work in 1970

(Гляциологическая работа в 1970-ом году)

BY

OLAV LIESTØL

Contents

Abstract

Mass balance measurement was carried out by Norsk Polarinstitutt on four glaciers in the budget year 1969–70: on Storbreen and Hardangerjøkulen in southern Norway and on Austre Brøggerbreen and Midre Lovénbreen in Spitsbergen. The results are shown in Table 1 together with the measurements carried out by NVE (The Norwegian Water Resources and Electricity Board).

The length fluctuations on ten glaciers were measured. Only Engabreen in northern Norway advanced, the other ones were retreating.

Glacier surges of Spitsbergen glaciers are also described.

Аннотация

В балансовом году 1969–1970 сотрудниками Норвежского Полярного Института (Norsk Polarinstitutt) был измерен вещественный баланс четырех ледников: Storbreen, Hardangerjøkulen (в южной Норвегии), Austre Brøggerbreen и Midre Lovénbreen (на Шпицбергене). Результаты измерений сопоставлены в табл. 1 с соответствующими разультатами измерений других ледников, проведенных сотрудниками учреждения Norges Vassdrags- og Elektrisitetsvesen (управление гидрологической службы).

Измерены колебания длины десяти ледников, из которых наступил лишь один, Engabreen в северной Норвегии, в то время как отступили остальные.

Описаны также ледниковые пульсации шпицбергенских ледников.

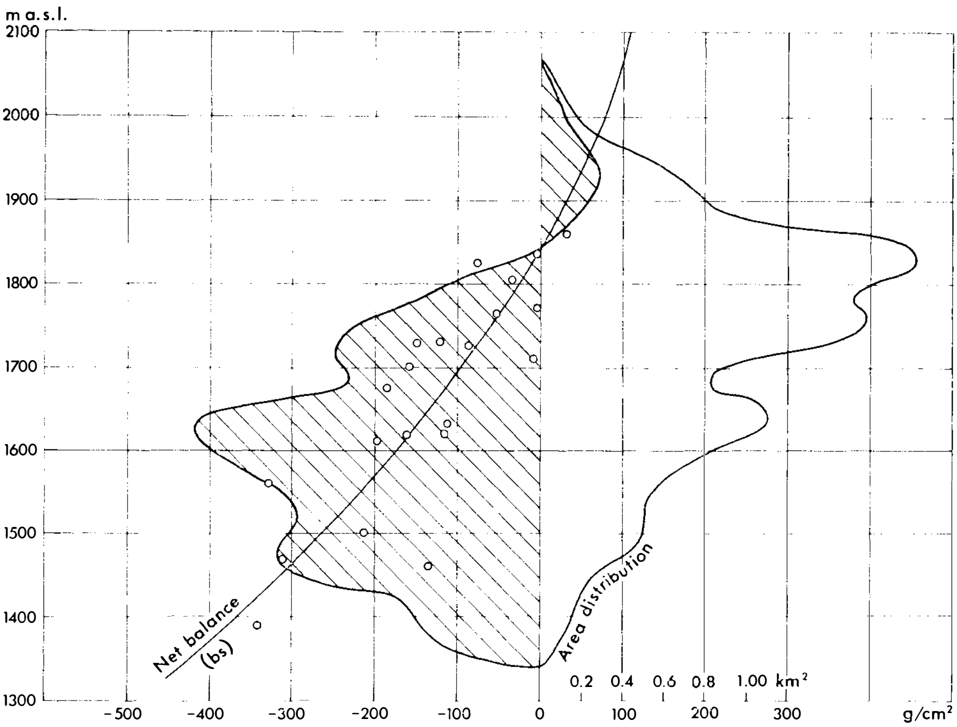


Fig. 1. *Variations in mass balance on Storbreen 1969–70 in relation to height a.s.l.*
Вариации вещественного баланса на леднике Storbreen в 1969/70 г. в зависимости от высоты над уровнем моря.

Storbreen in Jotunheimen

In the autumn of 1969 accumulation started in September with heavy snowfalls above 1 600 m. However, mild weather in October caused the greater part of this early accumulation to melt. The next month was cold with precipitation high above the normal, but the rest of the winter was dry with snowfalls below average. The snow accumulation map of Norway, worked out by the Meteorological Institute in Norway, showed by 30 April 1970 for West-Jotunheimen c. 70% of a normal year at a height of 1 200 m. The accumulation on the glacier was measured in the beginning of May and was calculated to 95 g/cm² which also is about 70% of an average year.

June was extremely warm an sunny. This caused most of the winter snow to melt already during this month. The mean temperature at the meteorological station Fannaråki (2 060 m a.s.l.) was in June 5.0°C, which is 5.1°C above normal and the highest mean measured since the station was established in 1932. In the rest of the ablation period the temperature was below or near the average.

Measurements of ablation were carried out on several trips to the glacier during the summer, the last time on 13 September.

As accumulation was below and ablation above normal, the result of the mass

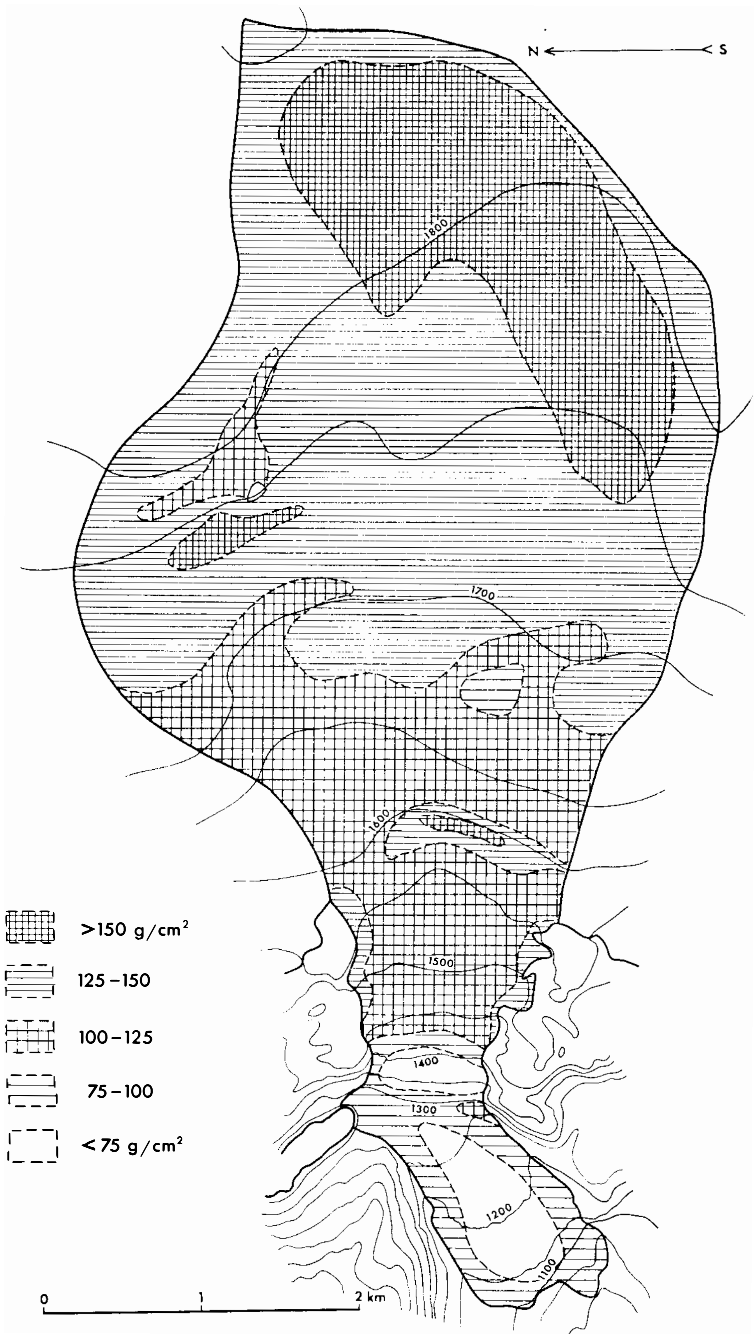


Fig. 2. *Distribution of snow accumulation in the part of Hardangerjøkulen that flows to the outlet glacier Rembesdalsskåki.*

Распределение снегонакопления в части ледника Hardangerjøkulen, текущей на выводной ледник Rembesdalsskåki.

balance was negative but not as high as the previous year's extremely high negative figure. Accumulation, ablation, and mass balance were, respectively: 95, 167, and 72 g/cm². See Fig. 1.

Hardangerjøkulen

Measurements during the last seven years show that the pattern of the snow accumulation is in general the same every year, even if the total mass is variable. It is therefore to be hoped that a good correlation between simple measurements on a few stakes and the total mass could be obtained. A problem is that the stakes are moving and thus change their position. The stakes therefore have to be moved upstream and replaced every year to keep their position.

Weather conditions were almost the same as described for Storbreen. Ablation was great in June and moderate in the other summer months. The result was a negative balance for the whole glacier. Only the height interval around 1 800 m a.s.l. showed a positive balance. As in all previous years the accumulation and net balance decreased towards the top of the glacier. This is due to the effect of the wind that blows the snow away from the highest part of the glacier.

The result of the measurement in 1970 is shown in Table 1 and on Figs. 2 and 3.

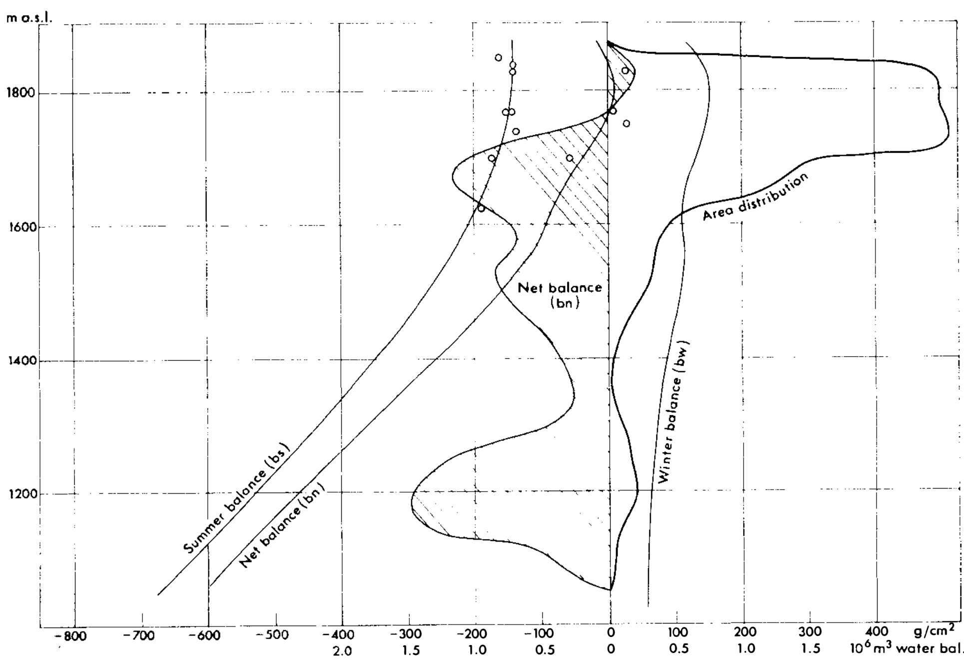


Fig. 3. *Variation in mass balance on Hardangerjøkulen (Rembesdalsskåki) 1969–70 in relation to height a.s.l.*

Вариация вещественного баланса на леднике Hardangerjøkulen (Rembesdalsskåki) в 1969/70 г. в зависимости от высоты над уровнем моря.

Table 1

Hardangerjøkulen 1969–70

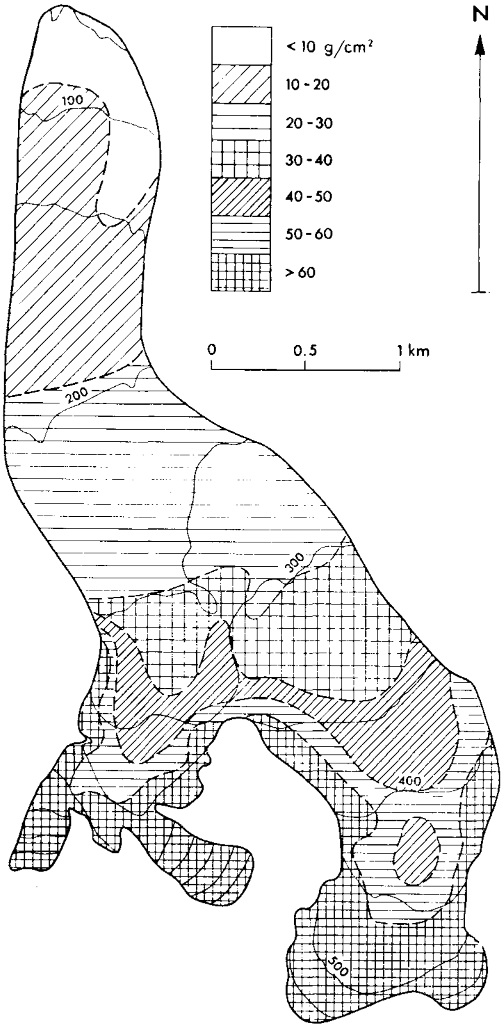
Height intervals m a.s.l.	Area km²	Winter balance			Summer balance			Net balance		
		Bw 10^6m^3	bw		Bs 10^6m^3	bs		Bn 10^6m^3	bn	
			g/cm²	L/s km²		g/cm²	L/s km²		g/cm²	L/s km²
1850–1900	0.074	0.101	136	43	0.104	140	44	–0.003	–6	–2
1800–1850	3.358	4.965	148	47	4.735	141	45	+0.230	+7	+2
1750–1800	3.763	5.454	145	46	5.454	145	46	0.000	±0	±0
1700–1750	4.033	5.536	137	43	6.251	155	49	–0.715	–18	–6
1650–1700	2.219	2.680	121	38	3.861	174	55	–1.180	–53	–17
1600–1650	0.971	1.108	114	36	1.893	195	62	–0.785	–81	–25
1550–1600	0.624	0.757	122	39	1.385	222	70	–0.628	–100	–32
1500–1550	0.569	0.662	116	37	1.451	255	80	–0.789	–139	–44
1450–1500	0.371	0.389	105	33	1.076	290	92	–0.687	–185	–57
1400–1450	0.176	0.167	95	30	0.577	328	104	–0.410	–233	–73
1350–1400	0.109	0.093	85	27	0.403	370	117	–0.310	–285	–90
1300–1350	0.078	0.059	75	24	0.321	412	130	–0.262	–337	–106
1250–1300	0.265	0.186	70	22	1.208	456	144	–1.022	–386	–122
1200–1250	0.308	0.200	65	20	1.540	500	158	–1.340	–435	–137
1150–1200	0.312	0.199	64	20	1.716	550	174	–1.517	–486	–153
1100–1150	0.109	0.065	60	20	0.651	597	188	–0.586	–537	–170
1050–1100	0.059	0.035	60	20	0.381	645	203	–0.346	–585	–185
1050–1900	17.44	22.65	*129*	41	33.00	*189*	60	–10.35	*–60*	–19

Glaciers in Spitsbergen

In Spitsbergen mass balance studies were carried out on the glaciers Austre Brøggerbreen and Midre Lovénbreen. Stake measurements continued during the whole balance year except in the darkest period. In addition, soundings were carried out along lines perpendicular to the central line of the glaciers, with 100 m intervals. To improve the accuracy of the accumulation map, aerial photographs were used. See Fig. 4. As late as in the beginning of November most of the glaciers were uncovered by snow. When the accumulation was measured in the last days of May, the lower half of the glaciers still had less than 20 g/cm² of snow. The mean accumulation on Austre Brøggerbreen and Midre Lovénbreen was 37 g/cm² and 36 g/cm² respectively. The ablation was 91 g/cm² and 89 g/cm², causing a deficit of, respectively, –54 g/cm² and –53 g/cm² in the mass balance. See Fig. 5. The climatic parameters are not known well enough to calculate the average mass balance figures.

Table 2 shows the results of the mass balance measurements carried out till now.

As can be seen from Table 2, all the years have a negative balance. It is interesting and curious to compare these observations with meteorological recordings at Isfjord Radio for the same years. One should expect that negative balance years are caused by summer temperatures above normal and/or by precipitation below normal in the accumulation season. In fact, both temperature and precipitation go in the opposite direction except in 1969 when the precipitation was c. 10% below average. The actual summers have temperatures below the average for the



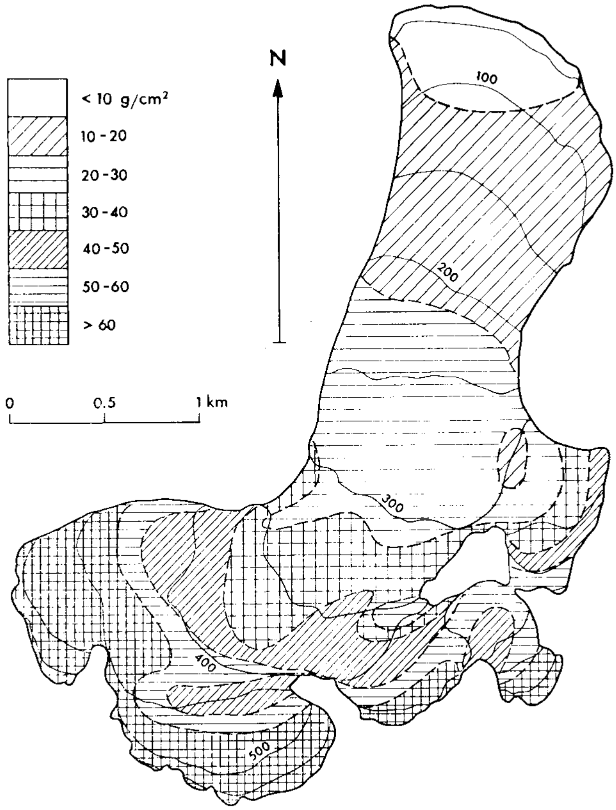


Fig. 4b. *Distribution of snow accumulation on Midre Lovénbreen.*
Распределение снегонакопления на леднике Midre Lovénbreen.

Fig. 4a. *Distribution of snow accumulation on Austre Brøggerbreen.*
← Распределение снегонакопления на леднике Austre Brøggerbreen.

period 1912–68, and the precipitation is above normal. There could be different reasons or explanations for this discrepancy. It is possible that the meteorological station Isfjord Radio is not representative for this region, but both the station and the two glaciers are located near to the west coast and only c. 100 km apart. One should therefore expect that a good correlation, at least in temperature, was likely. The measurement of the precipitation is often unreliable in arctic regions and the correlation even over short distances is not good. Another possibility is that the glaciers are not at all adapted to the climate in the period 1912–68 on which the mean summer temperature is based. Photographs from the beginning of this century show that the ice margin was situated at the outermost moraine. Since then the glaciers have been in continuous retreat. The upper part of the glaciers have, however, at least in the latest ten years, increased in thickness. No reliable

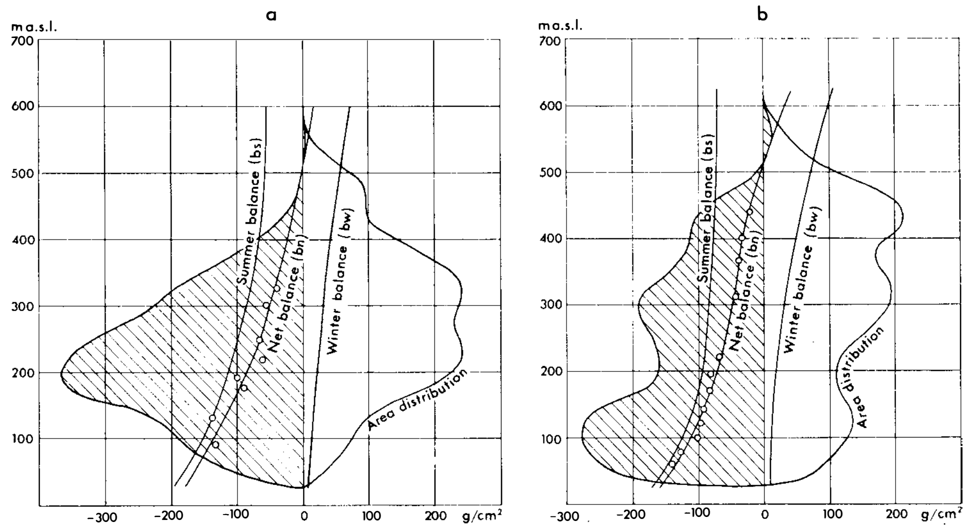


Fig. 5. *Variation in mass balance in relation to height a.s.l. on Austre Brøggerbreen* (*a*) *and Midre Lovénbreen* (*b*) 1969–70.

Вариация вещественного баланса в зависимости от высоты над уровнем моря на ледниках Austre Brøggerbreen и Midre Lovénbreen в 1969/70 г.

old map exists on which a change in the total volume could be calculated. A comparison between photographs, however, indicate that the two glaciers have diminished considerably.

Observations in the field and on air photographs show that at least 12 glaciers are advancing or surging in Spitsbergen. The largest surges occur on the glaciers Hinlopenbreen and Tunabreen. Hinlopenbreen, which is 60 km long and 8 km wide at the front, had a mean velocity of c. 16 m a day in the period August 1969 to August 1970. Crevassed areas from the sea-front to the uppermost tributaries indicate that the entire glacier takes part in the surge. The Tunabreen and Von Postbreen glaciers flow together and form a 3 km broad front at the head of Tempelfjorden. Tunabreen had a surge in 1932 when it advanced c. 3 km. Since

Table 2

Year	Mass balance						Summer temp. at Isfjord Radio		Precipitation in mm at Isfjord Radio	
	Austre Brøggerbreen			Midre Lovénbreen						
	$\bar{c}$	$\bar{a}$	$\bar{b}$	$\bar{c}$	$\bar{a}$	$\bar{b}$	1/6–30/9	Deviation from means 1912–68	1/9–30/6	Deviation
1967	77	142	–65				2.63	–0.27	390	+76
1968	57	67	–10	48	51	–3	1.68	–1.22	340	+26
1969	40	133	–93	41	125	–84	2.60	–0.30	290	–34
1970	37	91	–54	36	89	–53	2.62	–0.28	572	+258

then it has retreated steadily until 1970 or 1969, when a new surge started. See Figs. 6 and 7. A visit to the glacier in spring 1971 showed that it was still advancing with a velocity of c. 1 m a day, breaking and disturbing the fjord ice far ahead of the glacier front. Two outlet glaciers from the glacier cap Hellefonna, near Agardhbukta on the east coast of Spitsbergen, are also making violent advances. The southern one is now advancing down Helledalen over ground probably not covered by ice since the last ice age. The northern one, Marmorbreen, is crossing the Fulmardalen. A hut in the middle of the valley is broken and overrun by the glacier, and a 5 km long lake has been dammed on the east side. See Fig. 8.

