ÅRBOK
1977

NORSK POLARINSTITUTT
OSLO 1978

DET KONGELIGE DEPARTEMENT FOR INDUSTRI OG HÅNDVERK

NORSK POLARINSTITUTT

Rolfstangveien 12, Snarøya, 1330 Oslo Lufthavn, *Norway*

SALG AV BØKER

Bøkene selges gjennom bokhandlere, eller bestilles direkte fra:

SALE OF BOOKS

The books are sold through bookshops, or may be ordered directly from:

UNIVERSITETSFORLAGET

Postboks 307
Blindern, Oslo 3
Norway

Global Book Resources Limited
109 Great Russel Street
London WC1B 3ND
England

Columbia University Press
136 South Broadway
Irvington-on-Hudson
NY 10038
USA

Publikasjonsliste, som også omfatter land- og sjøkart, kan sendes på anmodning.

List of publications, including maps and charts, may be sent on request.

ÅRBOK
1977

NORSK POLARINSTITUTT
OSLO 1978

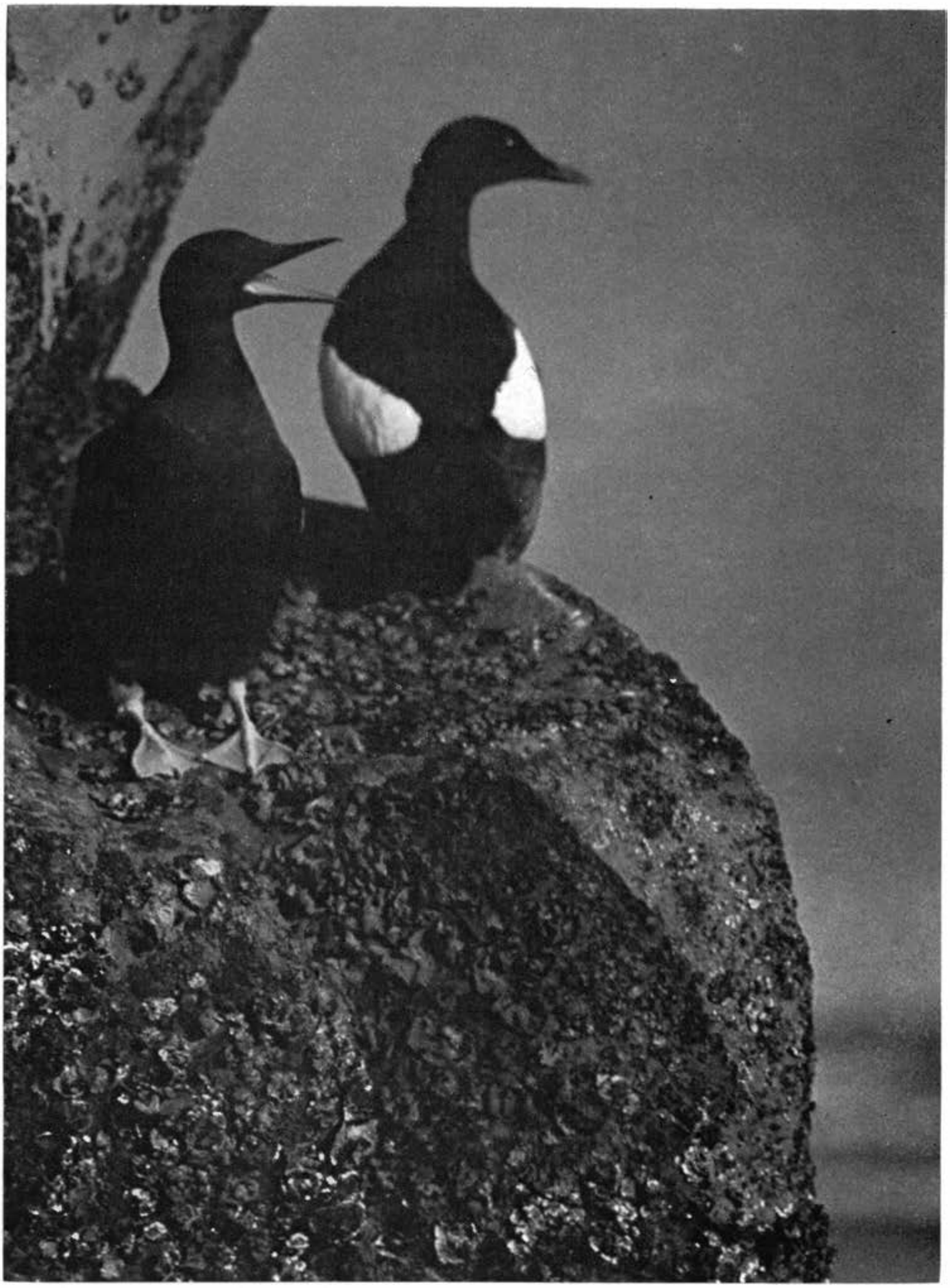
Utgitt ved direktør TORE GJELSVIK

Redaksjonssekretær: ANNEMOR BREKKE

Fagkomité:
VIDAR HISDAL, THOR LARSEN, ØRNULF LAURITZEN,
PETER HAGEVOLD

Trykt desember 1978

ISBN 82-90307-01-2



Teist *(Cepphus grylle)* på Kong Karls Land. I de siste årene er Norsk Polarinstitutts biologiske undersøkelser blitt konsentrert om de nordøstlige områder på Svalbard.

Black guillemots (Cepphus grylle) *on Kong Karls Land. The northeastern areas of Svalbard have been given priority in Norsk Polarinstitutt's biological research program in recent years.*

Photo: THOR LARSEN

Contents

The geology of northeastern Svalbard

By A. HJELLE, Y. OHTA, and T. S. WINSNES

Abstract

New information is prestented from the little known area of the north-eastern-most Svalbard: northeastern Nordaustlandet and adjacent islands.