Other investigations

In addition to the investigations carried out by Norsk Polarinstitutt on Storbreen, Hardangerjøkulen, Austre Brøggerbreen and Midre Lovénbreen, NVE (The Norwegian Water Resources and Electricity Board) carried out measure-

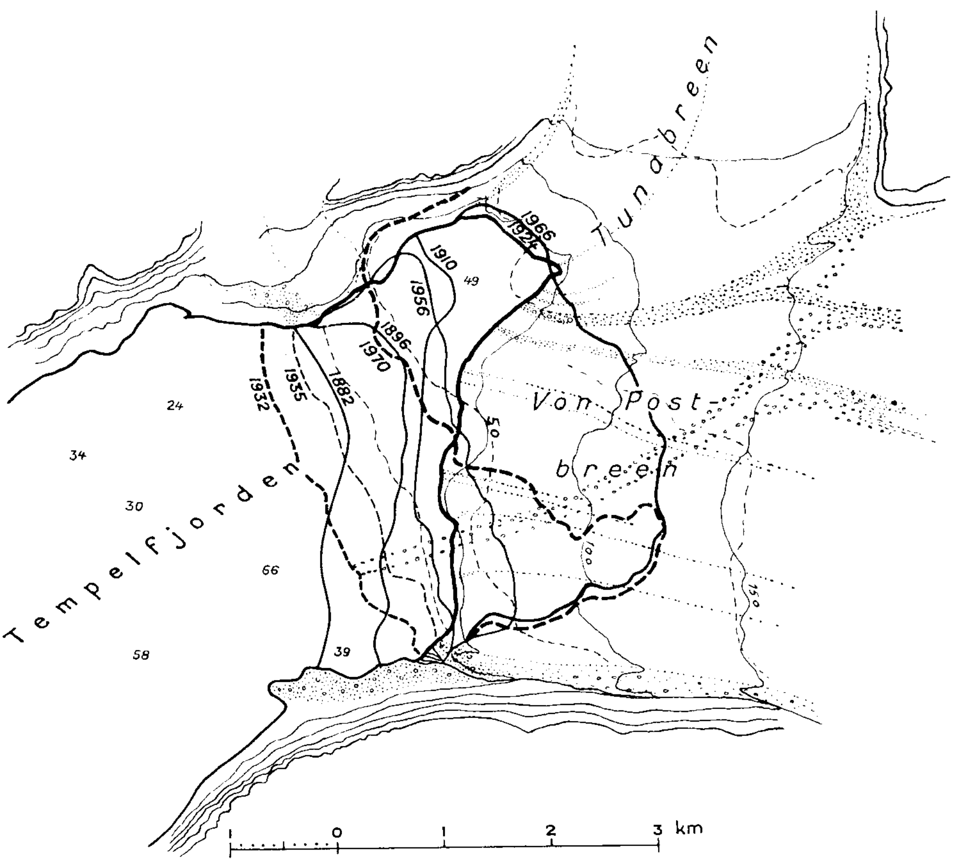


Fig. 6. *Fluctuations of the front of Tunabreen and Von Postbreen.*
Колебания фронтов леднпков Tunabreen и Van Postbreen.

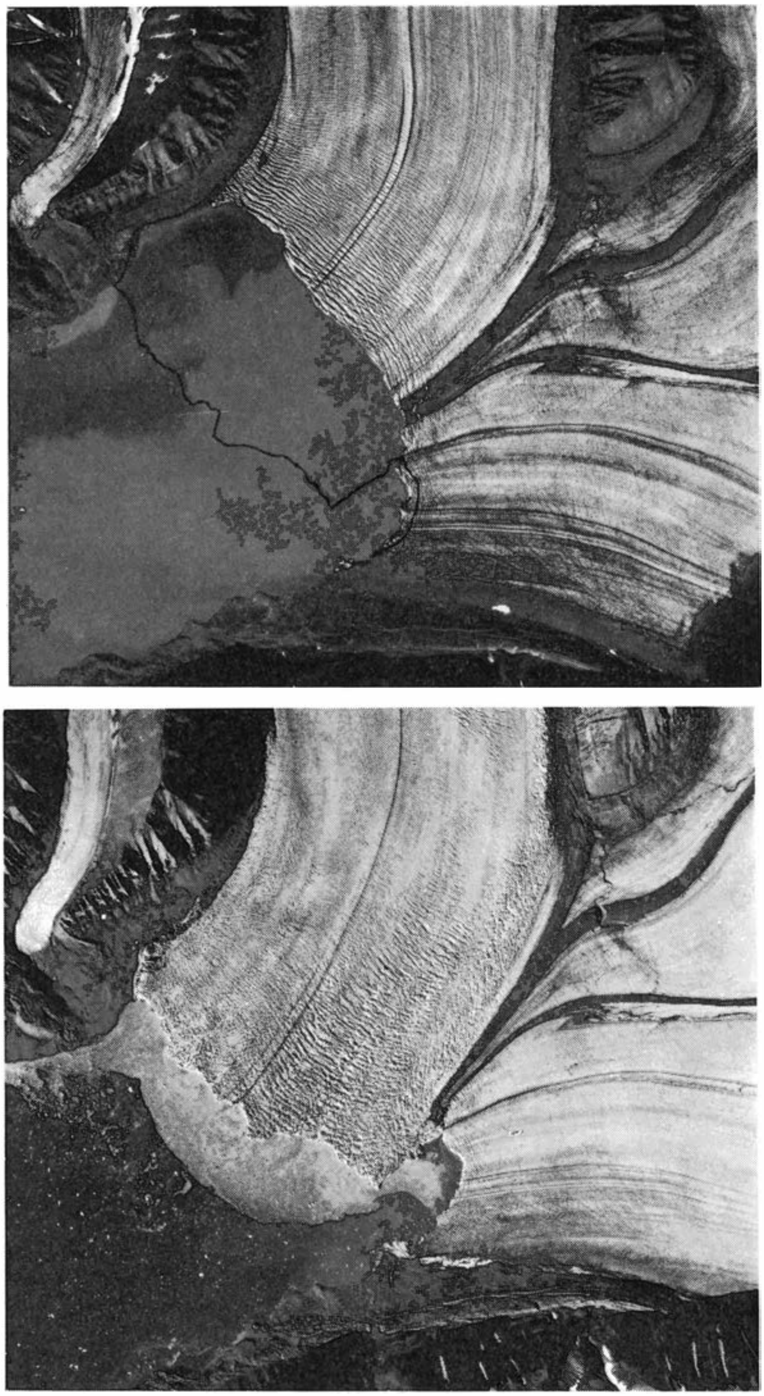


Fig. 7. *Aerial photographs – the upper from 1966 and the lower from 1970 – showing the surging glacier Tunabreen. The position of the front in 1970 is indicated on the photo from 1966.*

Воздушные фотографии – верхняя с 1966 г. и нижняя с 1970 г. – показывающие пульсирующий ледник Tunabreen. Положение ледникового фронта в 1970 г. указано в фотографии с 1966 г.

Fig. 8. *Aerial photograph of the surging glacier Marmorbreen. The glacier tongue to the left is Skruisbreen which had a surge about 1925. The glacier to the lower left, calving in the glacier dammed lake, is part of Elfenbeinsbreen that surged in 1897.*

Воздушная фотография пульсирующего ледника Marmorbreen. Ледниковый язык налево – Skruisbreen, где имела место пульсация около 1925 г. Ледник внизу налево, «телящийся» в запруженном ледником озере – часть ледника Elfenbeinsbreen, пульсировавшего в 1897 г.

ments on nine glaciers in South-Norway. In Table 3 the results of all mass balance measurements on glaciers in Norway and Spitsbergen are presented.

In addition, Fig. 9 shows the mass balance figures for 1969–70 and, for comparison, also the mean for the eight previous years and a calculated normal equilibrium.

Calculations of the fluctuations in metres were carried out for in all ten glacier tongues, and the results are presented in Table 4. Only Engabreen, an outlet glacier of Svartisen, has advanced. This glacier has now had a continuous advance since 1965 of in all 79 m.

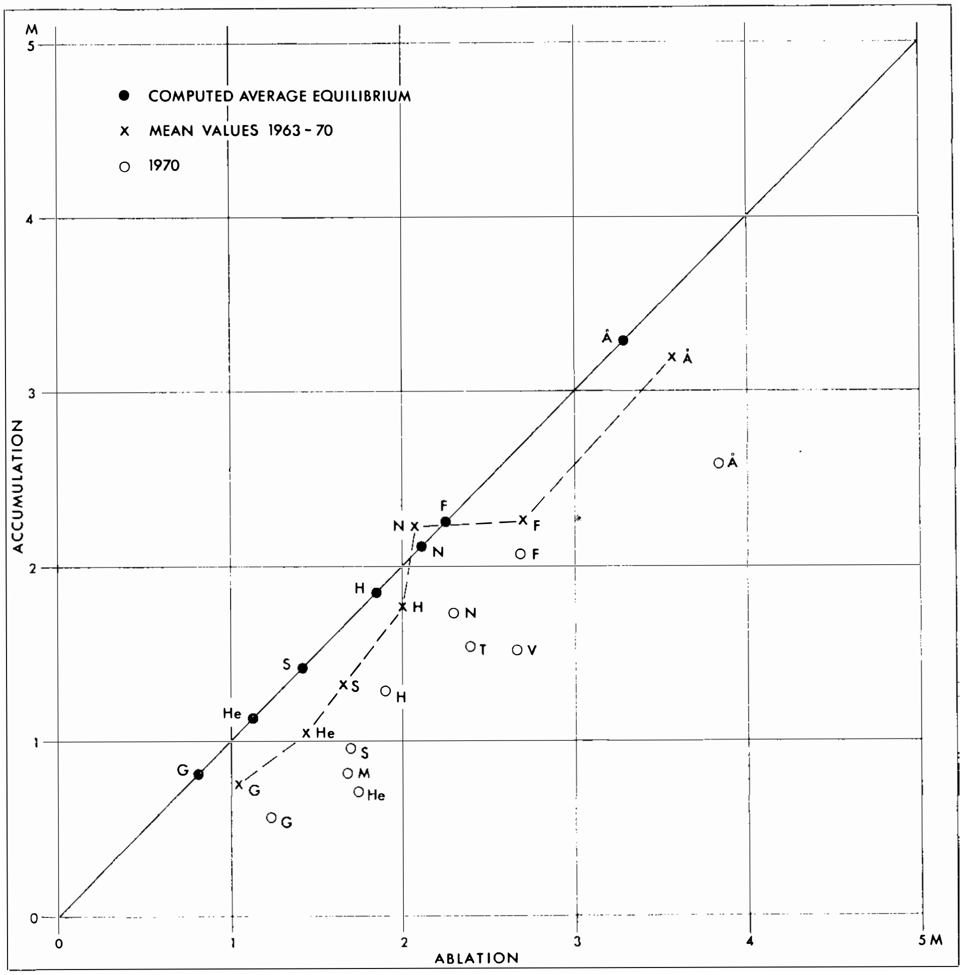


Fig. 9. *Relation between accumulation and ablation compared to the mean of the previous eight years and also to that of a year with a computed balanced budget and a "normal" mass exchange.*
F = Folgefonni, Ha = Hardangerjøkulen, He = Hellstugubreen, G = Gråsubreen, N = Nigardsbreen, O = Omnsbreen, AM = Austre Memurubre, VM = Vestre Memurubre, S = Storbreen, T = Tunsbergdalsbreen, V = Vesledalsbreen, and Å = Ålfotbreen.

Взаимоотношения между аккумуляцией и абляцией в сравнении с средими значениями предыдущих восьми лет, так же как с значениямн года с рассчетным балансированным бюджетом и «нормальным» вещественным обменом.

Table 3

Mass balance measurements

Glacier	Winter balance bw m	Summer balance bs m	Net balance bn m
Southern Norway			
Ålfotbreen	2.59	3.83	−1.24
Vesledalsbreen	1.52	2.66	−1.14
Nigardsbreen	1.73	2.29	−0.56
Tunsbergdalsbreen	1.54	2.38	−0.84
Midtre Folgefonni	2.07	2.69	−0.62
Hardangerjøkulen	1.29	1.89	−0.60
Storbreen	0.97	1.69	−0.72
Hellstugubreen	0.71	1.73	−1.02
Vestre Memurubre	0.84	1.63	−0.79
Austre Memurubre	0.81	1.71	−0.90
Gråsubreen	0.57	1.23	−0.66
Spitsbergen			
Midre Lovénbreen	0.36	0.89	−0.53
Austre Brøggerbreen	0.37	0.91	−0.54

Table 4

Fluctuations of some glacier tongues

Jotunheimen		*Folgefonni*	
Storbreen	− 18 m	Buarbreen	0 m
Styggedalsbreen	− 9 »		
		Møre	
Jostedalsbreen		Trollkyrkjebreen	− 8 »
Briksdalsbreen	− 19 »		
Lodalsbreen	−116 »	*Svartisen*	
Fåbergstølbreen	−121 »	Engabreen	+34 »
Austerdalsbreen	− 13 »	Østerdalsisen	−11 »

The weather in Svalbard in 1970

BY

VIDAR HISDAL

Fig. 1 presents some important meteorological elements observed at Isfjord Radio during 1970: the daily maximum and minimum temperatures, the cloud amount, and the direction and speed of the wind. The cloud and wind observations entered are those taken at 12 GMT. The figure furthermore shows the average annual temperature variation for the period 1947–69. The symbols used are explained by examples in the diagram.

The table contains the monthly mean temperatures for Isfjord Radio, Hopen, and Bjørnøya for 1970 as well as their deviations from the monthly means based on the period 1947–69.

At Isfjord Radio the first half of January was characterized by clear skies, advection of cold air from higher latitudes, and below normal temperatures. The lowest temperature of the year, –25.1°C, occurred during this period, on 6 January. The last half of the month, on the other hand, was mild, partly with strong southerly winds, and several cyclones passed over the area. The maximum temperature on the 22nd and the 23rd was as high as 3.0°C. It is further noteworthy that on these two days it was raining more or less continuously, the total amount of rain at Isfjord Radio in the course of this period reaching nearly 40 mm (cf. Fig. 2). February, particularly the first part of the month, was relatively cold, with a predominantly easterly to north-easterly air stream from the Polar Basin. These wind directions prevailed during March as well, although now accompanied by several spells of relatively mild weather. During these mild periods the air flow which turned eastwards over the Svalbard area, was in reality the continuation of a southerly stream in front of extensive low pressure areas in lower latitudes. April was again a cold month, dominated by Arctic air masses. The lowest temperatures occurred during the middle of the month, when five days in succession had minimum temperatures below –20°C. The weather during the first third of May was influenced by cyclonic passages accompanied by southerly to westerly winds, and the temperature was considerably above normal. During the rest of the month the weather was mostly calm and cool, except for the last few days, when depressions and milder air again entered the region. As is generally the case, the temperature fluctuations were far less pronounced during the summer season than during the rest of the year. The most extreme deviations from the average temperature are found at the end of July and the beginning of

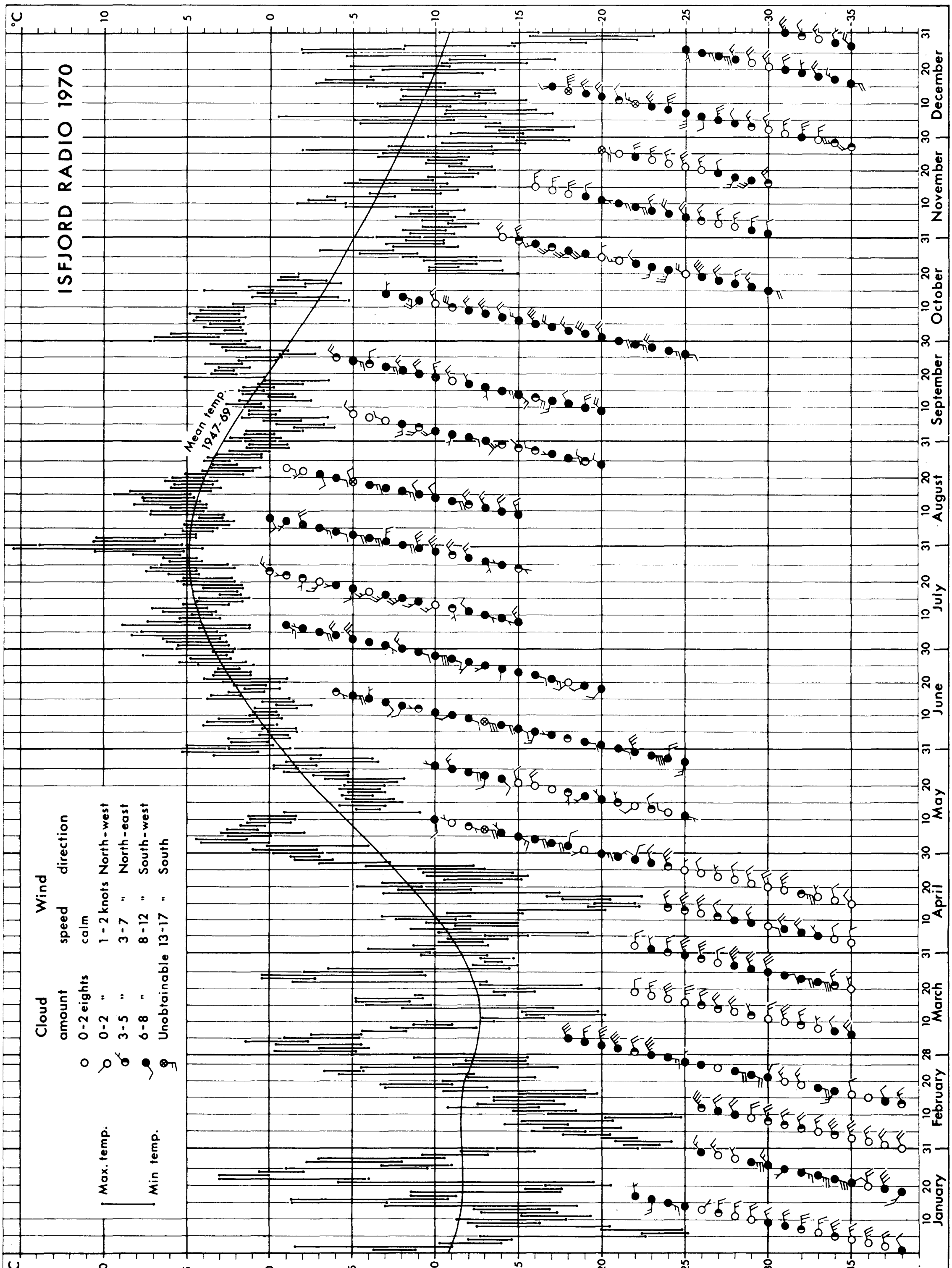

ISFJORD RADIO 1970
Max. temp.
Min. temp.
Cloud amount
0-2 eights
0-2 "
3-5 "
6-8 "
Unobtainable
Wind speed
calm
1-2 knots
3-7 "
8-12 "
13-17 "
Wind direction
North-west
North-east
South-west
South
Mean temp. 1947-69
°C
January
February
March
April
May
June
July
August
September
October
November
December

Fig. 1.

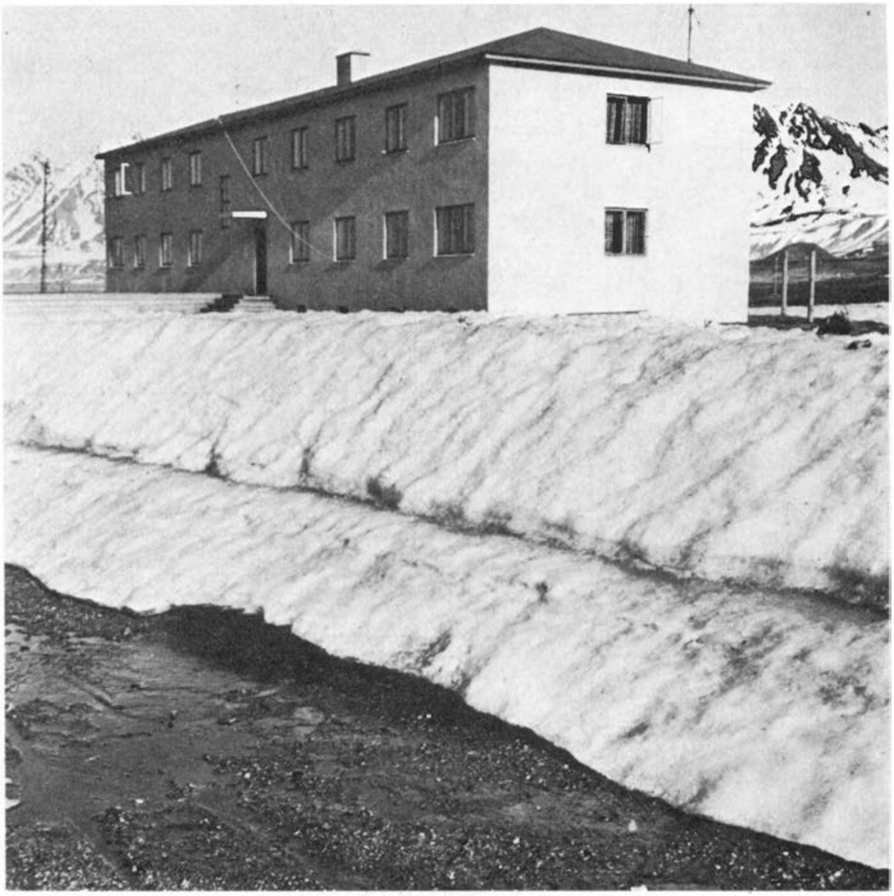


Fig. 2. *This picture of a melting snow-drift, taken in Ny-Ålesund at the end of June 1970, clearly shows the ice layer dating from the two mild, rainy days in January.*
(Photo: V. HISDAL.)

August, when the highest temperatures of the year were observed. The maximum for the year, 15.4°C on 30 July, occurred in connection with advection of mild air from lower latitudes. The air seems, in addition, to have been heated by subsidence when passing the mountain ranges farther east. The first part of September was characterized by northerly winds and cool weather, while during the last couple of weeks of the month, and especially during the first half of October, the temperature was considerably above normal. The typical wind direction was north-east during this period. As in March, however, the air masses were not of polar origin, but came from temperate regions in lower latitudes. During the last part of October, cold air from the Polar Basin invaded the islands. This cold weather type also characterized the greater part of November, while the temperature in December was more variable, but mostly below normal.

Considering the relationship between the mean temperatures of the three stations in the table, the most conspicuous feature is the great negative deviation from the "normal" value of the mean temperature of February for Hopen and Bjørnøya, compared with that for Isfjord Radio. The monthly mean for the latter station is in fact higher than the corresponding one for Bjørnøya, which is a highly unusual feature. Studying the data available, it seems clear that the main reason for this anomaly is the fact that Isfjord Radio in a few cases was influenced by advection of relatively mild, oceanic air, which did not affect the two other stations. In addition there are indications that during this month Isfjord Radio benefited at times from a foehn effect induced by the mountain ranges in eastern Spitsbergen.

Monthly mean temperatures for 1970 (T) and their deviations (d) from the means of the period 1947–69.

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Isfjord Radio	T	–11.6	–14.9	–9.2	–11.7	–2.6	1.2	4.6	3.9	0.8	–2.9	–9.6	–11.1
	d	0.1	–3.2	3.6	–2.5	0.9	–0.3	0.1	–0.3	–0.1	0.3	–2.9	–1.6
Hopen	T	–15.4	–19.6	–9.7	–12.8	–3.2	0.2	1.6	3.4	1.1	–2.1	–10.9	–13.3
	d	–2.0	–7.1	4.6	–2.3	1.8	0.6	–0.3	1.3	0.5	0.9	–4.3	–2.8
Bjørnøya	T	–8.4	–15.3	–4.6	–6.1	–0.3	3.3	4.2	5.3	2.8	0.9	–4.2	–8.2
	d	–0.6	–8.2	3.5	–0.7	1.3	1.5	0.1	1.1	0.0	1.0	–1.7	–2.5

Sea ice and drift speed observations in 1970

BY

TORGNY E. VINJE

The distribution of sea ice between Iceland and Novaja Zemlja is shown in Figs. 1–12. The main source of data is the pictures taken by the American weather satellites. The observations have been plotted from satellite pictures, partly at Norsk Polarinstitutt, partly at Det norske meteorologiske institutt. The date of the different observations is noted in the figures. When the observations are taken from aircraft or from ships, the suffix "air" or "ship" has been noted. (Sources: The Royal Norwegian Air Force and Norwegian ships.) Observations from infra-red satellite pictures are marked with the letter N. Weekly information has been collected from the Arctic weather stations, Hopen, Bjørnøya, Isfjord Radio and Jan Mayen.

When comparing satellite pictures with surface observations, some inconsistencies have been found. It turns out that a concentration of less than about 3/8 is not always registered by the satellite pictures. Observations indicate that when a satellite camera fails to register this smaller concentration, the drift ice consists of strips.

The ice conditions north of Iceland are considerably better than in 1968 and 1969 (cf. e. g. VINJE, Årbok 1968 and 1969). The sea ice disappeared from this area about one month earlier in 1970 compared with 1969 and about two months earlier compared with 1968. In Fig. 5 is also entered the ice edge at the beginning of May 1969. It is seen that there is a considerably smaller amount of ice in the East Greenland Sea in 1970 compared with 1969 at this time of the year.

In Vesterisen (cf. Fig. 1), Odden and Nordbukta may be identified during January and February; and during March and April the above mentioned features in the ice distribution are extraordinarily well developed compared with what has been observed since the satellite pictures became available.

The ice condition in the Svalbard area became very favourable during the sailing season in 1970. And we have to go back to 1960 to find a better ice year.

In Østisen (cf. Fig. 1), Nordostodden can be identified during January and February. During March the ice edge is pressed northward by prevailing southerly and south-easterly winds (cf. HISDAL, this vol.). Fig. 5 shows that the sailing season started with considerably more ice in the Barents Sea in 1970 as compared with 1969. The far better ice conditions east of Svalbard during the summer 1970 thus indicate a more extensive disintegration of sea ice in this area in 1970.

In Table 1 are given some observations of the drift speed of giant floes in Vesterisen and Østisen as determined from satellite pictures. The positions of the floes have been plotted with the aid of a pantograph with reference to well marked points which can be identified from picture to picture. An estimation of the error of the drift speed determinations indicates that it is about 10% for the smallest values and decreases to less than 5% for the largest values.

Table 1 shows the well known increase in speed as the drift ice passes southward through the Fram Strait. Comparing with similar observations made in 1969 (VINJE, Årbok 1968) it is seen that great fluctuations occur in the drift speed. An extreme variation is found at about 78°N, 5°W. In Table 2 are given the values obtained in this area in 1968, 1969, and 1970.

Table 1

Position	Speed km/24h	Drift from	Period
	Vesterisen		
81.5N–02W	8.4	NNE	12.IV–17.IV
81.0N–04W	5.5	NNW	1.V –10.V
80.5N–03W	5.1	NNW	24.IV– 8.V
80.5N–05E	6.2	NNE	13.IV–20.V
80.5N–08E	5.5	NNE	13.IV–20.IV
80.0N–03W	5.5	N	1.V –10.V
80.0N–02W	14.8	N	8.V –13.V
79.5N–03W	6.5	NNE	1.V –10.V
79.5N–06W	15.1	N	13.IV–20.IV
79.5N–04W	26.6	NNE	11.V –13.V
79.0N–03E	27.0	NNE	13.IV–16.IV
78.5N–02W	32.0	N	13.IV–15.IV
78.5N–04W	27.0	N	13.V –22.V
78.5N–05W	25.0	N	13.IV–17.IV
78.5N–08W	8.8	NNE	5.V –10.V
78.5N–11W	4.4	N	5.V –10.V
78.0N–11W	7.9	NNE	5.V –10.V
75.5N–15W	11.6	N	3.IV–16.IV
76.0N–14W	11.0	NNE	5.V –10.V
73.5N–17W	16.8	NNE	4.IV–16.IV
	Østisen		
78.0N–48E	3.5	SSW	25.IV– 3.V
78.0N–50E	5.6	NW	3.V –10.V
78.8N–49E	6.7	ENE	10.V –15.V
78.5N–48E	7.8	N	15.V –20.V

Table 2

Position	Speed km/24h	Drift from	Period
78.8N–05W	17	NNE	8.IV–19.IV, 1968
78.5N–05W	10	NNE	3.V –30.V, 1969
78.5N–04W	27	N	13.V –22.V, 1970

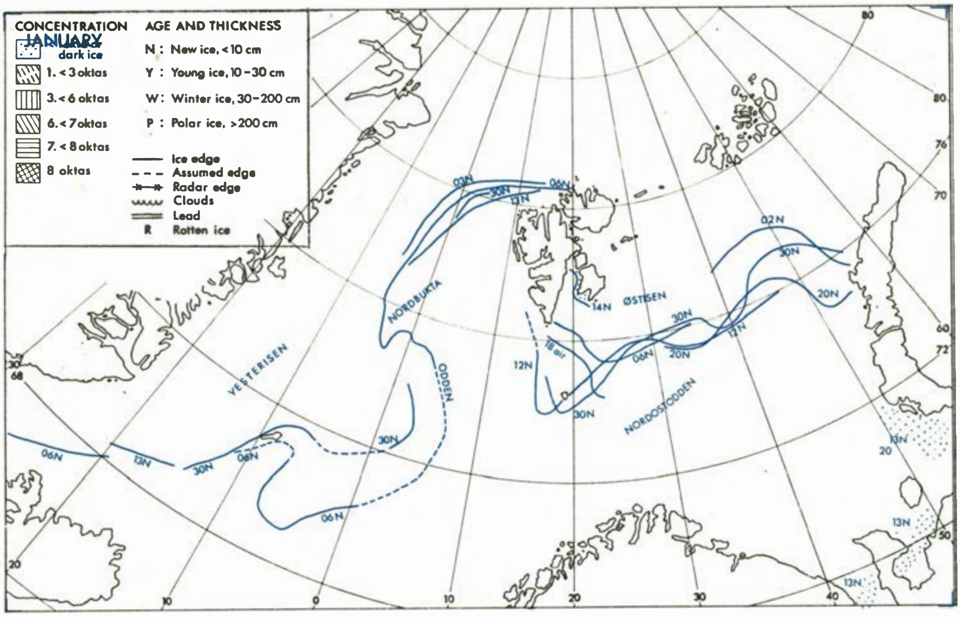

JANUARY
CONCENTRATION
dark ice
1. < 3 oktas
3. < 6 oktas
6. < 7 oktas
7. < 8 oktas
8 oktas
AGE AND THICKNESS
N : New ice, < 10 cm
Y : Young ice, 10 – 30 cm
W : Winter ice, 30 – 200 cm
P : Polar ice, > 200 cm
Ice edge
Assumed edge
Radar edge
Clouds
Lead
R Rotten ice
VESTERISEN
NORDBUKTA
ODDEN
ØSTISEN
NORDOSTODDEN

Fig. 1.

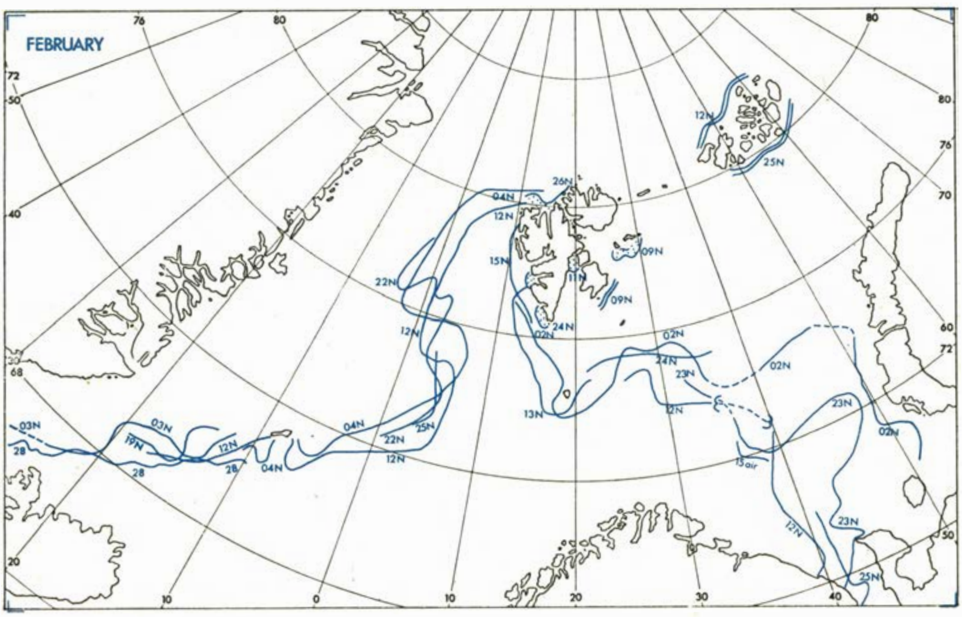

FEBRUARY

Fig. 2.

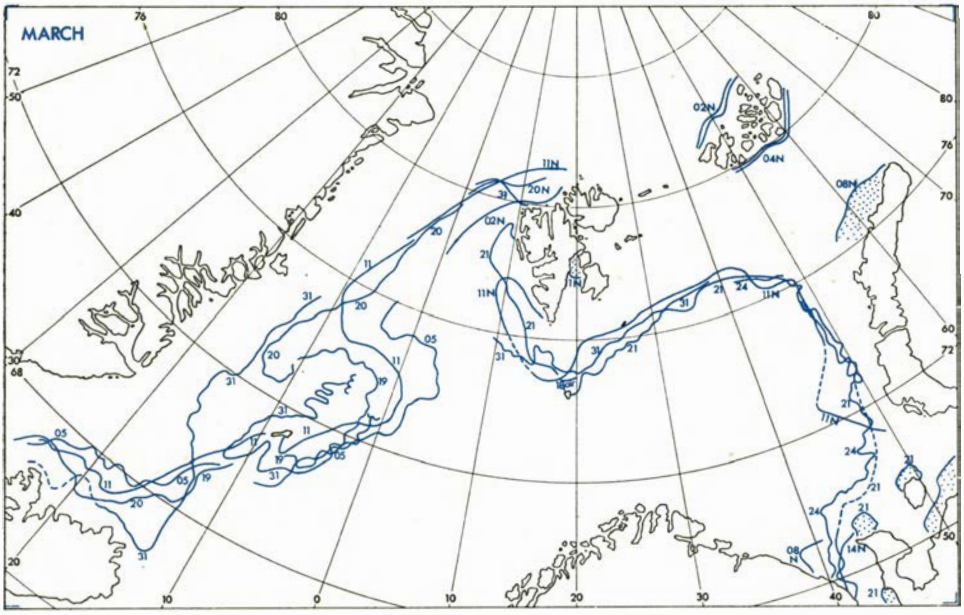


Fig. 3.

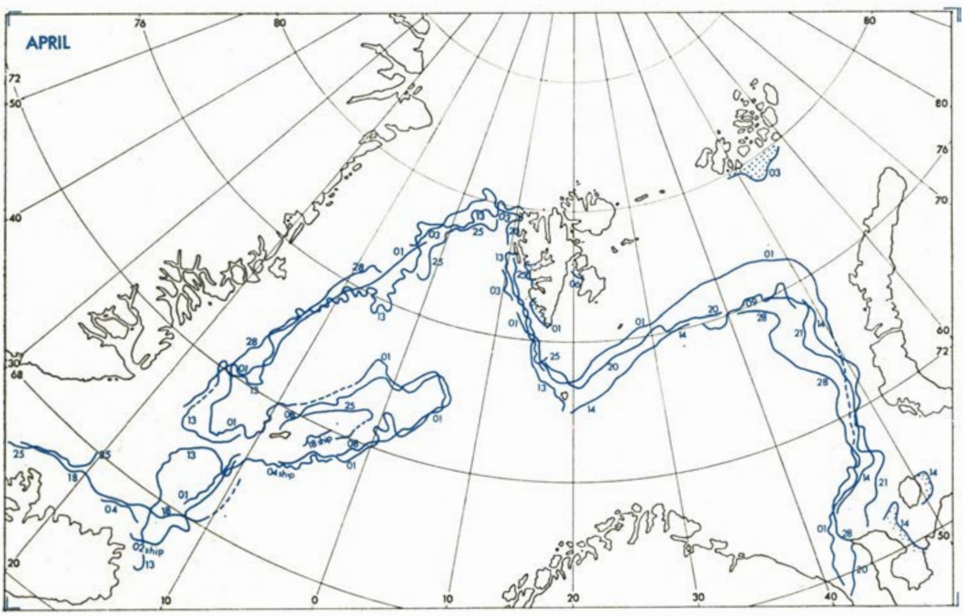


Fig. 4.

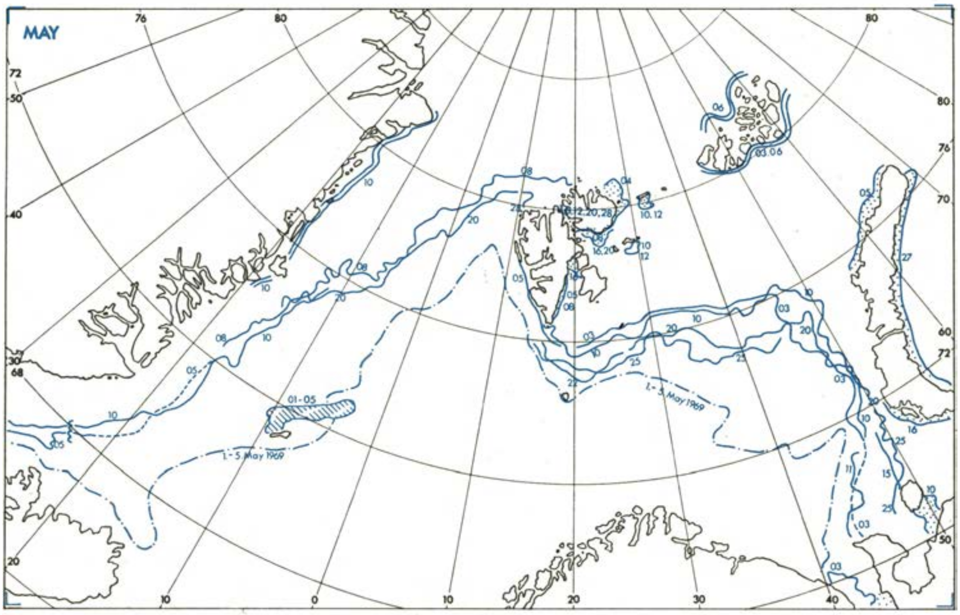


Fig. 5.

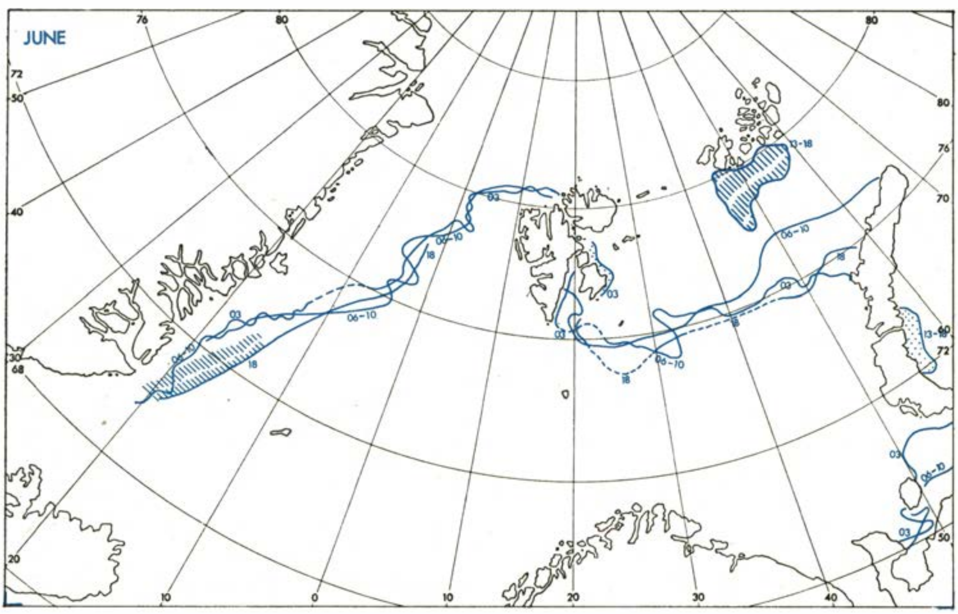


Fig. 6.

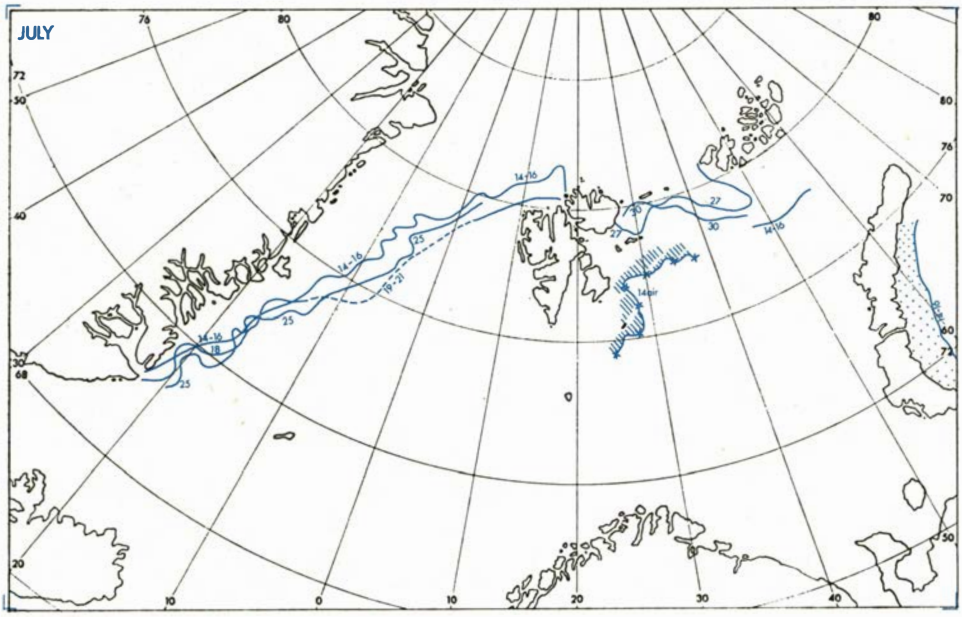


Fig. 7.

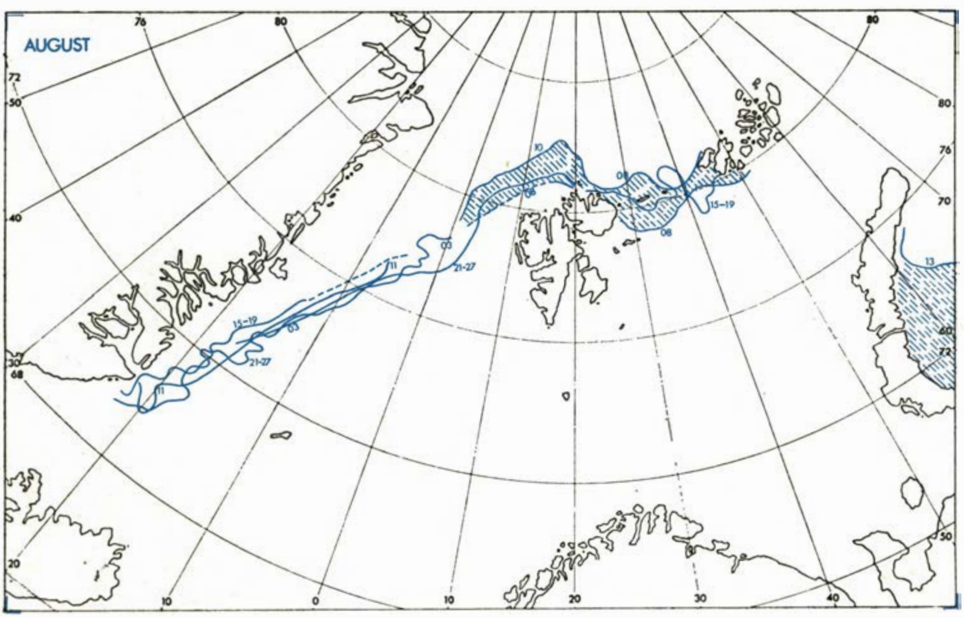


Fig. 8.

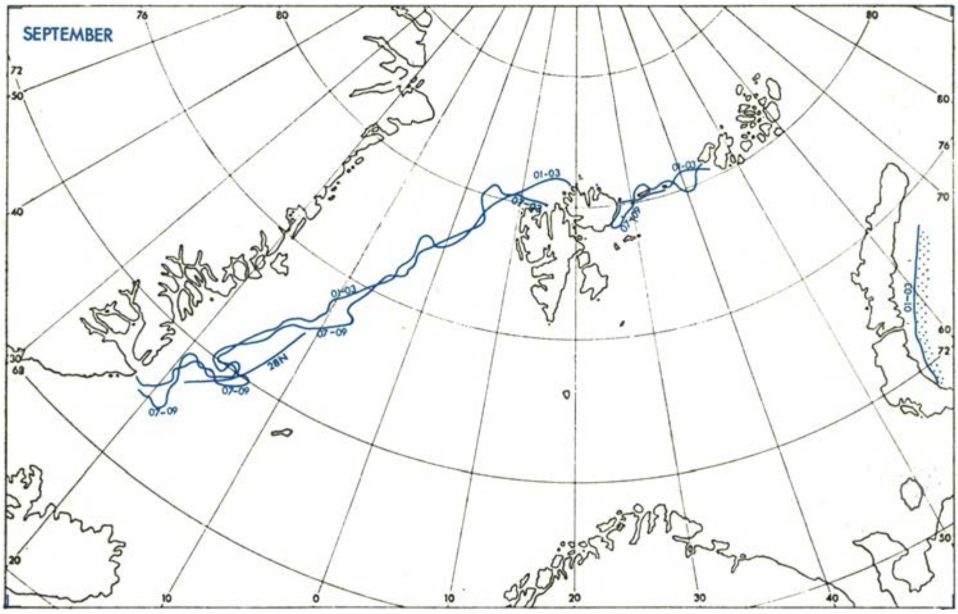

SEPTEMBER
01-03
07-09
28N

Fig. 9.