The oldest rocks are layers and paleosomes of meta-supracrustal rocks, belonging to the Late Precambrian Lower Hecla Hoek succession older than the Botniahalvøya Group. These rocks occur in a wide area of Caledonian migmatites of nearly horizontal structure. Towards the east, syn- to late-tectonic gabbroic rocks are predominant. In Storøya, a stratiform basic complex of a few km estimated thickness suggests crustal conditions similar to that of a continent. The existence of basement rocks is not confirmed yet, however.

Late Caledonian post-tectonic two-mica granite intrudes the migmatites near Duvefjorden and in the Isispynten area.

The metamorphism is of the low pressure — high temperature facies series, and the occurrence of some hypersthene gneiss paleosomes in the migmatites indicates former granulite facies conditions.

Two tectonic phases have been distinguished: D-1 — in the N-S trend with some deviations to the NW-SE and NE-SW, representing the structural trends of regional metamorphism and migmatization; and D-2 — in the E-W trend, mainly caused by the emplacement of granites and gabbros. Both phases belong to the Caledonian orogeny of Svalbard.

Introduction

The area covered extends from 23°30' E to 33°30'E and from 79°45'N to 80°40'N, at the northeastern corner of Svalbard, and includes scattered exposures of rocks around the edge of the Austfonna plateau glacier, and some islands north and east. The east-west extension is about 210 km (Fig. 1). Due to its remote position in ice-packed sea, only few expeditions have worked in this area, and old data from the last century to the 1920's are still important sources of geological information (Nordenskiöld 1875; Nathorst 1910; Sandford 1926 etc.). Recent study of Nordaustlandet (Flood et al. 1969) includes only few and scattered observations from the area east