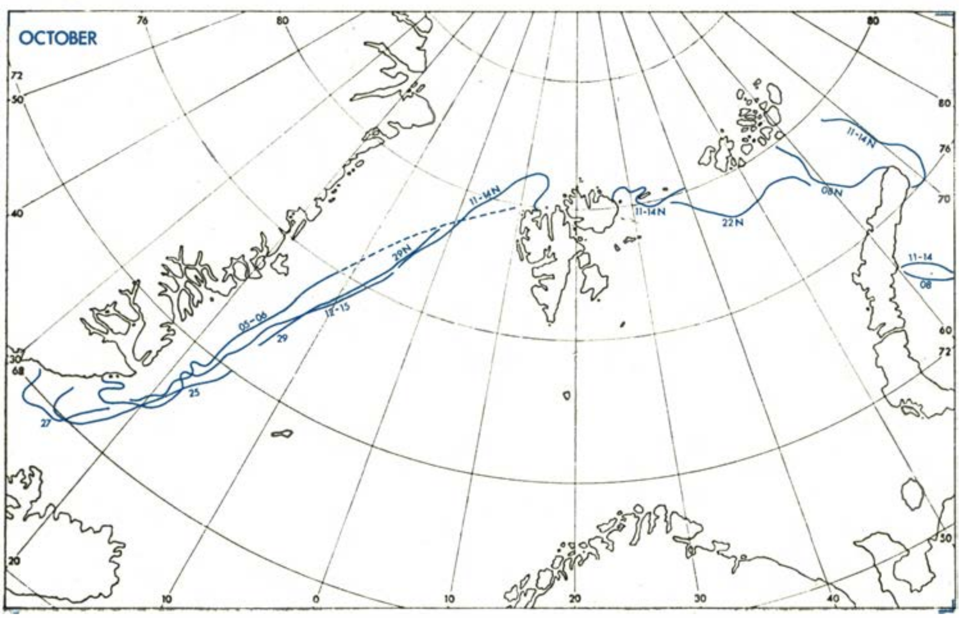
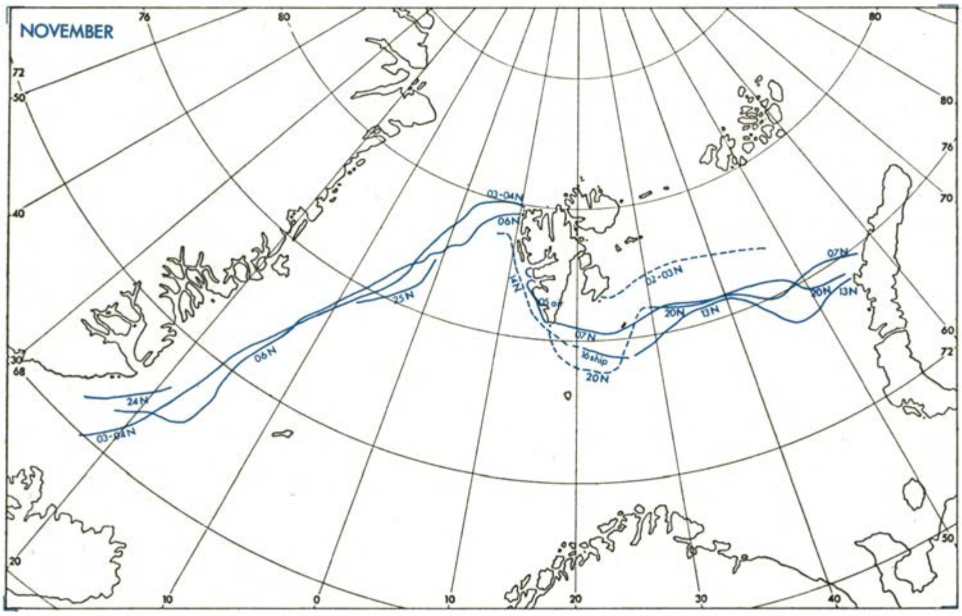

OCTOBER
11-14N
29N
05-06
12-15
29
25
27
22N
08N
11-14
08

Fig. 10.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06N
25N
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03-04N
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07N
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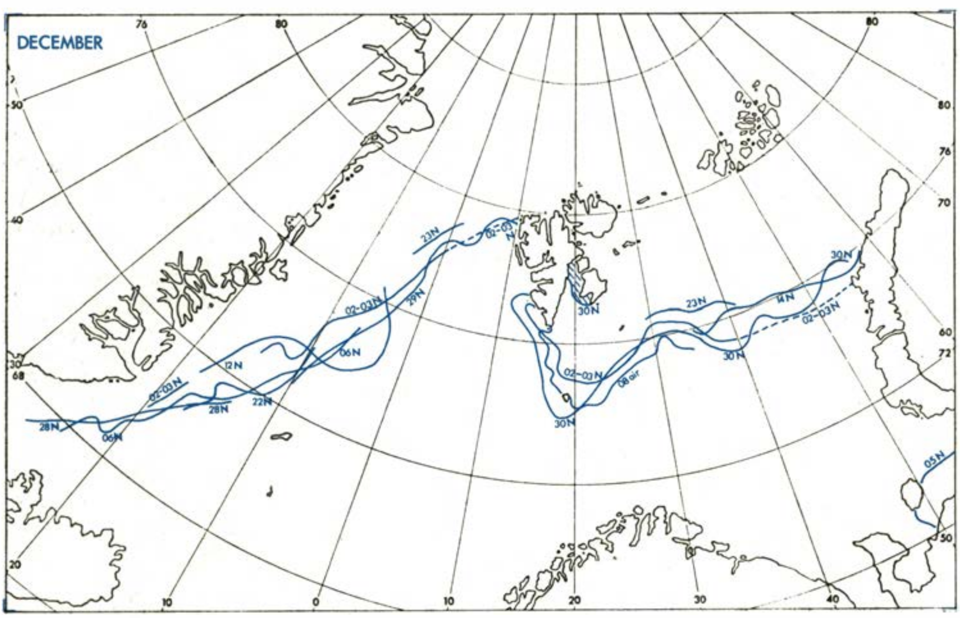
Fig. 11.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12N
02-03N
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30N
05N

Fig. 12.

Iakttagelser over dyrelivet på Svalbard 1970

(Observations of animal life in Svalbard 1970)

(Наблюдения над фауной Свальбарда в 1970-ом году)

AV

MAGNAR NORDERHAUG

Abstract

The present paper on biological observations from Svalbard is based on records from members of Norsk Polarinstitutt's expedition 1970 and on information from other field parties and persons visiting Svalbard in 1970.

Observation of 40–50 walruses (*Odobenus rosmarus*) from Kvitøya indicates that a small population still exists in Svalbard.

Crane (*Grus grus*), Moorhen (*Gallinula chloropus*) and White-rumped Sandpiper (*Calidris fuscicollis*) are recorded for the first time in Svalbard. The second record from Svalbard of Shoveler (*Spatula clypeata*), Steller's Eider (*Polysticta stelleri*), Red-breasted Merganser (*Mergus serrator*), and Short-eared Owl (*Asio flammeus*) is mentioned. The first breeding record of Geat Skua (*Catharacta skua*) from Svalbard is reported from Bjørnøya. Observations of some other less common birds are summarized in Table 1.

Аннотация

Настоящий отчет о биологических наблюдениях произведенных на Свальбарде основан на сведениях членов летней экспедиции Норвежского Полярного Института (Norsk Polarinsttiutt) 1970-го г. и информации других полевых партий и отдельных лиц, посетивших Свальбард в 1970 г.

Наблюдение 40-50 моржей *(Odobenus rosmarus)* на о. Kvitøya (Белом) указывает, что на Свальбарде все еще обитает небольшая популяция их.

Впервые обнаружены на Свальбарде – журавль *(Grus grus)*, камышница *(Gallinula chloropus)* и бонапартов песочник *(Calidris fuscicollis)*.

Во второй раз установлено пребывание на Свальбарде широконоски *(Spatula clypeata)*, малой гаги *(Polysticta stelleri)*, длинноносый крохаль *(Mergus serrator)* и болотной совы *(Asio flammeus)*. Первое сведение о гнездовании большого поморника *(Catharacta skua)* на Свальбарде сообщено с о. Bjørnøya (Медвежьего).

Наблюдения нескольких других, менее обычных птиц приводятся в таблице 1.

Innledning

Observasjonsmaterialet fra 1970 kommer fra en rekke ulike kilder. Hoveddelen av materialet er innsamlet under instituttets egen biologiske virksomhet i ulike deler av Svalbard (Kapp Linné, Kongsfjorden, Krossfjorden, Prins Karls Forland, Wijdefjorden, Hinlopenstretet og Kvitøya).

Rapporter av særlig verdi er dessuten mottatt fra J. ANGARD i sammenheng med biologiske vårundersøkelser på Spitsbergens nordvestre del, fra to svenske biologistudenter (A. HOFF og K. WADÉN) som oppholdt seg i Kongsfjorden og Krossfjorden, og fra R. MACHE som drev undersøkelser på Gåsøyane. Fra S. YTRELAND og O. I. RUUD er mottatt vinterrapporter fra sesongen 1969/70. Dette materialet er også inkludert i oversikten.

Av plasshensyn er bare de viktigste informasjoner tatt med. Resten er kartotekført i Norsk Polarinstitutts arkiv. For bidragsyterne er følgende initialer brukt: J. ANGARD (JA), O. BAKKEN (OB), K. BIRKENMAJER (KB), O. MUNKEBY (OM), R. MACHE (RM), O. I. RUUD (OIR), S. JENSEN (SJ), A. STRAND (AS), D. SOGNSTAD (DS), S. YTRELAND (SY), A. HOFF og K. WADÉN (H&W), samt Norsk Polarinstitutts biologparti (NPB).

Der årstall ikke er angitt refereres det til 1970.

Takk

Jeg vil med dette få takke instituttets ekspedisjonsdeltakere og de øvrige personer som har bidradd med observasjoner i 1970.

En særlig takk går til mine assistenter stud. real. K. HAGELUND og stud. real. J. MICHAELSEN, for deres effektive innsats under feltarbeidet på Svalbard. HAGELUND har forøvrig vært behjelpelig med bearbeidelsen av det foreliggende materiale.

Pattedyr

Polarhare (*Lepus arcticus groenlandicus*). – Rester av et individ oppgis funnet ved fuglefjellet nord for Fjortende Julibreen i Krossfjorden (H&W).

Moskus (*Ovibos moschatus*). – En flokk på 9 voksne ble sett 15/7 i Adventdalen (H&W).

Rein (*Rangifer tarandus platyrhynchus*). – I 1970 er det foretatt flere undersøkelser for Norsk Polarinstitutt for å utrede reinens utbredelse nærmere. Materialet er sammenfattet i et eget arbeide i denne årbok (NORDERHAUG 1972).

Isbjørn (*Thalarctos maritimus*). – Ved Roosneset såes en hann 10/3. Innerst i Woodfjorden såes en binne med fjorårsunge 10/4, og en binne med to årsunger såes ved Norskøyane 17/4 (JA). En binne med fjorårsunge ble sett ved Nordenskiöldøya 18/8. På Kvitøya ble det 20/8 sett en ved Andréeneset og tre ved Kræmerpynten og tre inne på Kvitøyjøkulen (NPB).

Grønlandssel (*Phoca groenlandica*). – Ca. 10 individer ble sett ved Halvmåneøya 11/2 (SY).

Hvalross (*Odobenus rosmarus*). – En ny observasjon er kommet til fra 1969, idet et individ ble sett ved Halvmåneøya 15/10 (SY). Den 12/8 ble, ifølge sysselmann STEPHENSEN, et individ sett på Moffen. I tiden 20–21/8 oppholdt N.P.'s ekspedisjonsfartøy seg nord og nordvest for Kræmerpynten på Kvitøya. Hvalross ble da stadig sett. De opptrådte gjerne i småflokker på opptil 15 individer. På grunnlag av observasjonene ble bestanden ved denne delen av Kvitøya anslått til 40–50 dyr (NPB). Observasjonene fra Kvitøya kan taes som det første sikre bevis på at det innen Svalbardområdet fortsatt eksisterer en mindre, fast populasjon.

Fugler

Smålom (*Gavia stellata*). – Hekking ble påvist ved Kapp Linné, Ny-Ålesund og Mossellaguna. To individer ble dessuten sett på Moffen 9/8 (NPB).

Skjeand (*Spatula clypeata*). – En hunn såes i Fyrsjøen (Kapp Linné) i tiden 2–16/7 (NPB). Funnet er det andre fra Svalbard, idet et skjeandpar ble sett på Bjørnøya 30/5–10/6 i samme sesong (WILLIAMS 1971).

Havelle (*Clangula hyemalis*). – I området Kapp Linné–Båtodden ble funnet 19 reir (hvorav 13 ved Kapp Linné). Fra Grøssfjell i Austfjorden foreligger dessuten et hekkefunn (NPB).

Stellers and (*Polysticta stelleri*). – En hann såes i en praktærfuglflokk ved Kapp Linné 27/6 (NPB). Det foreligger tidligere ett funn av arten fra Svalbard (NORDERHAUG 1970).

Siland (*Mergus serrator*). – En hunn såes i Fyrsjøen (Kapp Linné) 19–20/6 (NPB). Dette er første gang arten er påvist på Svalbard. Førsteobservasjonen (1♂) ble gjort samme sted 16/6, 1963 (NYHOLM 1966).

Kortnebbgås (*Anser fabalis brachyrhynchus*). – Ved Hornsund såes 4–500 individer på trekk 3/10, 1969 (OIR). Ved Engelskbukta såes 9 voksne og 17 unger 30/7 (JA). Hekking ble videre påvist ved Stuphallet (JA) og på Lovénøyane (NPB). Ved Grøssfjell (Austfjorden) såes 10 mytende individer 3/8 (NPB).

Ringgås (*Branta bernicla hrota*). – På Gyllensköldholmane (søndre) ble sett 14 individer hvorav to par med henholdsvis 1 og 4 unger (NPB).

Hvitkinngås (*Branta leucopsis*). – Ved Kapp Linné såes 1–9 individer i tiden 27/6–28/7. Enkeltindivider ble videre sett i Kongsfjorden, og i Heleysundet ble 13 individer sett 25/8 (NPB).

Rype (*Lagopus mutus hyperboreus*). – Masseopptreden av rype ble rapportert fra Hornsund i første halvdel av oktober 1969 (OIR). På Halvmåneøya såes 6 individer 13/10, 1969 (SY). I området Kongsfjorden–Reinsdyrflya ble spor av enkeltindivider sett i april (JA). På Midifjellet (Sørkapp Land) såes ett individ 1/8 (KB), og 19 individer (sannsynligvis 2 kull) såes 27/8 vest for Grøssfjell i Austfjorden (NPB).

Trane (*Grus grus*). – Et dødt individ ble funnet på Nathorstbreen 20/8 (BIRKENMAJER 1972). Antagelig dreier det seg om samme individ som ble rapportert fra Edgeøya (AS/SY) medio juni (Habenichtbukta) og 13/7 (Russebukta). Det er første gang arten er påvist på Svalbard.

Sivhøne (*Gallinula chloropus*). – Et individ hadde tilhold i Ny-Ålesund 21–30/6 (NPB). En sivhøne skal videre være innlevert til Tromsø Museum fra Hopen samme sommer (E. BRUN, pers. medd.). Det er første gang arten er funnet på Svalbard.

Steinvender (*Arenaria interpres*). – Hekkefunn ble registrert ved Kapp Linné (2 par), ved Ny-Ålesund (2–3 par), i Møllerhamna, Krossfjorden, (1 par) og på Mitrahalvøya (1 par) (NPB, H&W). Par med territorium ble videre registrert på Gåsøyane (RM), på Horneflya, Prins Karls Forland og på Kvadehuken (NPB). Spredte observasjoner foreligger dessuten fra Ebeltofthamna (2), Diesetsletta (10) og Mossellaguna (2) (NPB, H&W).

Polarsnipe (*Caladris canutus*). – Ved Kapp Linné såes enkelteksemplarer 21/6 og 29/7. Ved Ny-Ålesund såes 8 individer 19/6 og 12 individer 2/7 (NPB).

Bonapartesnipe (*Calidris fuscicollis*). – Et individ hadde tilhold i Ny-Ålesund i tiden 19–22/7 (NPB). Det var mulig å foreta en sikker feltbestemmelse, og funnet er dokumentert fotografisk. Arten er tidligere ikke funnet på Svalbard (eller Norge forøvrig).

Myrsnipe (*Calidris alpina*). – Ved Kapp Linné ble gjort 12 obseivasjoner (1–7 individer) i tiden 19/6–27/7. Fra Longyearbyen fins 5 observasjoner (1–6 individer) i tiden 18/6–2/9. Fra Ny-Ålesund fins 9 observasjoner (1–7 individer) i tiden 19/6–22/7, og et reir ble rapportert funnet sør for Ny-Ålesund (NPB). På Diesetsletta såes en 27/7 (H&W) og ved Grøssfjell (Austfjorden) ble det gjort et hekkefunn (NPB).

Sandløper (*Crocethia alba*). – Ved Kapp Linné ble gjort 12 observasjoner (1–12 individer) i tiden 19/6–26/7. I Longyearbyen såes 7 individer 18/6 og 1 individ 8/8. I Ny-Ålesund såes arten (1–8 individer) i tiden 19/6–21/8 og sannsynligvis hekket ett par. Ved Grøssfjell (Austfjorden) ble gjort et hekkefunn (NPB).

Polarsvømmesnipe (*Phalaropus fulicarius*). – Følgende hekkefunn er rapportert: Kapp Linné (5 reir), Gåsøyane (sannsynligvis hekking), Ny-Ålesund (2 reir), Bjørnnesholmen, Austfjorden (1 reir) (NPB, RM).

Fjelljo (*Stercorarius longicaudus*). – Ved Kapp Linné såes 2 individer 14/7. Ved Storholmen (Kongsfjorden) hadde 2 individer tilhold 9–28/7, tilsynelatende uten å hekke (NPB). På Diesetsletta (Mitrahalvøya) ble 2 sett 26/7 (H&W). I Austfjorden, på tangen sørøst for Bjørnnesholmen, ble det gjort 5 observasjoner (1–3 individer) i tiden 3–9/8. Et par, muligens ovennevnte individer, hevdet territorium ved Tryggvebreen (4/8), men hekking ble ikke påvist. Et individ ble videre sett ved Gyllensköldholmane 7/8 (NPB).

Storjo (*Catharacta skua*). – På Bjørnøya ble et reir med 2 egg funnet på en holme i Haussvatnet 9/7 (SJ). Dette er det første kjente hekkefunn av arten fra Svalbard, men det er mulig at hekking fant sted på Bjørnøya (en holme i Røyevatnet) også i 1969 (OM).

Ismåke (*Pagophila eburnea*). – Kolonien i Bendefjellet, funnet i 1962 (BIRKENMAJER & SKRESLET 1963), ble besøkt 27/8. Det ble registrert 49 reir og 52 voksne individer (BIRKENMAJER 1972). Forøvrig ble en ny koloni på 12–13 par funnet i samme fjell (sørvestskråningen, ca. 600 m o.h.) (DS). I Grimfjellet ble en koloni funnet i skråningen rett sør for toppen, 6 voksne og 1 unge ble sett (DS). På Kvitøya såes 2 individer ved Kræmerpynten 20/8 og 5–6 samme sted 21/8 (NPB).

Rødnebbterne (*Sterna macrura*). – Følgende kolonier ble innrapportert (NPB): Bjørnnesholmen (ca. 50 par), Gyllensköldholmane, nordre (ca. 12 par), Gyllensköldholmane, søndre (ca. 50 par), Moffen (50–75 par), Foottøya i Lomfjorden (ca. 55 par), Nordenskiöldøya, Hinlopenstretet (60–65 par). På Kvitøya hekket 4 par på Hornodden, 30–40 par på Kræmerpynten.

Jordugle (*Asio flammeus*). – Et individ, antagelig omkommet på vårparten, ble funnet i Ny-Ålesund 22/6 (OB). Så vidt vites er funnet det tredje fra Svalbardområdet, idet tidligere er kjent ett funn fra Bjørnøya 1962 og ett fra Hopen 1964 (HEINTZ & NORDERHAUG 1966, ØSTERHOLM 1966).

Steinskvett (*Oenanthe oenanthe*). – Ved Kapp Linné såes et individ 20/6 og 25/6. To døde ble dessuten funnet. I Ny-Ålesund såes en hunn 20–21/6. På Fuglehuken ble gjort 4 observasjoner (3 enkeltindivider, samt et par) i tiden 25–29/6 (NPB).

Tabell 1.

Observasjoner i 1970 av noen mindre vanlige arter, ikke omtalt i teksten.

(Observations in 1970 of some less common birds, not mentioned in the text.)