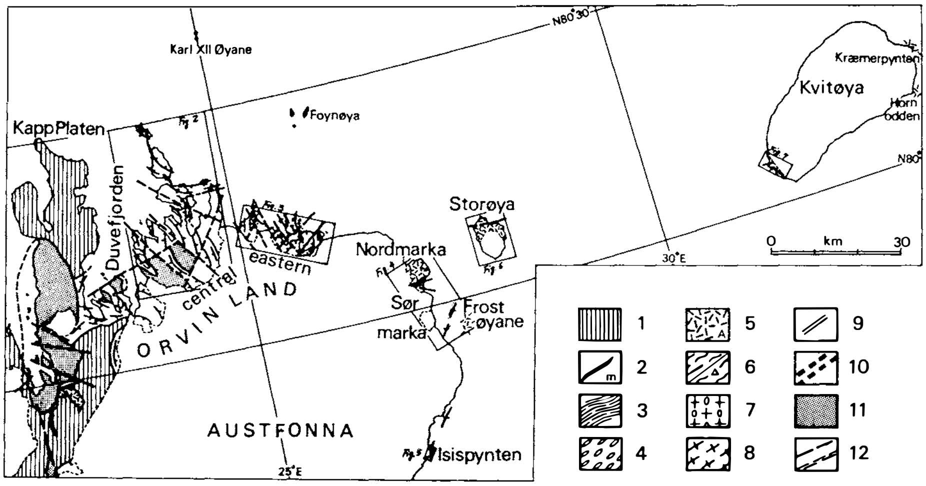


Fig. 1. *General geology of NE Svalbard, with location of the sub-areas. Legend (common in all figures): 1. meta-sediments (the Botniahalvøya Group), 2. marble, 3. crystalline schists and gneisses, 4. augen gneisses, 5. amphibolites and gabbro, 6. nebulitic-, streaky-, agmatitic migmatites, 7. porphyritic granites, 8. migmatitic granites, 9. aplites, 10. meta-porphyrites, 11. late- and post-tectonic granites, and 12. fault and sheared zone. Metamorphic and migmatitic rocks in the sub-areas are not distinguished in Fig. 1.*

of Duvefjorden. During our two weeks work in August 1976, we obtained observations and specimens from all the main parts of this area.

Since the time of Nordenskiöld it has been known that the northeastern part of Nordaustlandet are composed of extensive migmatites having almost horizontal structures, and Sandford (1926 and 1954) mentioned that the islands to the east include a large amount of gabbro. These general characteristics have been confirmed by the present work.

The central part of Orvin Land

This area is limited to the west by Duvefjorden—Duvebreen, to the east by Albertinibukta-Schweigaardbreen, and to the south by the Austfonna plateau glacier, the total area being about 350 km^2, including the islands to the north. The southern and central part of the area, Damflya, appears as an outwash plain with numerous small lakes and glacial rivers running northwards from Austfonna. The highest levels occur in the north-south trending peninsulas to the east and west, with a maximum level of 410 m in Polarklubben. The geological map is shown in Fig. 2.

The main types of rocks distinguished are:

1. Migmatites, mostly nebulitic and streaky. The main distribution is between Schweigaardbreen and Adlersparrefjorden-Portsundet.
2. Coarse-grained, faintly gneissose, porphyritic grey granite distributing mainly between Albertinibukta and Finn Malmgrenfjorden.