Art *Species*	Lok./dato *Loc./date*	Anmerkning *Remarks*	Observatør *Observer*
Krikkand (*Anas crecca*)	Fyrsjøen, Kapp Linné 30/6–2/7	2 ♂♂, 1 ♀	NPB
—»— —»—	—»— —»— 12/7	2	–»–
—»— —»—	—»— —»— 20/7	1	–»–
Svartand (*Melanitta nigra*)	Kapp Linné 19–24/6	1 ♂, 1 ♀	–»–
—»— —»—	—»— 5/7	3 ♀♀	–»–
—»— —»—	—»— 20/7	1 ♀	–»–
Jaktfalk (*Falco rusticolus*)	Isbjørnhamna, Hornsund 9/10 (1969)	1	OIR
—»— —»—	Hyttevika 17/10 (1969)	1	–»–
—»— —»—	—»— 4/11 (1969)	2	–»–
Heilo (*Pluvialis apricaria*)	Ny-Ålesund 20–24/6	1	NPB
Rødstilk (*Tringa totanus*)	Kapp Linné 26–29/6	1	–»–
—»— —»—	—»— 10–13/7	1	–»–
—»— —»—	Longyearbyen 2/9	1	–»–
—»— —»—	Ny-Ålesund 19–24/6	1	–»–
—»— —»—	—»— 4/7	1	–»–
Svømmesnipe (*Phalaropus lobatus*)	Longyearbyen 18/6	1	–»–
Svartbak (*Larus marinus*)	Kapp Linné 24/6–4/8	1–2 (7 observ.)	–»–
—»— —»—	Gåsøyane 9/7	1	RM
—»— —»—	Kongsfjorden 22/6	2	NPB
—«— —»—	—»— 4/7	1	–»–
—»— —»—	Kohnøya, Krossfjorden, primo juni	2	JA
—»— —»—	Kapp Mitra 27/7	2	H&W
Sildemåke (*Larus fuscus*)	Kapp Linné 1–3/7	1	NPB
Gråmåke (*Larus argentatus*)	Longyearbyen 18/6	1	–»–
Hettemåke (*Larus ridibundus*)	Kapp Linné 5/7	1	–»–
—»— —»—	Longyearbyen 18/6	4	–»–
Gråtrost (*Turdus pilaris*)	Hyttevika, Hornsund 21/10 (1969)	1	OIR
—»— —»—	—»— —»— 23/10 (1969)	flere	–»–
—»— —»—	Kapp Linné	9 døde fra høsten 1969	NPB
—»— —»—	Fuglehuken	1 død fra høsten 1969	–»–
Måltrost (*Turdus philomelos*)	Kapp Linné	1 død frs høsten 1969	–»–
Rødvingetrost (*Turdus iliacus*)	Hyttevika, Hornsund 10/10 (1969)	1	OIR
—»— —»—	—»— —»— 20/10 (1969)	flokker	–»–
—»— —»—	Kapp Linné	14 døde fra høsten 1969	NPB
—»— —»—	Ny-Ålesund	1 død fra høsten 1969	–»–
Svarttrost (*Turdus merula*)	Isbjørnhamna, Hornsund 24/10 (1969)	flere	OIR
—»— —»—	Kapp Linné	1 død fra 1969	NBP
Linerle (*Motacilla alba*)	Hyttevika, Hornsund 5/5 (1969)	1	OIR
Stær (*Sturnus vulgaris*)	Isbjørnhamna. Hornsund 24/10 (1969)	flere	–»–
—»— —»—	Hyttevika, Hornsund 28/10 (1969)	flere	–»–
—»— —»—	Austfjorden	1 død fra 1969	NPB
Bjørkfink (*Fringilla montifringilla*)	Kapp Linné	1 død fra 1969	–»–

Litteratur

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— 1972: Distribution of the Svalbard reindeer (*Rangifer tarandus platyrhynchus*) in 1969–70. Dette bind (this vol.), 153–158.

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Norsk Polarinstitutts virksomhet i 1970

AV

TORE GJELSVIK

Organisasjon og administrasjon

Personale

Norsk Polarinstitutt hadde i 1970 32 faste stillinger, like mange som foregående år. SØREN RICHTER fratrådte sin stilling som bibliotekar (med invalidepensjon) 28. februar. Med departementets samtykke har assistentbibliotekar VIBEKE EGG-HENRIKSEN bestyrt stillingen siden. DAG NORBERG fratrådte sin stilling som topograf I 31. juli. HÅKON HILL ble innvilget ett års permisjon uten lønn fra sin stilling som topograf i særklasse, regnet fra 1. oktober. BOYE FLOOD ble innvilget ett års permisjon uten lønn fra sin stilling som geolog II, regnet fra 6 desember. Disse tre stillinger stod ledige resten av året p.g.a. mangel på kompetente søkere.

Midlertidig engasjerte:

EEG-HENRIKSEN, FRIDE, assistent
EEG-HENRIKSEN, VIBEKE, assistentbibliotekar
HELLE, INGEBJØRG, assistent
HOLMSEN, ELI, redaksjonssekretær
JENSEN, KJERSTI, assistentbibliotekar
KLOUMANN, PETTER, geolog
RYE, JOHAN H., cand. mag.
SKANCKE, TURID, assistent
TANDBERG, ROLF, konsulent

Stipend og forskningsbidrag er ytt til:

Lektor ODD LØNØ, stipend til å studere fangststatistikk for hvalross og polarrev, samt norske overvintrende fangstfolks historie på Svalbard.

Forfatteren HELGE INGSTAD, bidrag til en ekspedisjon til sørøstre Baffin Island for å lete etter mulige spor av norrøn virksomhet.

Cand. real. NILS GULLESTAD, bidrag til dekning av utlegg i forbindelse med innsamling av røyemateriale fra Linnévatnet på Svalbard.

Stud. real. KARL HAGELUND, stipend til bearbeidelse av innsamlet materiale om ærfuglens hekkebiologi på Svalbard.

Oppnevnelser:

MAGNAR NORDERHAUG til medlem av en nyopprettet "Committee on Arctic Habitats" under Den internasjonale naturvernunion (IUCN) og av redaksjonskomitéen for "Astarte, Journal of Arctic Biology".

Gjesteforskere med arbeidsplass ved Norsk Polarinstitutt:

Professor dr. KRZYSZTOF BIRKENMAJER, Det polske vitenskapsakademi, Geologisk institutt, Kraków (stipend fra NTNF – hele året) og dosent dr. JAN SZUPRYCZYŃSKI, Det polske vitenskapsakademi, Geografisk institutt, Toruń (utvekslingsstipend gjennom UD – fra oktober).

Utlån av utstyr

Etter at sommerens hydrograferingsarbeid med O/S «Senja» var avsluttet, ble instituttets HI-FIX-utstyr i september utlånt til NTNFs Kontinentalsokkelkontor, som utførte opplodninger m.v. over Norskerenna med henblikk på legging av oljeledninger.

REGNSKAP FOR 1970

Kap. 950. Poster:	*Bevilget:*	*Medgått:*
1. Lønninger	kr. 1 566 500	kr. 1 658 600
9. Deltakelse i Antarktisekspedisjon	» 112 600	» 86 700
10. Kjøp av utstyr	» 26 000	» 26 000
15. Vedlikehold	» 29 600	» 28 700
20. Ekspedisjoner til Svalbard og Jan Mayen	» 1 412 800	» 1 436 500
29. Andre driftsutgifter	» 350 000	» 480 700
70. Stipend	» 40 000	» 36 000
	kr. 3 537 500	kr. 3 753 200
Kap. 31. Fyr og radiofyr på Svalbard	kr. 30 000	kr. 42 100
Kap. 340. Forskningsstasjonen på Svalbard:		
9. Driftsutgifter	kr. 281 000	kr. 153 100
10. Inventar og utstyr	» 74 000	» 56 800
30. Innreiing og vitenskapelig utstyr, overf. fra 1969	» 58 100	» 58 100
	kr. 413 100	kr. 268 000
Kap. 3950. Inntekter:	*Budsjettert:*	*Innkommet:*
1. Salgsinntekter	kr. 25 000	kr. 134 000
2. Refusjon fra Svalbardbudsjettet	» 300 000	» 300 000
	kr. 325 000	kr. 434 000
Kap. 4909. Tilfeldige inntekter	—	kr. 14 300

Kommentarer til regnskapet:

Kap. 950.

Post 1. Lønninger. – Merforbruket skyldes lønnsrevisjon for offentlige tjenestemenn, omlegging av systemet for beregning av felttillegg og økte trygdepremier.

Post 9. Deltakelse i Antarktisekspedisjon. – Mindreforbruket skyldes vesentlig at det felttillegget som utbetales gjennom Skattefogden først ble utbetalt i 1971.

Post 20. Ekspedisjoner til Svalbard og Jan Mayen. – Merforbruket skyldes tillatt overskridelse for undersøkelse av vulkanutbruddet på Jan Mayen i september.

Post 29. Andre driftsutgifter. – Merforbruket har flere årsaker: Utgiftene til kopiering av flybilder ble større enn antatt, men ble mer enn oppveid ved salg av bilder. På grunn av det store behovet for trykking gav departementet tillatelse til å overskride trykningskontoen med inntil kr. 50 000. Ved makeskifte av rom med NVE ble det også installert nytt laboratorium, og dette medførte økte utgifter. Endelig ble Reiseposten tillatt overskredet mot innsparing på Ymse-posten.

Post 70. Stipend. – Jfr. foregående avsnitt.

Kap. 31. Fyr og radiofyr på Svalbard.

Merforbruket er med departementets godkjennelse gått til oppsetting av ny lykt på Blåhuken etter anmodning av Store Norske Spitsbergen Kulkompani A/S, som har begynt forberedelsene til gjenåpning av Sveagruva.

Kap. 340. Forskningsstasjonen på Svalbard.

Mindreforbruket skyldes at aktiviteten ved stasjonen fra norske forskere og forskningsinstitusjoner har vært mindre enn det ble ytret ønske om fra de medvirkende institusjoner. Aktiviteten har imidlertid tatt seg noe opp, og siden høsten 1970 har to mann vært ansatt ved stasjonen.

Kap. 3950. Inntekter.

Post 1. Salgsinntekter. – Merinntekten skyldes den uvanlig store etterspørselen etter flybilder fra Svalbard i forbindelse med oljeleting.

Feltarbeid

NORGE

Breundersøkelser

Akkumulasjonen på Hardangerjøkulen og Storbreen ble målt i slutten av april og begynnelsen av mai. I løpet av sommeren ble ablasjonen målt flere ganger på begge breene.

På Hardangerjøkulen undersøkte cand. mag. TRON LAUMANN snøens struktur og metamorfose som grunnlag for sin hovedoppgave i geografi.

Lengdevariasjonen av 8 breer i Sør-Norge og 2 av Svartisens breer i Nord-Norge ble målt. (Se O. LIESTØLS artikkel: "Glaciological work in 1970", s. 240–251.)

Kontinentalsokkelundersøkelser

EINAR NETELAND og JOHAN HENRIK CHRISTIANSEN deltok i tokt med O/S «Andenes», henholdsvis i tiden 14–19/9 og 30/9–9/10.

SVALBARD

I tillegg til den vanlige aktivitet begynte instituttet i samarbeid med NTNF og andre institusjoner en større undersøkelse av kontinentalsokkelen i Barentshavet

(Barentshavprosjektet). Et rammeforslag for dette ble fremsatt av Norsk Polarinstitutt høsten 1969 og godkjent av prosjektstyret for NTNFs Kontinentalsokkelkontor, og finansieres delvis av dette, delvis over Norsk Polarinstitutts ekspedisjonsbudsjett.

Norsk Polarinstitutts vanlige sommerekspedisjon til Svalbard ble organisert og ledet av operasjonssjef THOR SIGGERUD og omfattet – foruten besetninger på ekspedisjons- og hydrograferingsfartøy, helikoptre og fly – 42 personer: 14 av instituttets faste medarbeidere og 28 engasjerte, hvorav 6 fagmedarbeidere, 4 faglige assistenter og 18 vanlige assistenter. De første deltakerne kom til Svalbard 18/6 og de siste forlot området 8/9.

Ekspedisjonsfartøyet M/S «Polar Star» med kaptein KÅRE STOKKEHOLM og 13 manns besetning ble overtatt av ekspedisjonslederen i Ålesund 22/7. Følgende natt lastet det utstyr og tok inn ekspedisjonsdeltakere i Åndalsnes, der det også (6/9) losset utstyr og satte av deltakere etter endt tokt. Fartøyet ble hovedsakelig nyttet til base for helikopteroperasjoner, foruten til å frakte utstyr, sette ut og hente inn feltpartier. Fra fartøyet ble det sendt værmeldinger til Ny-Ålesund til orientering for flypartiet, som hadde sin base der.

Til transport ut i felten fra fartøyet var leid to Bell 47 J-helikoptre fra Helikopter Service A/S, betjent av tre flygere og en mekaniker.

Som base for topografisk, geologisk, geofysisk og biologisk feltarbeid oppholdt ekspedisjonsfartøyet seg i Woodfjorden, Wijdefjorden, Hinlopenstretet og ved Kvitøya. Et smidig opplegg i utnyttelsen av helikoptrene og den gunstige issituasjonen gjorde det mulig ikke bare å gjennomføre det planlagte feltarbeidet, men også å utvide det betydelig, om enn været ikke var det beste og snøen alt kom i slutten av august. SIGURD EGGEN var assistent for ekspedisjonslederen.

O/S «Senja» med kapteinløytnant RICHARD JENSSEN som skipssjef og 30 manns besetning var leid fra Sjøforsvaret. Fartøyet ble overtatt i Bodø 13/7 og avlevert i Harstad 3/9. Foruten hydrografering utførte fartøyet forskjellige undersøkelser under Barentshavprosjektet.

Et Cessna 337-fly med to manns besetning var leid fra Widerøe's Flyveselskap A/S til å fortsette flyfotograferingen av Svalbard, vesentlig i nordøst. Det var stasjonert i Ny-Ålesund.

Et tilbygg ble oppført og innredet til mannskapsrom ved instituttets båthus på Hotellneset i Longyearbyen.

Utenom sitt geologiske feltarbeid besøkte direktør TORE GJELSVIK, som oppholdt seg på Svalbard 18/6–8/7, Store Norske og sysselmannen i Longyearbyen, og i Ny-Ålesund inspiserte han Forskningsstasjonen på Svalbard, som Norsk Polarinstitutt administrerer.

Hydrografi

Med hydrograferingsbåten «Svalis» foretok HELGE HORNBÆK, assistert av JOHN AKSEL BYE, URS ERNST og SIVERT UTHEIM, detaljlodding i Kongsfjorden og undersøkte dessuten noen rapporterte grunner i Tempelfjorden. Partiet hadde en feltsesong på 71 dager (juli–september).

Hydrograferingsarbeidet med O/S «Senja» ble i toktets første halvdel ledet av underdirektør KAARE Z. LUNDQUIST og i annen halvdel av midlertidig engasjert hydrograf, kpt.ltn. KJELL-OLAV PETTERSEN. Ingeniør EINAR NETELAND var teknisk leder, og assistenter på HI-FIX-systemets slavestasjoner var: KNUT ELLEVOLD, TRULS FROGNER, ATLE MØRK og STURLA PEDERSEN.

Arbeidet i den nordvestre, gjenstående del av farvannet Sørkapp—Bjørnøya—Hopen ble fullført, og man fortsatte i den nordlige del av området vest for Sørkapp—Bjørnøya.

I alt ble det gått 6 800 naut. mil loddelinjer, hvorav ca. 3 000 mil også med magnetometer og penetrasjonslodd som ledd i kontinentalsokkelundersøkelsene under Barentshavprosjektet.

Topografi-geodesi

Geodet OLA STEINE og de to engasjerte topografene, JOHANNES HUS og CHRISTIAN NIELSEN, assistert av TROND A. EDIN, IVAR LUND-MATHIESEN og KJELL REPP, hadde «Polar Star» som mobil base og to helikoptre til felttransport. De bestemte passpunkter i Ny Friesland, Olav V Land, på Reinsdyrflya og i Hinlopenstretet. Bortsett fra Hinlopenstretet regner en med at passpunktmålingene er avsluttet i området. Femten punkter i et nytt triangelnett med sidemålinger for Svalbard ble markert med bolter. Noen målinger gjenstår før disse stasjonene også er ferdigmålt. Åtte sidelinjer ble målt med tellurometer. Et forsøk på ny astronomisk posisjonsbestemmelse av Kræmerpynten på Kvitøya mislyktes på grunn av dårlig vær.

Geologi

TORE GJELSVIK arbeidet i tiden 20/6—1/7 i den nordligste del av Prins Karls Forland og i indre del av Kongsfjorden.

HARALD MAJOR foretok i tiden 20/7—14/8 befaringer og undersøkelser ved Gruve III, VI og VII og innenfor prospekteringsområdet i Foxdalen. I Sveagruva ble forberedelser til detaljkartlegging gjort. Han var også på korte befaringer til Coraholmen i Ekmanfjorden og Conwentzodden i Van Mijenfjorden.

JENÖ NAGY foretok i tiden 17/8—25/8, sammen med bergmester TORMOD JOHNSEN og KRZYSZTOF BIRKENMAJER, befaringer av funnpunkter i Grimfjellområdet øst for Hornsund, og utførte stratigrafiske målinger både her og ved Burgerbukta. I tidsrommet 27/8—1/9 gjorde han stratigrafiske og paleontologiske undersøkelser i Adventdalen, og 2/9 var han og THOR SIGGERUD statens representanter i utmålsforretninger hos bergmesteren.

KRZYSZTOF BIRKENMAJER arbeidet i området sør for Hornsund i tiden 26/7—16/8 og 26/8—3/9 med geologisk kartlegging, strukturundersøkelser, paleontologiske innsamlinger og undersøkelser av økonomisk viktige mineraler. Assistenter var: SVEIN GULBRANDSEN og ØYVIND GULDAHL.

DAVID WORSLEY, assistert av NILS-MARTIN HANKEN, gjorde i tiden 29/7—11/8 sedimentologiske undersøkelser av devonlagene i nordre Andrée Land mellom Jakobsenbukta og Vogtvatnet. Fra 12/8 til 25/8 gjorde han stratigrafiske og sedimentologiske undersøkelser av karbon-perm-lagene på vestsiden av Hinlopen-

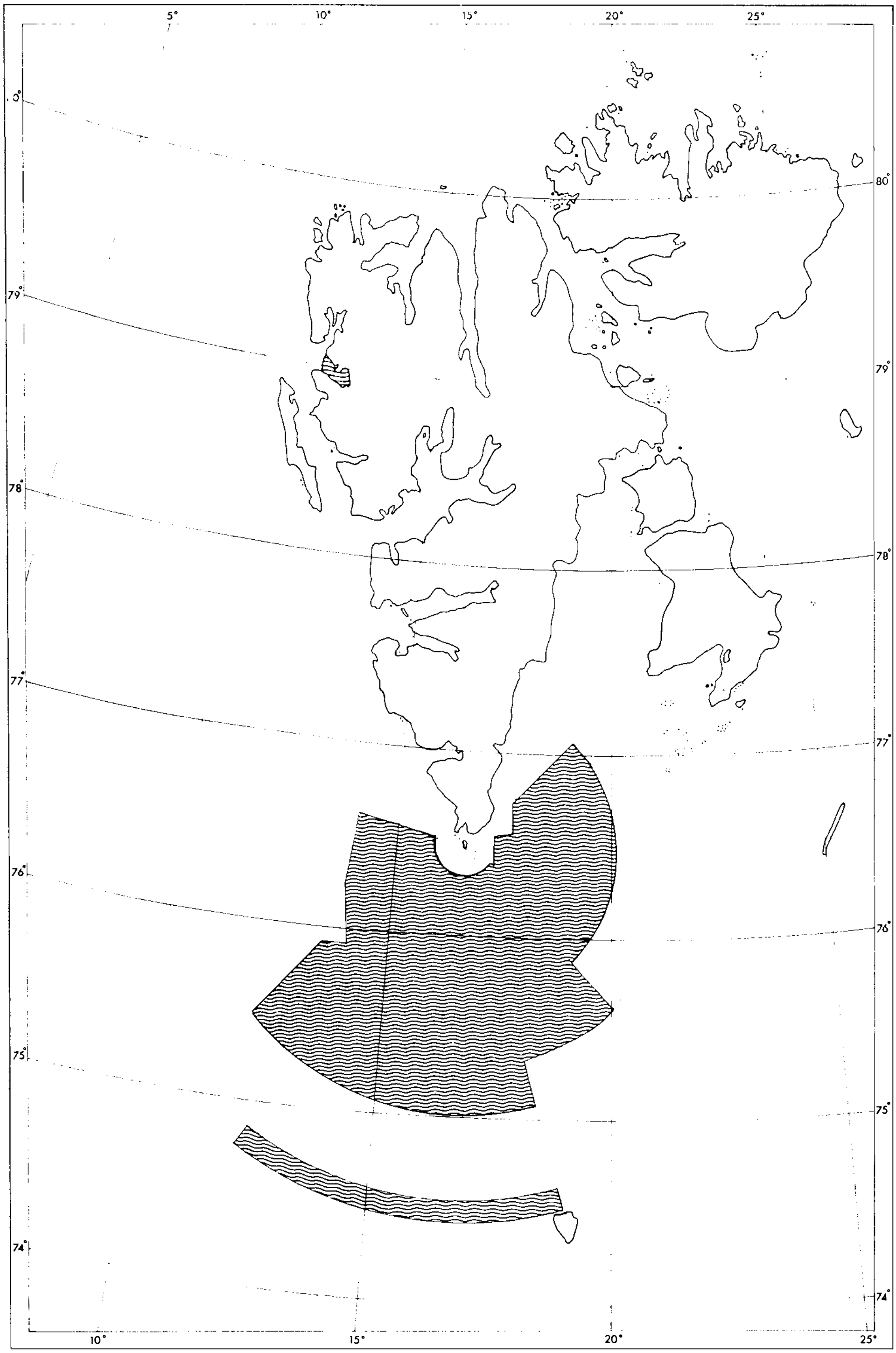

Fig. 1. *Kartet viser hvor Norsk Polarinstitutts hydrografiske feltpartier arbeidet sommeren 1970.*

stretet mellom Lomfjorden og Eremitten, samt stratigrafiske undersøkelser av mesozoiske lag på Wilhelmøya og i Hellwaldfjellet.

På Kvitøya i august gjorde THOR SIGGERUD geologiske undersøkelser i to isfrie områder på den østre delen.

Geofysikk

OLAV LIESTØL, som i tiden 27/7–21/8 med assistentene ANDERS ELVERHØY og KNUT LIESTØL besøkte Finsterwalderbreen ved Van Keulenfjorden, Austre Brøggerbreen og Midre Lovénbreen ved Ny-Ålesund, utførte massebalansemålinger og kartlegging av breene. Dessuten målte han brefronten på Kongsbreen og Blomstrandbreen.