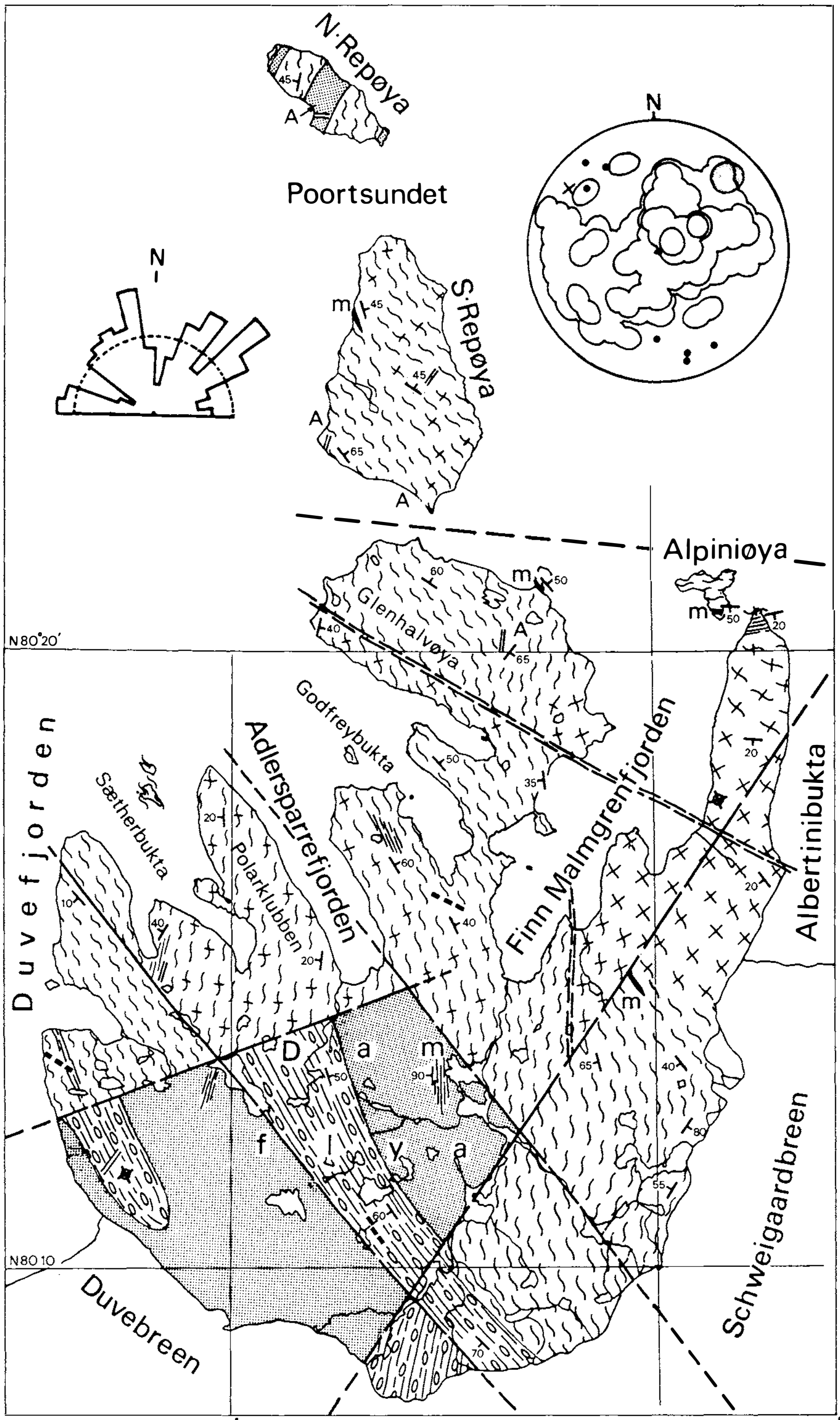


Fig. 2. *Geological map of central Orvin Land. The fabric diagrams. Left: strikes of the joints (105), demicircle indicates 5% of total counts, right: contours: foliations, gneissosities and beddings (contours for 143 observations, 1-3-5-7 per 1% area), shadow: calculated later fold axis, dots: local β's ,cross: maximum of the observed lineations. Scale 1:220 000.*

3. Coarse-grained K-feldspar augen gneiss, occurring mainly in the Damflya-Duvefjorden area.
4. Medium-grained reddish post-tectonic granite, in the southwestern part of the area, north and northeast of Duvebreen.

Migmatites, gneisses and syn-tectonic granites

The paleosomes in the migmatites probably represent the oldest rocks in the area. Layered siliceous paleosomes are far the most common, while amphibolite, marble, and quartzite are only occasionally seen. Basic inclusions occur in the soutwestern part of Nordre Repøya, where amphibolite is intruded by post-tectonic granite. Outside Repøyane, amphibolite is only recorded from Glenhalvøya. This northerly area of occurrences and a NE trend of the agmatite zone, compare well with the more extensive amphibolites further east (p. 13).

The migmatite metatects are of granitic to quartz dioritic composition, commonly somewhat porphyritic. The coarse grained porphyritic granite shows many similarities in composition and texture with the migmatite metatect, and gradual transitions are frequently seen, suggesting the highly mobilized parts of the migmatite to be closely related to this granite.

Homogeneous granitic gneisses occur; apparently they are of two different origins, being gneissic varieties of syn-tectonic granite, and homogenized streaky migmatites.

The coarse-grained K-feldspar augen gneiss occurs almost entirely within or adjacent to the post-tectonic granite. Mica schist is often associated with the gneiss; quartzite, marble or amphibolite is not recorded from this area so far. The size of the feldspar augen seems to increase towards the granite, with a recorded maximum diameter of c. 15 cm. The content of muscovite often equals that of biotite. It seems likely that the development of this muscovite-bearing augen gneiss is related to the emplacement of the post-tectonic two-mica granite.

Red two-mica granite, dyke rocks

The southwestern part of the area is dominated by reddish, medium-grained, massive two-mica granite. In mineralogy, texture, and relationship to the surrounding rocks it obviously relate to the Rijpfjorden granite, which occurs at the head of Duvefjorden and between Duvefjorden and Rijpfjorden (Flood et al. 1969). Incomplete observations near the front of Duvebreen suggest a near horizontal intrusion, capped by schistose augen gneiss in the northern part of Høgkollen. The thickness of the intrusion is estimated to be more than 100 m.

Minor bodies of a similar two-mica granite accompanied by pegmatitic muscovite tourmaline mineralization occur occasionally within the migmatites from near the front of Schweigaardbreen to Søndre Repøya. This is consistent with observations from other gneiss areas of Nordaustlandet and seems to be typical of areas along margins of the post-tectonic two-mica granite bodies.

The NE-striking granite including the amphibolite in Nordre Repøya, is medium-grained grey to reddish, somewhat K-feldspar porphyric and essentially unfoliated. Similar granite occurs as NNE-striking dykes at the extreme northwest and southeast of the same island. The dykes are cross-cutting the gneisses and clearly post-tectonic. An apparently similar granite composes the greater part of Foynøya, Brochøya and Schübelerøya about 35 km to the east.

Minor dykes of pink aplite and muscovite pegmatite occur in a number of places in the northern and western part of the area and cut all other rocks with steep dips. The mineral contents compare well with the Rijpfjorden granite, and the NNE and SSE strikes of the dykes with those of similar dykes from Rijpfjorden to Laponiahalvøya further west. The aplite and pegmatite dykes are thought to belong to the last intrusion phase of the Rijpfjorden granite.

Fragments of 1—5 m wide plagioclase porphyrite dykes with approximately southeast strike were found in the gneiss north of Duvebreen and near the head of Godfreybukta, and one dyke is estimated from air photographs in the central part of Damflya. Porphyrite dykes of the same strike is also recorded from Isispynten about 70 km to the southeast (Fig. 5).

Structure

The foliation, layering, and bedding in general have a «Caledonian trend» around NNW-SSE. Local mesoscopic fold axis and β's have pronounced maxima on the same direction with shallow plunge, 0-35^g (Fig. 2, fabric diagram). The somewhat asymmetrical pattern of the main β's suggest a refolding of older NNW-SSE structures by later ENE-WSW to NE-SW trending folds of about 25^g NE plunge. The later folding was probably related to late orogenic upwelling preceeding the granite intruison and block movements. The directions of the estimated faults seem to concentrate in two directions, one following the assumed trend of late folding, the other approximately normal to it.