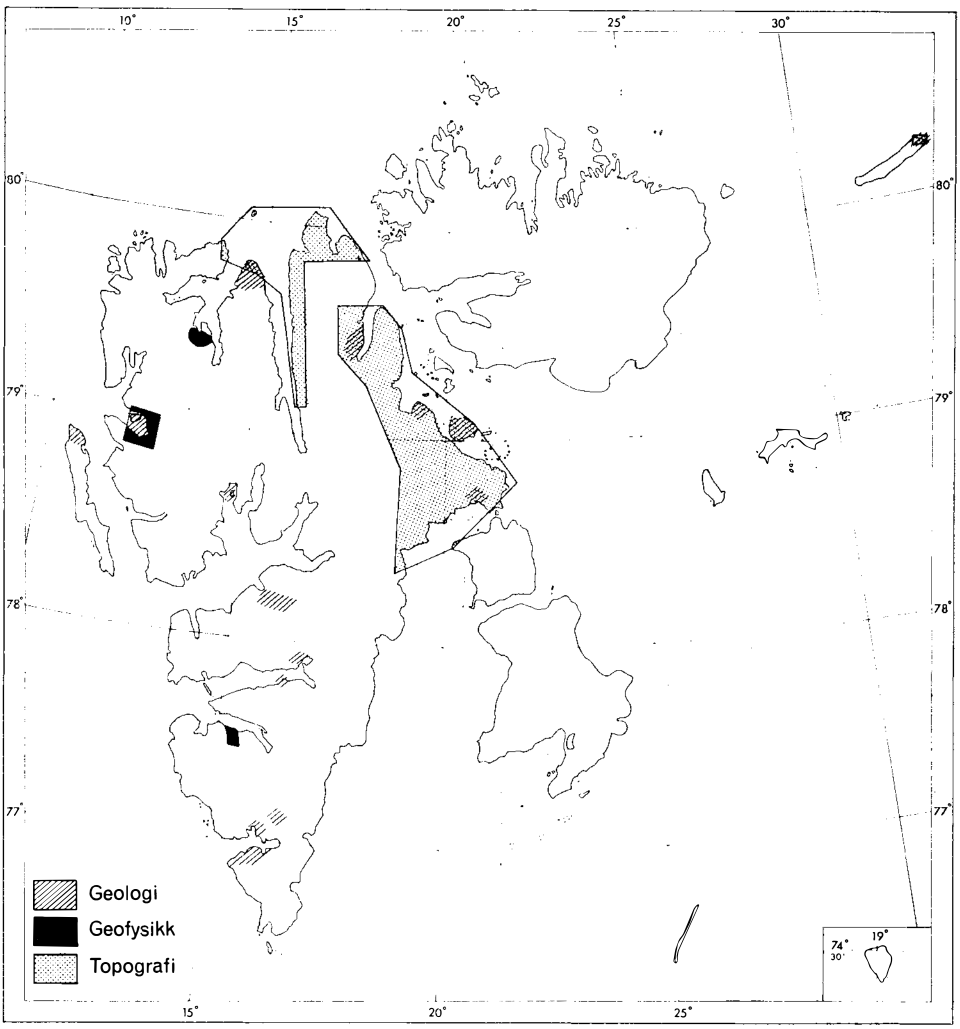

Fig. 2. *Kartet viser hvor Norsk Polarinstitutts topografiske, geofysiske og geologiske feltpartier arbeidet sommeren 1970.*

De helårlige målingene av Austre Brøggerbreen og Midre Lovénbreen ble utført av JENS ANGARD ved forskningsstasjonen i Ny-Ålesund.

VIDAR HISDAL og TORGNY VINJE arbeidet i Ny-Ålesund i tiden 19/6–24/7. HISDAL fortsatte sine målinger av totalstrålingens spektrale fordeling. Sammen med JENS ANGARD installerte de en datalogger og monterte og tilkoplet tre strålingsinstrumenter. På klare dager utførte VINJE kalibreringer ved hjelp av et Ångströms kompensasjonspyrheliometer.

Som ledd i utvidete sjøisundersøkelser under Barentshavprosjektet ble to strømmålere satt ut i slutten av sesongen, en vest for Hopen og en nordvest for Amsterdamøya. Målerne, som er plassert 50 m under havflaten, registrerer strømstyrke og -retning, samt vannets temperatur og saltholdighet en gang i timen.

Et feltparti fra Universitetet i Bergen, ledet av vit. ass. ERIK HALVORSEN assistert av cand. mag. EIVIND BRISEID og cand. mag. SVEIN SANDAL, samlet (juli–aug.) prøver av vulkanske bergarter og devonsk sandstein mellom Wijdefjorden og Woodfjorden og av doleritter fra vestsiden av Hinlopenstretet for paleomagnetisk analyse.

Biologi

JENS ANGARD, assistert av ARNLJOT GUDDING, utførte i mars–april reintellinger i de nordvestre deler av Spitsbergen, fra Smeerenburgfjorden til Wijdefjordens østkyst, dels med hundespann, dels med fly.

MAGNAR NORDERHAUG med assistentene KARL HAGELUND og JAN MICHAELSEN arbeidet på Svalbard fra 15/6 til 5/9. Første del av sommeren utførte de parallelle ærfuglundersøkelser på Kapp Linné og i Kongsfjorden. Siden takserte de fuglefjell i Kongsfjorden, Krossfjorden og på Prins Karls Forland. Fra 28/7 deltok MICHAELSEN i hovedekspedisjonens arbeid i de østre Svalbardfarvann, der han utførte biologisk kartlegging, bl. a. i Hinlopenstretet og på Kvitøya.

Under arbeidet i Kongsfjorden ble det ytt feltassistanse til dr. philos. HILDUR KROG fra Norsk institutt for luftforskning, som undersøkte lavvegetasjonen der.

Flyfotografering

Etter kontrakt med Widerøe's Flyveselskap A/S ble østlige områder av Svalbard flyfotografert med Wild RC8-kamera fra ca. 8 000 m høyde i målestokk ca. 1:50 000. Flyet opererte fra Ny-Ålesund i tiden 25/7–31/8 og ble ført av GØSTA JOHANSON, mens HELGE SKAPPEL navigerte og fotograferte. Værforholdene var ugunstige, og man lyktes ikke i å fullføre programmet; således måtte det høyest prioriterte området, Edgeøya, utstå.

Satellittfotografering

I samarbeid med Norges geografiske oppmåling, og derigjennom med Observatoire Royal de Belgique (Brussel) og Institut für theoretische Geodäsie (Bonn), ble det vinteren 1969–70 utført satellittfotografering med IGN-kamera betjent av dr. MANFRED BONATZ fra Institut für theoretische Geodäsie. Vind og lave temperaturer vanskeliggjorde arbeidet, og de første tilfredsstillende fotografier ble tatt

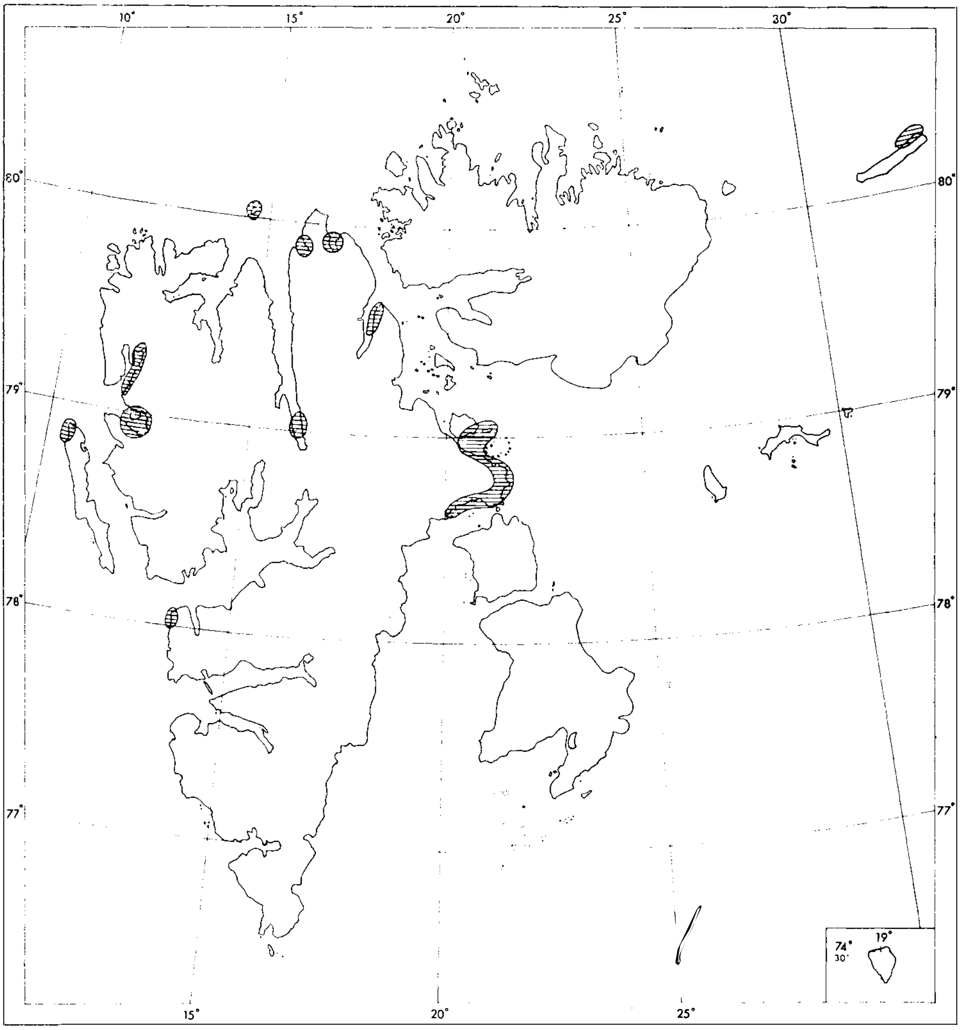

Fig. 3. *Kartet viser hvor Norsk Polarinstitutts biologiske feltpartier arbeidet sommeren 1970.*

i januar. Virksomheten ble avsluttet i april, da nettene ble for lyse for videre fotografering.

I et nytt samarbeid med Norges geografiske oppmåling, Deutsches Geodätisches Forschungsinstitut (München) og National Ocean Survey (Rockville, USA) ble ny satellittfotografering påbegynt høsten 1970 i Ny-Ålesund med et Wild BC4-kamera, betjent av dr. ing. GERHARD SOLTAU og ing. WALTER HOPPE fra Institut für Angewandte Geodäsie (Frankfurt). Fotograferingen startet 21. oktober og skal fortsette fram til midten av mars 1971. Med vellykket fotografering i Ny-Ålesund blir denne stasjonen bestemt både i det europeiske geodetiske nettet og i det amerikanske verdensomspennende satellittnettet.

Fyr og radiofyr

Utskifting av gassbeholdere og batterier i fyr og radiofyr fant sted i månedskiftet august–september. Av hensyn til virksomheten i Sveagruva ble alle tre lyktene i Van Mijenfjorden tent igjen etter å ha vært ute av drift siden 1960. I samme forbindelse ble en ny lykt montert på Blåhuken. Endel vedlikeholdsarbeid samt opppussing av lyktene i Bellsund og Billefjorden ble utført av KÅRE BRATLIEN og KNUT VABRÅTEN med assistanse fra mannskapet på M/S «Nordsyssel», som ble nyttet til transport under fyrettersynet.

JAN MAYEN

Fra Jan Mayen ble det 20/9 meldt om vulkansk utbrudd. Med en times varsel dro geologene BOYE FLOOD og THOR SIGGERUD til Bodø for å være med fly til Jan Mayen. Før de kom dit hadde i mellomtiden TORE GJELSVIK vært med på et observasjonstokt over øya i fly chartret av Norsk Rikskringkasting. SIGGERUD vendte tilbake straks fra Jan Mayen for å organisere en flyovervåking, mens FLOOD ble på øya, der han fra O/S «Heimdal» studerte utbruddet. Polarinstituttet etablerte samarbeid med Universitetet i Reykjavik, og 23/9 ble den islandske geolog, dr. GUDMUNDUR SIGVALDASON, fløyet til Jan Mayen med et islandsk fly chartret av Polarinstituttet. SIGGERUD dro til Island, hvorfra han med base i Akureyri gjennomførte flyovervåking av utbruddet til 8/10.

Undersøkelsene ble gjort mulig ved god og rask hjelp fra Industridepartementet og Finansdepartementet, som stillet til rådighet en ekstraordinær bevilgning på kr. 50 000. (Se T. SIGGERUD's artikkel: "The volcanic eruption on Jan Mayen", s. 7–18.)

ANTARKTIS

Den norske Antarktisekspedisjonen 1970/71, som kom til McMurdo 28/10, arbeidet i H. U. Sverdrupfjella, Dronning Maud Land, i tiden 30/11, 1970–3/2, 1971. Ekspedisjonen ble fløyet til området fra McMurdo-basen med amerikanske fly. Feltarbeidet omfattet geologi, glasiologi, meteorologi og biologi. Deltakere var: THORE S. WINSNES, leder, og AUDUN HJELLE, begge geologer; YNGVAR GJESSING, glasiolog; TORGNY VINJE, meteorolog; JENS ANGARD, biolog; EINAR NETELAND, radiooperatør. (Se THORE S. WINSNES' artikkel: "The Norwegian Antarctic Expedition 1970/71", s. 224–226.)

Arbeid ved avdelingene

I denne rapport er ikke regnet opp de arbeider som er knyttet til kart og avhandlinger som er kommet ut i 1970, da dette fremgår av oversikten over publikasjoner s. 285–286.

Hydrografi

Sjøkart 509 og 513 ble trykt i nye opplag etter mindre revisjoner. Forberedende arbeid på nye utgaver av sjøkart 505 og 507 ble igangsatt. Materialet fra havloddingene med HI-FIX i sesongene 1968, 1969 og 1970 ble bearbeidet.

Topografi–geodesi

En ny trianguleringsplan for *Svalbard* ble utarbeidet med henblikk på sidemålinger med tellurometer. Blad 2 Edgeøya og blad 4 Nordaustlandet i serien Svalbard 1:500 000 ble trykt i foreløpige utgaver. I serien Svalbard 1:100 000 ble kartblad B6 Eidsvollfjella og resten av kartblad B7 Tre Kroner konstruert. Av namnekart Svalbard 1:100 000 ble C5 Åsgårdsfonna og C8 Billefjorden utarbeidet i foreløpige utgaver, mens F4 Austfonna ble omarbeidet. Ellers ble rettinger utført på andre kartblad i denne serien. To kartblad og deler av fire andre kartblad ved Sveagruva ble konstruert i 1:2 000 etter oppdrag fra Store Norske Spitsbergen Kulkompani A/S. Det ble laget bladinndeling og nummerering for kart i store målestokker.

Beregningene for posisjonsbestemmelsene av Vestfjella i *Dronning Maud Land* ble på det nærmeste fullført. Triangulerings- og passpunktberegningene ble utført på EDB ved Norges geografiske oppmåling. Kart over Vestfjella ble konstruert i målestokk 1:200 000 etter skråbilder. Arbeidet med kartbladene KL34 og MN34 i 1:500 000 og L4 og M4 i 1:250 000 ble videreført.

Geologi

HARALD MAJOR bearbeidet observasjoner og prøver fra Gruve VII, deltok i utarbeidelsen av rapport til Ressursutvalget og fortsatte arbeidet med en beskrivelse av kartbladet Adventdalen.

THORE WINSNES bearbeidet sammen med AUDUN HJELLE geologisk materiale fra Vestfjella (Dronning Maud Land). Sammen med BOYE FLOOD og JENÖ NAGY utarbeidet han et kart med beskrivelse av geologien på Barentsøya, Edgeøya og Hopen, og planla instituttets ekspedisjon til Dronning Maud Land 1970/71.

AUDUN HJELLE og BOYE FLOOD bearbeidet materiale fra Bellsund–Hornsundområdet og forberedte ekskursjoner i forbindelse med SCAR/IUGS-symposiet. Til symposiet utarbeidet HJELLE et foredrag.

BOYE FLOOD tilrettela sammen med JENÖ NAGY teksten til det geologiske kartbladet over søndre del av Spitsbergen.

JENÖ NAGY deltok i planleggingen av geologiske og geofysiske undersøkelser i Barentshavet og besvarte en rekke henvendelser angående oljespørsmål på Svalbard og i Barentshavet. Han forberedte også en geologisk-geomorfologisk rapport om kontinentalsokkelen under Barentshavet. Sammen med PETTER KLOUMANN gjorde han forberedelser til framtidig prøvetaking her. Til beskrivelsen av det geologiske kartblad «Adventdalen» utarbeidet han deler av teksten.

Geofysikk

OLAV LIESTØL bearbeidet glasiologisk feltmateriale fra Svalbard og Norge.

VIDAR HISDAL bygde ferdig kalibreringsutstyret for instrumentene til måling av sol- og himmelstrålingens spektrale sammensetning, og utførte ved hjelp av en 1000 W Eppley standardlampe en rekke kalibreringer. Dessuten fastla han spektralfordelingene for to referanselamper av samme type. Han fortsatte bearbeidelsen av strålingsmålingene fra Ny-Ålesund, som snart er ferdige for sluttbehandling på EDB. En undersøkelse av høydevinden over Maudheim, utført sammen med G. DE Q. ROBIN, ble innlevert til trykking.

TORGNY VINJE utarbeidet havisoversikter, vesentlig på grunnlag av satellittbilder. Fra seilingssesongens begynnelse og ut mai ble ukentlige iskart sendt til interesserte rederier. (Denne tjenesten ble fra juni av overtatt av Meteorologisk institutt iflg. en samarbeidsavtale.) VINJE satte i tilknytning til Barentshavprosjektet opp et program for undersøkelser av isdrift og strøm i Svalbardfarvann i 1971. Han beregnet vind- og temperaturprofilmålinger fra januar 1959 på Norway Station.

Biologi

MAGNAR NORDERHAUG besvarte henvendelser vedrørende arktisk dyreliv og ga en rekke uttalelser til myndighetene angående jaktbestemmelser og viltstell på Svalbard. Han samlet inn og bearbeidet biologiske observasjoner fra Svalbard og ferdigbehandlet materialet til det tredje og siste arbeid om svalbardgjessenes status. For «Arbeidsgruppen for viltstell og naturvern på Svalbard» utarbeidet han utkast til nye jaktbestemmelser og planer for reservater og nasjonalparker på Svalbard. Videre ble det arbeidet med forslag om å gjøre den nye naturvernloven gjeldende for Svalbard.

Biblioteket

I årets løp ble 290 titler registrert: bl. a. 84 bøker, 64 særtrykk, 47 analytter og 90 nr. av gammel bestand. Et fotoalbum og 44 bøker ble innkjøpt. Særtrykksamlingen økte med 100 nr. til 5520, tre bytteforbindelser ble nedlagt, to nye ble opprettet og to tilvekstlister ble utsendt. Mange bøker ble mottatt som gave.

SØREN RICHTER sluttet 1. mars, og VIBEKE EEG-HENRIKSEN har som før utført det daglige rutinearbeid sammen med assistent. I november ble konsulent ROLF TANDBERG engasjert for å foreta opprydding og registrering av fotosamlingen som lenge har vært i nokså dårlig forfatning.

Konsulent- og informasjonstjeneste

Direktør TORE GJELSVIK ble ved flere anledninger intervjuet i kringkasting og fjernsyn og var, etter henstilling fra Utenriksdepartementet, i februar med i et større program i fransk fjernsyn om kappløpet mellom Scott og Amundsen til Sydpolen.

THOR SIGGERUD ble flere ganger intervjuet i kringkasting og fjernsyn og av aviser i forbindelse med Svalbardekspedisjonen og vulkanutbruddet på Jan Mayen.

BJØRN ARNESEN stod for utformingen av en utstilling som viser arbeidet ved instituttets forskjellige avdelinger. Utstillingen, som til vanlig er oppsatt i instituttet, var under det geologiske symposiet i forbindelse med SCAR-møtet midlertidig overført til Universitetet på Blindern, der møtene ble holdt.

Administrasjonen og fagavdelingene tok seg av konsulent- og informasjonstjeneste innen sine fagområder.

ELI HOLMSEN stod for teknisk bearbeidelse av publikasjoner til trykking og fungerte som redaksjonssekretær for instituttets Årbok.

PETER HAGEVOLD utarbeidet sammen med andre medarbeidere instituttets årsrapport, formidlet opplysninger om faglitteratur på russisk, oversatte en del av denne og utarbeidet et par tematiske litteraturlister over sovjetisk vitenskapelig litteratur.

Forskningsstasjonen på Svalbard

Ved Forskningsstasjonen på Svalbard ble registreringsarbeidet fra 1969 fortsatt. Høsten 1970 tiltrådte cand. real. NILS GULLESTAD som vitenskapelig assistent for særlig å ta seg av den biologiske sektor: marinbiologiske prøver og eget forskningsprogram for røye. Fra høsten av har FRED KLOKKERVOLD fra Nordlysobservatoriet virket som tekniker på stasjonen etter JENS ANGARD. (Se notis av T. SIGGERUD: «Forskningsstasjonen på Svalbard», s. 301–302.)

Reiser, møte- og kursvirksomhet

Direktør TORE GJELSVIK besøkte i mai Sveriges Geologiska Undersökning i Stockholm. I begynnelsen av oktober deltok han i møtet for geologidirektørene i Norden, som ble arrangert i Trondheim, på Hjerkinn og Røros. I Bryssel var han 3/11 med på et møte om et europeisk Antarktisprosjekt, og i siste halvdel av november deltok han som medlem av den norske delegasjon til det 6. konsultative møte under Antarktistraktaten i Japan. I tillegg kommer reiser for NTNFKs prosjektkomité til Trondheim, Bergen og Horten.

MAGNAR NORDERHAUG deltok i det 2. arbeidsmøte i IUCNs isbjørngruppe i Sveits 2–4/2 og la der fram en rapport: "Harvest and management of the Polar Bear in Norway 1967–69". I Finland deltok han 13–14/11 i et nordisk kontaktmøte om økologisk forskning og ga der en oversikt kalt: «Norsk Polarinstitutts biologiske virksomhet og pågående undersøkelser i Svalbardområdet».

SIGURD G. HELLE og OLA STEINE deltok i den 6. kongressen i Nordiska Kommissionen för Geodesi i Helsinki 10–16/5.

KÅRE BRATLIEN og KNUT VABRÅTEN deltok i kurs for teknisk laboratoriepersonell (5–8/4 og 2–4/11), arrangert av NTNF.

EINAR NETELAND var i Bergen 31/3–1/4 for å sette seg inn i en ny metode for testing av «timere» på HI-FIX; 13–22/4 deltok han i et tokt med F/F «H. U. Sverdrup» for å lære å kjøre magnetometer. Han deltok i kurs for teknisk laboratoriepersonell arrangert av NTNF 25–27/5 på Leangkollen i Asker, og 29/6–4/7 var han atter i Bergen for å få instruksjon i utsetting og kalibrering av strømmålere og kjøring av penetrasjonslodd.

VIDAR HISDAL besøkte 11–14/5 "International IEA Exhibition", "Electro-Optic and Laser Application Exhibition" og Hilger & Watts i London for å få en oversikt over nyvinninger innen automasjon og elektro-optikk av betydning for geofysikken.

TORGNY VINJE besøkte i mai Meteorological Office (Bracknell, London) for å studere ismeldingstjenesten. Senere samme måned var han i Bodø på et møte hvor isrekognosering fra militære fly ble diskutert. I juni var han to dager ved Universitetet i Bergen for å diskutere et opplegg til strømmåling ved Svalbard. I tiden 17—22/8 deltok han i møtene som SCAR Working Group on Meteorology holdt i Oslo.

AUDUN HJELLE deltok i en nordisk vulkanologisk ekskursjon til Island 14/7—29/7. På en reise i Sovjetunionen besøkte han 4—25/4 vitenskapelige institusjoner i Leningrad, først og fremst Vitenskapelig forskningsinstitutt for Arktis' geologi.

PETER HAGEVOLD var likeledes i Sovjetunionen 4—18/4 og besøkte bibliotek og vitenskapelige institusjoner som Norsk Polarinstitutt har litteraturutveksling med i Leningrad og Moskva.

BOYE FLOOD, AUDUN HJELLE, JENÖ NAGY, THOR SIGGERUD og THORE WINSNES deltok i Det IX nordiske geologiske vintermøte i Lyngby, Danmark, 4/1—8/1, der de la fram en rapport: «Stratigrafisk undersøkelse av de triassiske lagrekker på Edgeøya, Barentsøya (og Hopen), Svalbard».