Stratigraphy

The meta-supracrustal rocks in the area are too scattered and poorly preserved to permit a detailed stratigraphy. However, the distribution of quartzite-, marble- and amphibolite paleosomes in an eastern zone and mica schist in a western zone, suggests a general stratigraphy. The calculated late deformation axis with about 25° NE plunge, indicates that the upper part of the supracrustal sequence might be exposed in the NE, the lower in the SW:

Central Orvin Land:	Possible correlatives west of Duvefjorden:
Upper marble-quartzite-amphibolite bearing unit, NNW-wards from Schweigaardbreen to Repøyane.	Amphibolite and skarn rocks in migmatite northeast of Ahlmannfonna.
Lower mica schist (and augen gneiss) bearing unit, Damflya-Duvefjorden.	Mica schist and augen gneiss south of Ahlmannfonna.

All these supracrustal rocks may be older than the Botniahalvøya Group (Flood et al. 1969), and thus being correlatable to the (Lower Hecla Hoek) Stubendorffbreen Supergroup (Harland et al. 1966).

The eastern part of Orvin Land

This is a narrow coastal exposure between Schweigaardbreen to the west and Leighbreen to the east, about 20 km in the east-west direction and 10 km north-south, including many small islands. The whole area is composed of various migmatites, and block fault structures are estimated from the variation of gneissosities. The NNW-SSE striking faults are dominating, with subordinate NNE to ESE ones. Most of the faults are vertical, along which glacial erosion has often formed steep cliffs. The geological map is shown in Fig. 3.

Migmatites

The migmatites range from agmatite and nebulite to feldspar porphyroblastic varieties with gradual relationship. The granitic metatects are grey granite to quartz diorite in the nebulitic rocks, pink granite in the porphyroblastic ones and gneissose augen granite around the agmatitic blocks. The porphyroblastic migmatite occurs in the southwestern part. The rock shows gentle dome and basin structures in the south of the Kapp Bruun peninsula while having linear folds of north-south axial trend in the same peninsula and a NE-SW fold in the south of Behounekodden. Small gneissic paleosomes are often seen in the northern half of the Kapp Bruun peninsula and some large gneiss layers occur in the southeast of Behounekodden. The nebulitic and agmatitic migmatites occupy the main part of the area east of Kapp Bruun, in a zone of NW-SE trend, and with different structural trend in the different fault blocks.

The islands tend to have more agmatitic rocks than other blocks and a distinct NNE-SSW agmatitic zone occurs from Raschøya to the eastern shore of Bjørnvika.

The most common type of paleosomes are of pelitic and siliceous composition; they frequently occur as stretched layers. Pelitic paleosomes often contain garnet and cordierite. Gneissic structures are dominant in the migmatites around Kapp Bruun and Tschuknovskyodden, where amphibolite and marble layers are also preserved as agmatitic blocks and large paleo-

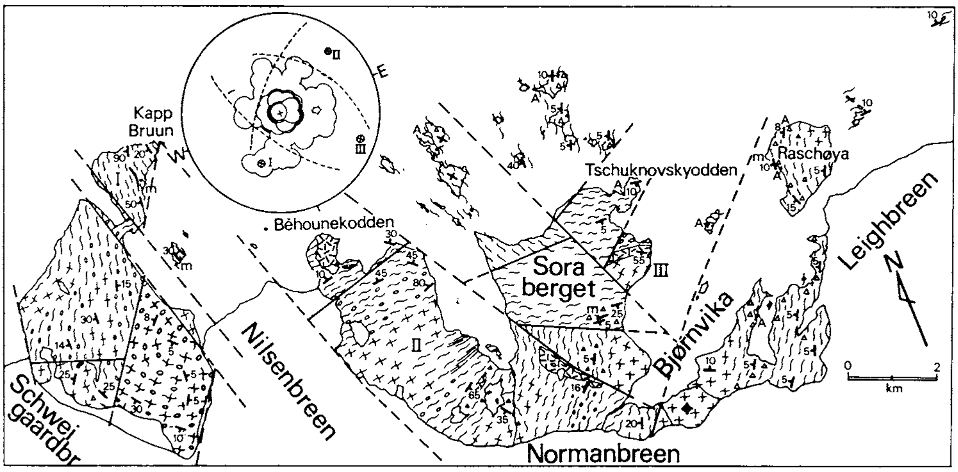


Fig. 3. *Geological map of eastern Orvin Land. The fabric diagram. Contours: foliations (95, 0-10-20-30-60%), excluding the I, II, and III blocks, dotted girdles and circles with cross: the girdles obtained from the I, II and III block and their calculated axes.*