OLAV LIESTØL deltok i mai i et symposium i København som behandlet radiologisk måling av istykkelsen.

JOHAN HENRIK CHRISTIANSEN kom tilbake til instituttet 28/9 etter endt studieopphold i USA. I tiden 10—12/11 var han med M/S «Helland-Hansen» for å få instruksjon i opptaking av strømmålere.

Norsk Polarinstitutt stod for SCAR/IUGS-symposiet og det XI SCAR-møtet som ble holdt i Oslo i tiden 6—21/8. (Se notis av T. S. WINSNES: "SCAR meetings in Oslo, 6—21 August 1970", s. 294.)

Forelesnings- og foredragsvirksomhet

Direktør TORE GJELSVIK holdt i mars foredraget: "Geology of the Svalbard area and Exploration for Petroleum since 1960" i Petroleum Exploration Society i London, og i mai i Oslo geofysikeres forening: «Norsk polarforskning på Svalbard». I november holdt han foredraget: «Barentshavprosjektet» i Polyteknisk Forening, Oslo, og i desember for Industriseminaret, Oslo Universitet, om: «Norsk Polarinstitutts virksomhet på sokkelen» (se s. 213—223).

Sammen med TORE GJELSVIK og THOR SIGGERUD holdt BOYE FLOOD i november i Det Norske Geografiske Selskab, Oslo, foredraget: «Vulkanutbruddet på Jan Mayen».

MAGNAR NORDERHAUG holdt i januar en forelesning ved Arkitekthøgskolen i Oslo om naturplanlegging.

OLAV LIESTØL holdt i vårsemesteret en forelesningsserie i glasiologi for hovedfagsstudenter ved Universitetet i Oslo, og veiledet i løpet av året fire hovedfagsstudenter i samme emne.

I vårsemesteret holdt geologer fra Norsk Polarinstitutt forelesninger ved Universitetet i Oslo om Svalbards geologi: BOYE FLOOD om Hecla Hoek-bergartene, HARALD MAJOR om tertiærlagene, JENÖ NAGY om den mesozoiske lagrekken og THORE WINSNES om karbon-trias-lagene.

Ved Geografisk institutt holdt NAGY i mars et foredrag: «Om Svalbards landskap og geologi».

THORE S. WINSNES holdt i april seks forelesninger om Svalbards geologi ved Geologiska Institutionen, Stockholms Universitet.

I februar deltok THOR SIGGERUD i møte i Kommisjonen for Det internasjonale geologiske verdenskart i Paris, der han presenterte kartsituasjonen på Svalbard. I november deltok han i England i et vulkanologisk symposium ved Royal Society, der han holdt foredraget: «The Recent Jan Mayen Eruption», som han i noe utvidet form etterpå holdt ved University of London. På slutten av året holdt han flere foredrag om utbruddet på Jan Mayen, bl. a. i Gæa Norvegica, Ingeniørforeningen, Polarklubben og på Rotary-møter.

Publikasjoner

Skrifter:

Nr. 147 – ANNA SIEDLECKA: Investigations of Permian cherts and associated rocks in southern Spitsbergen.

Nr. 149 – ODD LØNØ: The polar bear (*Ursus maritimus* PHIPPS) in the Svalbard area.

Nr. 150 – ALASDAIR H. NEILSON: Vascular plants of Edgeøya, Svalbard.

Nr. 151 – OLAV ORHEIM: Glaciological investigations of Store Supphellebre, West-Norway.

Nr. 152 – JENÖ NAGY: Ammonite faunas and stratigraphy of Lower Cretaceous (Albian) rocks in southern Spitsbergen.

Nr. 153 – KLAUS VONDERBANK: Geologie und Fauna der Tertiären Ablagerungen Zentral-Spitsbergens.

Meddelelser:

Nr. 99 – MAGNAR NORDERHAUG: Svalbard-reinen i 1960-årene.

Årbok 1968:

NORDERHAUG, M.: The present status of the Brent goose (*Branta bernicla hrota*) in Svalbard. 7–23.

— The present status of the Barnacle goose (*Branta leucopsis*) in Svalbard. 24–35.

SIEDLECKI, S.: A Helicoprion from the Permian of Spitsbergen. 36–54.

WINSNES, Th. S.: The Norwegian Antarctic Expedition 1968–69. 55–57.

KLEMSDAL, T.: A glacial-meteorological study of Gråsubreen, Jotunheimen. 58–74.

VINJE, T. E.: Some observations of the ice drift in the East Greenland Current. 75–78.

HELLE, S. G.: Namnebrigde på Svalbard. 79–80.

LIESTØL, O.: Glasiologiske undersøkelser i 1968. 81–91.

HISDAL, V.: The weather in Svalbard in 1968. 92–94.

VINJE, T. E.: Sea ice observations in 1968. 95–100.

NORDERHAUG, M.: Iakttagelser over dyrelivet på Svalbard 1968. 101–106.

GJELSVIK, T.: Norsk Polarinstitutts virksomhet i 1968. 107–121.

— The activities of Norsk Polarinstitutt in 1968. Extract of the annual report. 122–127.

— Other field activity in Svalbard 1968. 128–129.

Notiser:

HÅGVAR, S.: Collemboler som næring for vadere på Svalbard. 130–131.

GULLESTAD, N.: Observasjoner av pukkellaks (*Onchorhynchus gorbuscha*) på Svalbard i tiden 1960–65. 131–134.

– Merking av røye (*Salvelinus alpinus* (L.)) på Svalbard 1963–65. 134–136.

TAMRAZYAN, G. P.: The earthquakes of the Arctic and the tide-generating forces. 136–138.

Årbok 1969:

JOHNSON, G. L., J. S. FREITAG, J. A. PEW: Structure of the Norwegian Basin. 7–16.

BIRKENMAJER, K., and I. U. OLSSON: Radiocarbon dating of raised marine terraces at Hornsund, Spitsbergen, and the problem of land uplift. 17–43.

BIRKENMAJER, K., and B. W. BROWN: Zn-enriched whale bones on raised marine terraces at Hornsund, Spitsbergen. 44–54.

NORDERHAUG, M.: The present status of the Pinkfooted Goose (*Anser fabalis brachyrhynchus*) in Svalbard. 55–69.

— Investigations of the Svalbard reindeer (*Rangifer tarandus platyrhynchus*) in Barentsøya and Edgeøya, summer 1969. 70–79.

RØNNING, O. I.: Synopsis of the flora of Svalbard. 80–93.

LARSEN, T.: Polar bear investigations in Svalbard 1968 to 1969. A progress report. III. 94–100.

HÅGVAR, S.: Some observations on Coleoptera, Hymenoptera and Siphonaptera in Svalbard 1968. 101–106.

VOISIN, J.-F.: Some notes about birds and mammals in Svalbard, summer 1969. 107–115.

LIESTØL, O.: Glaciological work in 1969. 116–128.

HISDAL, V.: The weather in Svalbard in 1969. 129–131.

VINJE, T. E.: Sea ice observations in 1969. 132–138.

NORDERHAUG, M.: Iakttagelser over dyrelivet på Svalbard 1969. 139–144.

GJELSVIK, T.: Norsk Polarinstitutts virksomhet i 1969. 145–159.

— The activities of Norsk Polarinstitutt in 1969. Extract of the annual report. 161–165.

— Field work of scientific and economic interest carried out by expeditions to Svalbard in 1969. 166–167.

Notiser:

SVENSSON, H.: Pingos i yttre delen av Adventdalen. 168–174.

SIGGERUD, T.: Forskningsstasjonen på Svalbard. 175–176.

Landkart:

Svalbard 1:500 000

Blad 2 – Edgeøya, førebels utgåve

» 4 – Nordaustlandet —»—

Instituttets medarbeidere har utenom instituttets serier publisert:

GJELSVIK, TORE: Volcano on Jan Mayen alive again. *Nature.* **228**, (5269), 352.

LIESTØL, OLAV: Breer og klima på Spitsbergen (bidrag til en artikkelserie av H. W:SON AHLMANN: Klimatologiska förändringar omkring Nordatlanten under gammal och ny tid). *Ymer, Årsbok* 1970, 234–236.

— Bidrag til Glasiologiske undersøkelser i Norge 1969. Rapport nr. 5/70. *Vassdragsdirektoratet, Hydrologisk avd.* Oslo.

NORDERHAUG, MAGNAR: Harvest and management of the Polar Bear in Norway, 1967–1969. 2nd Working Meeting of Polar Bear Specialists. *Proceedings. IUCN Suppl. Papers* No. 29, 34–42. Morges.

— The role of the Little Auk, *Plautus alle* (L.) in Arctic Ecosystems. Editor: HOLDGATE, M. V. *Antarctic Ecology.* **1**, 558–560. London.

— Conservation and Wildlife Problems in Svalbard. Conference on Productivity and Conservation in Northern Circumpolar Lands. *Proceedings. IUCN Paper* No. 21, 192–199. Morges.

— Ornitologisk feltarbeid på Svalbard 1969. *Sterna.* **9**, (2), 107–109.

VINJE, TORGNY: Artikkel om drivisens ekstraordinære variasjoner, distribuert til landets aviser.

The activities of Norsk Polarinstitutt in 1970

Extract of the annual report

BY

TORE GJELSVIK

The permanent staff of the institute in 1970 numbered 32 persons, the same as the previous year. Nine persons worked on short-term contracts.

Field work

NORWAY

Glaciology

Accumulation of the glaciers Hardangerjøkulen and Storbreen in South-Norway was measured in the spring, and their ablation was measured several times during the summer.

T. LAUMANN studied the structure and metamorphosis of the snow of Hardangerjøkulen. Fluctuations of seven glacier tongues in South-Norway and two in North-Norway were measured. All glaciological work has been carried out either by or under the supervision of O. LIESTØL.

SVALBARD

The summer expedition of Norsk Polarinstitutt, led by T. SIGGERUD, comprised 42 persons plus the crews of the ships, two helicopters, and one aeroplane. The main expedition, based on M/S «Polar Star», used two Bell 47J helicopters for transport of parties in the field. A Cessna-337 aeroplane was contracted from Widerøe's Flyveselskap A/S to carry out aerial photography. Hydrological work off the coast was carried out with O/S «Senja».

Ice conditions were favourable but the weather was mostly bad in the eastern waters of the Svalbard archipelago where most parties worked.

Hydrography

H. HORNBÆK made detailed soundings in Kongsfjorden with the surveying boat «Svalis»; he also investigated some shoals reported from Tempelfjorden. Hydrographical work with O/S «Senja» was led by K. Z. LUNDQUIST during the first part of the season, and he was replaced later by K.-O. PETTERSEN.

E. NETELAND acted as technical leader throughout the summer. Sounding of the western, remaining part of the sea area between Sørkapp–Bjørnøya–Hopen was completed. In all 6 800 naut. miles of sounding lines were covered, of which 3 000 naut. miles were also run with magnetometer and penetration echo sounder.

Topography-geodesy

In August O. STEINE, J. HUS, and CHR. NIELSEN measured control points in Ny Friesland, Olav V Land, Reinsdyrflya, and Hinlopenstretet with logistic support provided by the expedition vessel and two helicopters. In a new triangulation net 15 points were marked and 8 sides were trilaterated. An attempt to make an astrofix on Kræmerpynten, Kvitøya, failed owing to bad weather.

Geology

T. GJELSVIK worked on northern Prins Karls Forland and in inner Kongsfjorden in the latter part of June.

J. MAJOR inspected coal mines III, VI, and VII in Adventdalen and Sveagruva.

In August T. SIGGERUD made geological observations in two ice-free areas on the eastern coast of Kvitøya.

J. NAGY carried out stratigraphical and palaeontological investigations in Mesozoic formations in Hornsund and in Adventdalen.

K. BIRKENMAJER carried out geological mapping and investigations of Hecla Hoek and younger rocks south of Hornsund.

D. WORSLEY carried out sedimentological investigations in the Devonian of northern Andrée Land and stratigraphical and sedimentological investigations of upper Palaeozoic and Mesozoic rocks on the west coast of Hinlopenstretet.

Geophysics

O. LIESTØL measured mass balance and mapped the glaciers Finsterwalderbreen, Austre Brøggerbreen, and Midre Lovénbreen, and measured the glacier front of Kongsvegen and Blomstrandbreen.

J. ANGARD carried out measurements of accumulation throughout the year on Austre Brøggerbreen and Midre Lovénbreen.

V. HISDAL and T. VINJE worked at the Research Station, Ny-Ålesund. HISDAL continued his measurements of the spectral composition of global radiation. Together with J. ANGARD they installed a data logger to which they connected three instruments for radiation measurements. On days with a clear sky VINJE carried out calibrations by means of an Ångström compensation pyrheliometer.

Every five minutes the data logger records time, global solar radiation, sky radiation, and long-wave atmospheric radiation. The signals are recorded on magnetic tape, but a strip printer is also available.

In August/September two Aanderaa buoys were anchored 50 m below sea level, one west of Hopen and one north-west of Amsterdamøya, to register hourly speed and direction of the current, temperature, and salinity.

A field party from Geophysical Institute, University of Bergen, headed by

E. HALVORSEN, collected samples of volcanic rocks and Devonian sandstones from Wijdefjorden and Woodfjorden and of dolerites from the west coast of Hinlopenstretet for palaeomagnetic analyses.

Biology

M. NORDERHAUG, assisted by K. HAGELUND and J. MICHAELSEN, carried out eider duck investigations at Kapp Linné and in Kongsfjorden, and evaluated rookeries in Kongsfjorden, Krossfjorden, and on Prins Karls Forland. Working in Kongsfjorden, the party rendered field assistance to Dr. H. KROG, who investigated the lichen vegetation of the area. At the end of July, MICHAELSEN joined the expedition vessel and performed biological mapping in Hinlopenstretet and on Kvitøya.

In March-April J. ANGARD carried out reindeer counts in the north-western parts of Spitsbergen, from Smeerenburgfjorden to Wijdefjorden; he travelled partly by dog team, partly by aircraft.

Aerial photography

Parts of eastern Svalbard were photographed on the scale of c. 1:50 000. A Cessna-337 aeroplane and a Wild RC8 camera were used.

Satellite photography

In a joint project by Norsk Polarinstitutt, Norges geografiske oppmåling (Geographical Survey of Norway), Observatoire Royal de Belgique, and Institut für theoretische Geodäsie (Bonn) satellite photography was carried out in Longyearbyen during the winter of 1969–70. Dr. M. BONATZ from Institut für theoretische Geodäsie carried out the work using an IGN camera.

In another joint project by Norsk Polarinstitutt, Norges geografiske oppmåling, Deutsches Geodätisches Forschungsinstitut (Munich), and National Ocean Survey (Rockville, USA), a new series of satellite photography was initiated in the autumn of 1970 at Ny-Ålesund with a Wild BC4 camera, operated by Dr. G. SOLTAU and engineer W. HOPPE from Institut für Angewandte Geodäsie (Frankfurt). The purpose is to determine the station in relation to the European geodetic network and the US world-wide satellite network.

JAN MAYEN

A major eruption was reported on September 20 from an almost inaccessible part of the Beerenberg volcano, Jan Mayen. On the morning of the next day T. Gjelsvik surveyed the eruption from the air, while in the afternoon B. FLOOD and T. SIGGERUD landed on the island by aircraft. SIGGERUD returned to make aerial observations, using an aircraft based at Akureyri, Iceland, while FLOOD, later joined by G. SIGVALDASON from Reykjavik, studied the eruption on the north-east coast of the island from O/S «Heimdal». In the course of a week, he made three landings in the eruption area and collected samples of the lava. M/S «Polarbjørn» then patrolled outside the eruption area for the first five days of October.

On October 8 SIGGERUD again landed on the island and, replacing FLOOD, continued observations from onboard ship, and succeeded in making a fourth landing in the area.

ANTARCTICA

The Norwegian Antarctic Expedition 1970–71 worked in the period November 30, 1970–February 3, 1971 in the H. U. Sverdrupfjella area, Dronning Maud Land; the members were flown into the area from McMurdo Station by US aircrafts. Field work comprised geology, glaciology, meteorology, and biology, and the participants of the expedition were: T. S. WINSNES, leader, and A. HJELLE, both geologists; Y. GJESSING, glaciologist; T. VINJE, meteorologist; J. ANGARD, biologist; E. NETELAND, radio operator.

Preparation of data

Hydrography

Chart Nos. 509 and 513 were printed in new issues. Preparatory work on new editions of chart Nos. 505 and 507 was initiated. Bathymetric data from 1968, 1969, and 1970 were processed.

Topography-geodesy

A new triangulation plan for *Svalbard* was worked out. Sheet 2 Edgeøya and sheet 4 Nordaustlandet in the series Svalbard 1:500 000 were printed in preliminary editions. In the series Svalbard 1:100 000, sheet B6 Eidsvollfjella and the rest of B7 Tre Kroner were compiled. Place-name work sheets (Namnekart), 1:100 000, were prepared for the maps C5 Åsgårdsfonna and C8 Billefjorden, while FA Austfonna was revised. Two map sheets and parts of four other sheets of the Sveagruva area were compiled on the scale of 1:2 000. Maps of Vestfjella, Dronning Maud Land, were constructed. Work continued on map sheets KL 34, MN 34 (1:500 000), L4 and M4 (1:250 000), Dronning Maud Land.

Geology

H. MAJOR prepared observations and samples from the coal area in Adventdalen and worked on the description of the geological map (1:100 000) of Adventdalen.

T. WINSNES, in cooperation with A. HJELLE, investigated geological material from Vestfjella, Dronning Maud Land. Jointly with B. FLOOD and J. NAGY, he wrote a report on the geology of Barentsøya, Edgeøya, and Hopen. He prepared the SCAR/IUGS symposium on the geology of Antarctica and planned the Institute expedition to Dronning Maud Land 1970–71.

A. HJELLE and B. FLOOD worked on material from the Bellsund–Hornsund area.

B. FLOOD, in cooperation with J. NAGY, prepared the text of the geological sheet "Spitsbergen, southern part".

J. NAGY participated in the planning of a geological and geophysical investigation of the Barents shelf, the Barents Shelf Project, which is a joint operation by Norsk

Polarinstitutt and the Continental Shelf Division of the Royal Norwegian Council for Scientific and Industrial Research. In cooperation with P. KLOUMANN he made plans for future sampling in this area.

Geophysics

O. LIESTØL prepared glaciological material from Svalbard and Norway.

V. HISDAL completed the construction of calibration equipment for the instruments used for measurement of the spectral composition of global solar and cosmic radiation. By means of a 1000 W Eppley standard lamp he carried out a series of calibrations and established the spectral composition of two lamps of the same type to be used as 'working standards'. A paper on the upper wind over Maudheim Station, Dronning Maud Land, written in cooperation with G. DE Q. ROBIN, was submitted for printing.

T. VINJE prepared weekly reviews of the distribution of sea ice, primarily on the basis of satellite photographs. Weekly charts were distributed to shipping companies' operating vessels in these waters from the beginning of the sailing season until June. This service was then taken over by the Meteorological Institute. As part of the Barents Shelf Project VINJE worked out a programme for investigation of ice drift and currents in Svalbard waters during 1970 and 1971. He also continued analyses of wind and temperature measurements from Norway Station.

Biology

M. NORDERHAUG prepared biological observations from Svalbard and finished a third paper on the status of geese in Svalbard. The working group for wildlife management and conservation in Svalbard, of which he is chairman, continued work on projects for new hunting regulations in Svalbard and for national parks and nature reserves in the archipelago.

Field work of scientific and economic interest carried out in Svalbard in 1970

BY

TORE GJELSVIK

Nationality	Institution or company (residence) Name of expedition	Number of participants Name of leader(s)	Area of investigation Period	Work
Norwegian	Norsk Polarinstitutt (Oslo)	45 THOR SIGGERUD	Mostly eastern Svalbard	Se p. 287–290,
Norwegian-German	Norsk Polarinstitutt in cooperation with Norges geografiske oppmåling (Oslo) and Institut für Angewandte Geodäsie (Frankfurt a. M).	2 GERHARD SOLTAU	Ny-Ålesund c. 6 months from Oct. 6	Satellite triangulation (photography)
Norwegian-Belgian-German	Norges geografiske oppmåling (Oslo) in cooperation with Observatorie Royal de Belgique (Brussels) and Institut für theoretische Geodäsie (Bonn)	3–1 M. BONATZ	Longyearbyen, Aug. 21, 1969–July 4, 1970	Earth-tide and gravimetry registration, laser nivellement, and satellite triangulation (photography)
Norwegian	Norges geologiske undersøkelse (Trondheim)	7 (Aircraft crew included) HENRIK HÅBREKKE	Svalbard-Barents Sea April 11–25	Magnetic measurements of the continental shelf
—»—	Norpetrol A/S (Norsk Hydro) (Oslo)	9 EIGILL NYSÆTHER	Hornsund area July 2–Sept. 4	Geological investigations
—»—	Norsk institutt for luftforskning (Oslo)	1 HILDUR KROG	Kongsfjorden	Study of lichens
Norwegian-Belgian	Norske Fina A/S (Oslo) Petrofina (Brussels)	c. 30 NICOLAS GOLENKO BERT PRONK	Eastern areas of Svalbard, Spitsbergen April 2–May 2 Aug.–Sept.	Aeromagnetic measurements, geological field work
British	Felsted School, Essex The Felsted Spitzbergen Expedition	5 GARY STUDD	Tempelfjorden July 24–Aug. 22	Zoological and ornithological studies

Finnish	(Turku)	2 Risto Lemmetyinen Pekka Savontaus	July 9–Aug. 1	Ornithological studies
French	Compagnie Française des Pétroles	6 André Brun	Edgeøya Sept. 1–14	Preliminary study for installing a logistic support for drilling operations
German-Norwegian	Institut für Paläontologie der Rhein. Friedrich-Wilhelms-Universität (Bonn)	7 Hans-Joachim Schweitzer	Van Mijenfjorden–Bellsund June 25–Aug. 22	Systematic, ecological, and sociological investigations of plants
Polish	University of Wroclaw The Polish Spitsbergen Expedition 1970	6 Stanislaw Baranowski	Hornsund area June 26–Sept. 12	Glaciology, geomorphology
Soviet	Scientific Research Institute of the Geology of the Arctic (Leningrad)	16 Valentin N. Sokolov Dmitrij V. Semevskij	Bjørnøya, Hornsund, Mimerdalen, Magdalenefjorden, Raudfjorden July–Sept.	Study of Precambrian, Ordovician, Devonian, and Mesozoic deposits
Swedish	Lunds Universitet (Lund)	2 Anders Hoff Krister Wadén	July 14–Aug. 10	Biological studies
—»—	Umeå Universitet (Umeå)	1 Folke Wikbergh	Longyearbyen July 6–26	Collection of fossils
Swiss-German	Geographisches Institut der Universität Zürich Geographisches Institut der Universität Würzburg Expedition Spitzbergen 1970	30 Gerhard Furrer Ulrich Glaser	Base: Hotellneset July 2–Aug. 8	Geomorphological, glaciological, and ecological studies

Notiser

SCAR meetings in Oslo 6–21 August 1970

A symposium on Antarctic geology and solid earth geophysics was held in Oslo 6–15 August under the auspices of IUGS (International Union of Geological Sciences) and SCAR (Scientific Committee on Antarctic Research). Sixteen countries were represented with a total of 105 participants. Twelve reviews and 115 other papers were presented during the sessions. The meetings took place at the University at Blindern. Several excursions were arranged in connection with the symposium, of which the excursion 1–4 August to the northern part of Gudbrandsdalen and Østerdalen was arranged and led by PER HOLMSEN of the Geological Survey of Norway.

The XI SCAR meeting was opened 17 August at the University at Blindern. The closing session was on 21 August in the same place. The rest of the meetings were held in Middelthuns gt. 29, where also the secretariat was situated. Apart from the meetings of the head delegates, five working groups had their meetings, viz. the working group on geology, solid earth geophysics, cartography and geodesy, meteorology, and logistics.

Norway was represented in the main committee by T. GJELSVIK, R. FJØRTOFT, F. SOLLIE, and T. S. WINSNES.

The following took part in the working groups: T. VINJE, geophysicist; S. G. HELLE, topographer; M. SELLEVOLL, geophysicist; and T. S. WINSNES, geologist.

Norway was represented by F. LIED in a special group for tele-communication problems.

Several receptions were arranged during the meetings: Aftenposten gave a reception in connection with a visit to "Polhøgda", the home of Nansen; the Fram-Committee gave a reception after a visit to the museums of the viking ships, "Fram" and "Kon Tiki"; and the Department of Industry held a reception in Parkveien with state secretary S. KONGSHAVN as host.

The meetings were arranged by the staff of Norsk Polarinstitutt under the chairmanship of T. S. WINSNES.

The University of Oslo and the Norwegian Water Resources and Electricity Board contributed to the success of the meetings by supplying facilities for the different sessions held.

Thore S. Winsnes

Polar bear fetuses found in Svalbard

Up to 1967 no polar bear fetuses have been found in Svalbard. The first fetuses found in two females will be described here. Both females were taken by spring-guns, and they had been lying dead for one or two days in the frost and snow before being skinned and before the reproductive tracts were removed. Most probably the specimens had been put into formaline in the spring after the skins had been thawed. After being stored for one and two years the specimens were examined and the weights and measurements taken. The ovaries from the females with the big fetuses were serially sectioned about 8 micra and stained with Hematoxylin and Eosin. From the other two ovaries only a few sections were made, owing to the bad condition of these specimens.

Materials. – The female with the small fetuses (Fig. 1) was found on December 3, 1969, on Halvmåneøya. A single gestation swelling occurs in each uterine cornu. They were located about two-thirds of the way along the cornua from the corpus uteri. The biggest swelling was 2.8 cm long and contained a fetus of 0.05 grams;

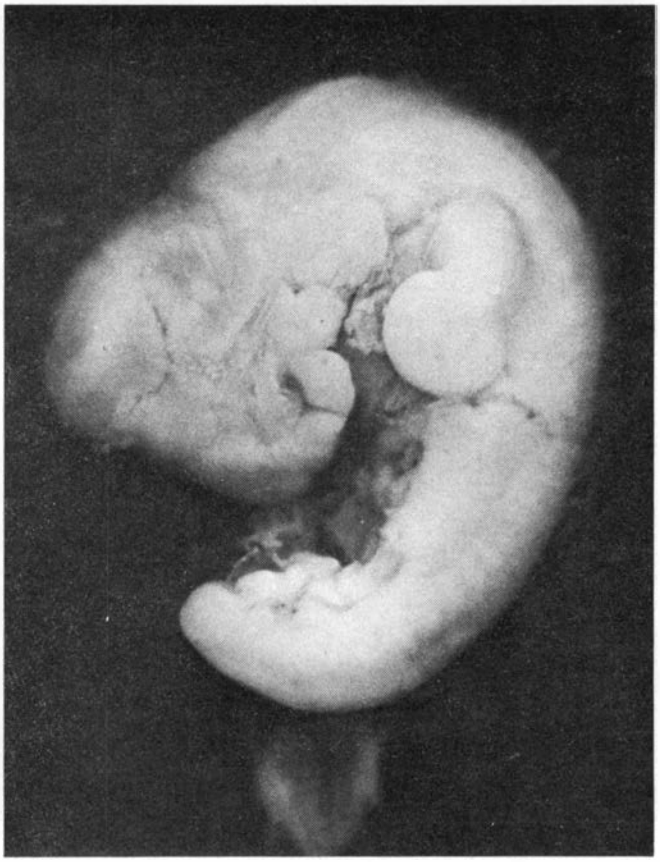

Fig. 1. *A fetus of 0.05 grams found in a polar bear taken on Halvmåneøya on December 3rd. The eyes have fallen out before the photographing.*

the total length is 18 mm and the crow-rump length is 5 mm. The forelimb bud is well shaped, but the hindlimb bud is not visible. The ovary weighed 5.1 gr and contained two corpora lutea. Unfortunately the other half of the reproductive tract was in worse shape. The swelling was smaller, and a smaller fetus was expected to be found in this. No fetus was found. The small fragile fetus or blastocyst was either dissolved, owing to the long stay in the body before the skinning of the animal, or it was lost during the dissection. The ovary weighed 3.0 gr and contained no corpora lutea.

The female with the big fetuses (Fig. 2) was found on December 21, 1967, on Ryke Yseøyane (70 km north-east of Halvmåneøya). One of the cornua had a male fetus of 120 gr, total length 191 mm and crow-rump length 115 mm. The other cornu had a female fetus 115 gr, whose total and crow-rump lengths were the same as the male. One of the ovaries weighed 3.7 grams and had two corpora lutea. The other ovary weighed 2.0 grams and had no corpora lutea.

Results and discussion. – The most interesting is the finding of the small fetus in the female found on December 3. It has long been assumed that the polar bear has delayed implantation as shown in the black bear and the brown bear where the blastocyst is implanted 8–10 weeks before parturition (DITTRICH and KRONBERGER 1963). This finding of the small fetus highly indicates that this is also the case in the polar bear. Compared with the development stages of the fetus and the time for implantation in cow, ewe and sow (HAFEZ 1968), this small polar bear fetus has just been implanted or would have been implanted in a few days. (The

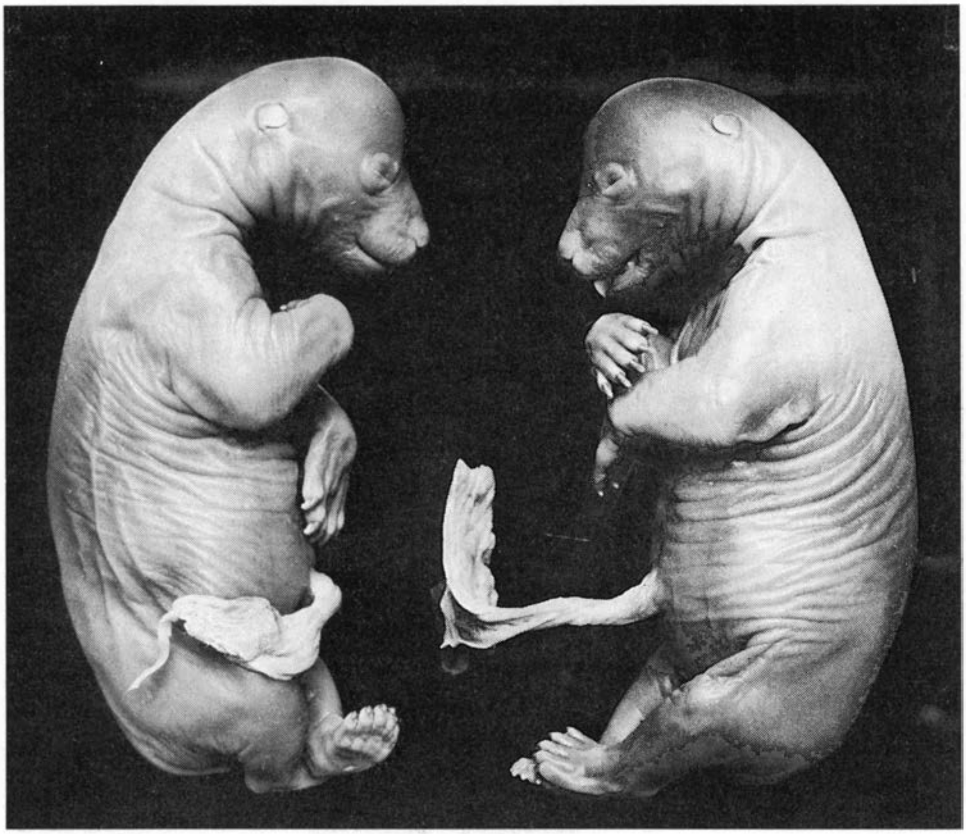

Fig. 2. *A male and a female fetus, 120 and 115 grams respectively, found in a polar bear taken on Ryke Yseøyane on December 21st.*

pig-fetus implants about 5 days after fore- and hindlimb buds are visible, and that is about 24 days after fertilization.) If we assume that implantation takes place 10 weeks before parturition, the birth would have taken place in the middle of February.

It is difficult to estimate the age of the two big fetuses found in the female on December 21. We know that the cubs at birth weigh about 600 to 700 grams (KOST'JAN 1954). If we assume that it takes 10 weeks from implantation to birth, I presume, according to the weight development of fetus in other animals, that the big fetuses are implanted about 7 weeks earlier. Roughly we can say that implantation has taken place in the beginning of November and birth would have taken place in the middle of January.

The find of these fetuses shows that the time for parturition in the polar bear in the Svalbard area takes place later than in Arctic Canada and in captivity. Fetuses as big as the biggest here described, and even bigger, are found as early as the first days of October in Canada (HARINGTON 1968). The reason why polar bear fetuses never before have been found in Svalbard must be that the implantation and the development of the gestation swellings take place at the time when the female enters the den. We can assume that the female with the big fetuses just had left her den for a short time. No den was found on Ryke Yseøyane, so if that is the case, the female must have travelled out on the pack ice for at least 20 km.

The examination of the corpora lutea shows that they are of the same size,

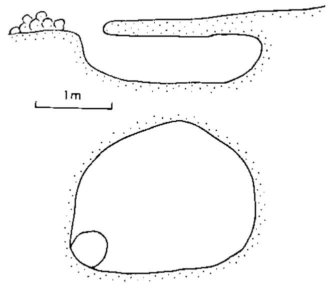

Fig. 3. *Cross and top view of the den. After* STAXRUD'S *drawing.*

6 to 10 mm, as I have earlier found in the ovaries in June–September (LØNØ 1970). A dramatic change in the histological character of the corpora lutea has occurred in these two pregnant females compared with the summer condition of the corpora lutea during the summer. Only the outer 1/3 to 1/4 of the corpora lutea has a condition similar to that of the corpora lutea in late summer. These cells possess mostly rounded or polygonal profiles and cytoplasm showing granules with rounded vesicular nuclei. In the remainder of the corpora lutea, that lies centrally in the ovaries, we find great changes. The radial strands of connective tissue are scarcely evident. A great change has occurred in the vascular frame work – the vascularization is very rich and uniformly distributed. Only a few of the lutein cells are in the summer condition. Most of the cells have dense and dark stained nuclei.

In both females only one of the ovaries had corpora lutea, so in both cases one of the blastocysts had been passed to the other uterine cornu.

An ususually late birth of a polar bear cub. – Recently I found in the files of Norsk Polarinstitutt a letter, dated February 4th 1930, from OLAV STAXRUD who was the foreman for 20 miners in Bjørnøya in 1917–18. In his letter he tells us about a small polar bear cub he caught in Bjørnøya.

He had chased a femal polar bear for many hours on the 15th of April 1918 until the bear finally disappeared in her den. Here she was shot, and a cub was taken out of the den (Fig. 3). The cub was about 20 cm long, and it could not stand on its feet. STAXRUD estimated the cub to be about 8 days old. The cub was taken to Norway one of the first days of May. None of the experienced sealers and trappers in Tromsø had ever seen such a small cub. The female was unusual meagre, and in the stomach it had some moss and grass.

The female polar bear had probably arrived at Bjørnøya in the last days of January or in the first part of February. The winter before, 13 bears had been shot on the island, so the miners did much travelling on the island during the winter in search of bears. They did not see any sign of bears before January the 28th. That day they got their first bear. On the 5th of February they shot 6. They did not get any more except for the female and the cub on the 15th of April. All the first 7 bears must have come svimming to the island in the last days of January or the first part of February. At that time the drift ice was observed north of the island at a distance of 20 to 30 nautic miles. Most probably, the female polar bear came to the island at the same time as the other bears.

We can assume that the eyes of the cub were open as STAXRUD says nothing about it. From cubs born in the Zoo, we know that the eyes open on the 30th day, and the cubs walk (crawl) about in the den at about 45 days of age (KOST'JAN 1954), so probably this cub was between 30 and 45 days old. It was an unusually small cub. AFONSKAJA and KRUMINA (1958) give the length of the newborn cubs in Moscow Zoo from 28 to 30 cm. The birth must have taken place in the first half of March.

This is the smallest polar bear cub and the latest time of birth ever known in the Svalbard area (LØNØ 1970). Most probably the explanation is that this female has had an unusually long delay of the implantation of the fetus.

Acknowledgements. – I am grateful to PER JOHNSON who took care of the specimen with the small fetuses and to THOR LARSEN who generously turned the other two fetuses, caught by KRISTIAN TORSVIK, over to me. A special word of thanks to UNNI SVERRE and BEATE NICOLAISEN for making the microscope sections.

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Ornithological observations from Torell Land, Spitsbergen, in 1970

Abstract. First record of crane (*Grus grus* L.) from Svalbard, and new observations on the growth of a colony of Ivory Gull (*Pagophila eburnea* (PHIPPS)) at Bendefjellet in Torell Land, Spitsbergen, are given.

Introduction. – In the course of August, 1970, the author carried out geological investigations in the central part of Torell Land, Spitsbergen (the Svalbard archipelago), on behalf of Norsk Polarinstitutt, while on his post-doctoral fellowship at Norges Teknisk-Naturvitenskapelige Forskningsråd (The Royal Norwegian Council for Scientific and Industrial Research, Oslo). On August 20th, he made a long snow-scooter trip (Fig. 1) from his camp below Grimfjellet, along Langleikbreen, Nathorstbreen, Polakkbreen, and Trekløverbreen, in the company of Tormod Johnsen, the chief mining-inspector in Svalbard, and the author's son Iwo as an assistant.

A. First record of crane (*Grus grus* L.) *from Svalbard.* – While crossing Nathorstbreen we found a young dead crane, *Grus grus* L. (Fig. 2A), lying on the surface of the glacier close to Blankfjella. The preservation of the bird was so good that it seemed certain that the crane had reached Spitsbergen the same summer, possibly during a strong warm south-easterly gale which blew a couple of weeks before. On arriving it died of exhaustion and lack of food.

In June and July, 1970, a crane was also seen on two different occasions on Edgeøya (NORDERHAUG 19xx). It seems possible that this was the same individual which later was found on Nathorstbreen.

The summer season of 1970 was in the southern part of Spitsbergen a quite exceptional one. The air temperatures at the turn of July/August reached on the glaciers up to +12°C, and on the coast of Hornsund up to +15°C. Warm easterly or south-easterly gales acquiring an exceptional speed as the air masses descended from high mountain ridges to the fjord, blow more frequently than usual. The abnormally high temperatures and the strong warm winds were probably responsible for this spectacular Polar trip undertaken by the crane. It seems probable

Fig. 1. *Location of the dead crane (*Grus grus *L.) in Torell Land, Spitsbergen (black triangle). Dashed – author's route with snow-scooter.*

Fig. 2A. *Dead crane (*Grus grus *L.) as found at Nathorstbreen, Torell Land, Spitsbergen, in 1970.* Photo: K. BIRKENMAJER.

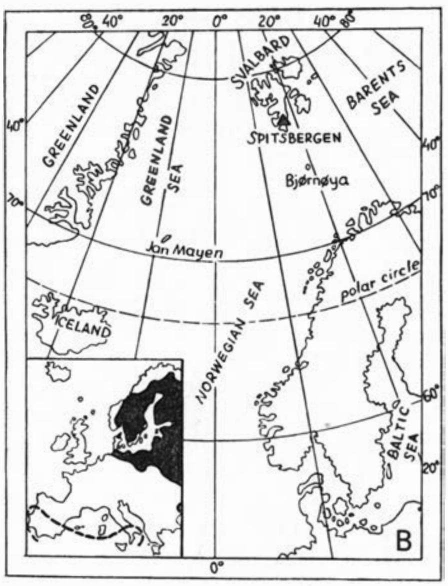

Fig. 2B. *Location of the dead crane (*Grus grus *L.) in Spitsbergen (black triangle). Distribution of the crane (*Grus grus *L.) in Europe (after* PETERSON *et al. 1967) shown in box.*

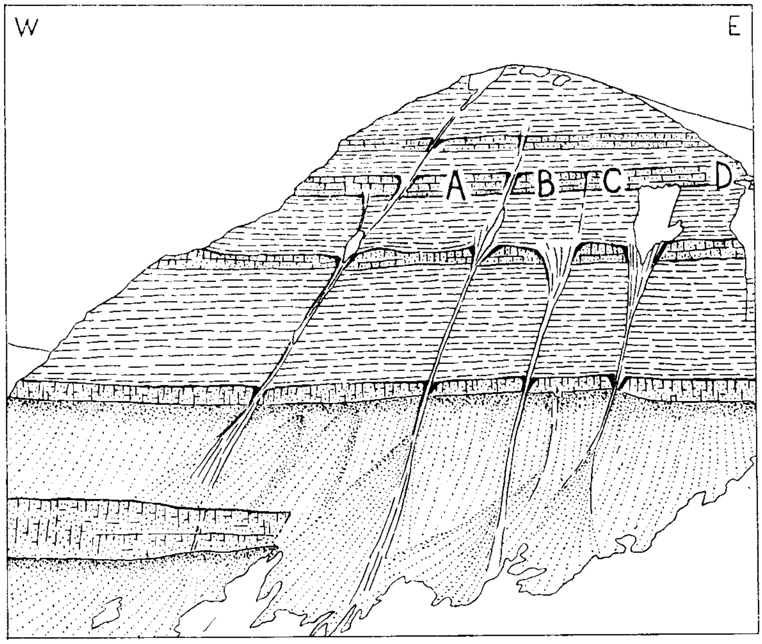

Fig. 3. *Breeding grounds of Ivory Gull (Pagophila eburnea* (PHIPPS) *at Bendefjellet, Torell Land (A–D) in 1970.*

that the bird achieved an absolute northern record for this species: nearly 77°30′N.

Our specimen could have reached Spitsbergen either from Finland, Norway, or the U.S.S.R. In any case, its lonely flight across the Barents Sea would amount to a minimum of 850 km (Fig. 2B).

B. Breeding place of Ivory Gull at Bendefjellet revisited. – On August 22, 1970, the author revisited a breeding place of Ivory Gull, *Pagophila eburnea* (PHIPPS), at Bendefjellet in Torell Land. The colony had been discovered in 1962 (BIRKENMAJER & SKRESLET 1963) and it consisted of 16 nests in three groups A, B, and C containing 6, 3, and 7 nests respectively. When revisited in 1970, the colony had grown to 49 nests. The breeding grounds A, B, and C were still in use, and contained 22, 6, and 16 nests respectively, and a new site D contained 5 nests (Fig. 3, Tab. 1).

Repeated observations on the breeding grounds of Ivory Gull in Svalbard are rather infrequent. Those made in the largest colonies at Storøya, Wahlenbergfjorden S, Palanderbukta, and Bodleybukta, all within the north-eastern part of the Svalbard archipelago – Nordaustlandet and its vicinity (see LØVENSKIOLD 1954, 1964; BATESON & PLOWRIGHT 1959), have shown a drastic decrease or even disappearance of the colonies (see BIRKENMAJER 1969, Tab. 2). This was particularly evident in the case of Bodleybukta, where the colony of 12 nests found in 1957 by T. S. WINSNES was reported to be empty in the following year.

The only colonies of Ivory Gull so far known from Svalbard, which have shown a tendency to increase, are those at Polakkfjellet (BIRKENMAJER 1968) and Bendefjellet, both situated far away from the coast, in the inner, highly glaciated part of Torell Land (Tab. 2). This is especially evident at Bendefjellet where in an 8-year period (1962–1970) the colony has increased by about 300 per cent, the mean rate of colony growth averaging about 4 new nests per year.

Table 1
Number of nests of Ivory Gull at Bendefjellet, Torell Land, (see Fig. 3)

Site	Number of nests		Number of new nests 1962–1970
	1962	1970	
A	6	22	16
B	3	6	3
C	7	16	9
D	0	5	5
Total number	16	49	33

Table 2
Rates of Ivory Gull colony increase in Torell Land, Spitsbergen

Colony	Number of nests (year of observation)		Rate of colony growth (per year)
Polakkfjellet	1 (1958)	6 (1966)	0.6
Bendefjellet	16 (1962)	49 (1970)	4.1

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Forskningsstasjonen på Svalbard

Ved Forskningsstasjonen på Svalbard har arbeidet fortsatt som i 1969 med følgende prosjekter:

1. Intensiteten av direkte og diffus solstråling er registrert i det tidsrommet solen er oppe, dvs. fra mars til oktober.
2. Spektrale intensitetsmålinger av sol- og himmelstråling, juni–juli.
3. Massebalansemålinger av breer, dvs. den årlige akkumulasjon og ablasjon.
4. Tidevannsregistreringer gjennom hele året.
5. Kontinuerlig mottaking av VLF-signaler hele året.
6. HF absorbsjonsmålinger ved riometre hele året.
7. Fotometrering av pulserende nordlys fra oktober til mars.
8. Natthimmelfotografering med «all-sky»-kamera fra oktober til mars.

9. Registrering av jordmagnetismen hele året.
10. Seismiske registreringer av 6 komponenter hele året.
11. Elektrontetthetsmålinger av F-lag fra november til mars.
12. Biologiske observasjoner hele året, men særlig i april/mai.

Det har ikke vært noen økning i interessen for stasjonen.

Høsten 1970 tiltrådte cand. real. NILS GULLESTAD som vitenskapelig assistent for særlig å ta seg av den biologiske sektor. Han arbeidet dessuten med sitt eget forskningsprogram om røye.

JENS ANGARD fungerte som tekniker til sommeren, og fra høsten fungerte FRED KLOKKERVOLD fra Nordlysobservatoriet mens ANGARD var i Antarktis.

Det har vært foretatt en del utbedringer av husene, særlig ved den seismiske stasjon.

Thor Siggerud

A. W. BRØGGERS BOKTRYKKERI A/S - OSLO