somes. The amphibolites are gneissose or schistose, and some contain garnet and orthopyroxene. The metatect of amphibolite-agmatite is always leucocratic. No skarn has been found around the marble blocks.

Meta-gabbros

Gabbroic bodies, several hundreds of meters in length were found at three localities at Behounekodden and south of Soraberget. They are of clinopyroxene hornblende gabbro to diabasic type, cut by white granitic veins. Biotite rich zones occur along margins and fracture cleavages, with fresh basic rock preserved only in the cores. At the northwest of Bjørnvika a noritic gabbro occurs, containing large biotite crystals in random orientation. The rock shows orbicular weathering with fresh noritic cores surrounded by hornblende-biotite rich material.

The elongation trend of these massive gabbroic rocks have no relation to the general trend of surrounding migmatites. The lithology and mode of occurrence show that the gabbros are late- or postkinematic intrusions, which has been influenced by the latest migmatization activity.

Structure

As shown in the fabric diagram (Fig. 3), dome and basin structures and gentle undulating foliations prevail. Linear fold axes of gentle to moderate plunges with NNE-SSW trend are estimated in two of the blocks. A gentle folded structure of NNE-SSW trend is recognized in the eastern islands and the eastern side of Bjørnevika. The NNW-SSE trending fracture zones are generally later than the NE-SW trending ones.

Foynøya, Brochøya and Schübelerøya

These islands are located 20—25 km north of Orvin Land around 80° 27'N and 26°E (Fig. 1). All three islands are composed of medium-grained, homogeneous grey granite with well developed platy and cubic joint systems. Very faint dark bands represent flow structures, in Foynøya of north-south strike, in Brochøya and Schübelerøya NW-SE, with steep to moderate dips to the NE. Adjacent to the joints, the granite is often stained red. Pink aplite dykes cut the granite in north-south strike with almost vertical dips, and in east-west strike as nearly horizontal sheets. The largest dyke in the middle of Foynøya is 20 m in thickness.

Nordmarka, Sørmarka and Frostøyane

Small exposures occur discontinuously from Kapp Laura and southwards for about 15 km along the northeastern edge of Austfonna: Nordmarka and Sørmarka at the mainland and the Frostøyane islands (Fig. 4). A group of small unmapped islands were found southeast of Frostøyane.

Meta-gabbros

A massive partly layered mass of meta-gabbro occurs in the northern half of Nordmarka. The gneisses and granitic rocks in the south dip below the meta-gabbro, and a shallow synform of gneisses with marble occur at the eastern shore in the meta-gabbro area, thus the shape of this meta-gabbro mass can be a sub-concordant sheet, at least along its southern margin. A large block of gneisses with a marble bed, about 1 km long, is included in the middle, and another small gneiss body in the northwestern part of the meta-gabbro.

The meta-gabbro shows a wide range of lithologic variation: the main facies is primarily a two-pyroxene gabbro with a small amount of hornblende as rims around the pyroxenes, while a large amount of biotite was introduced during amphibolitization and primary plagioclase was strongly granulated and replaced by quartz, with development of mosaic and myrmekitic textures. An apparently porphyritic facies has large idioblastic microline, converting the rock locally into syenitic amphibolite. A gneissose facies contains clinopyroxene-biotite-hornblende. On the other hand some rocks have retained pyroxene-cumulative textures and the dioritic later differentiates include the fine-grained dark rocks as agmatitic blocks. The mode of metamorphism of this meta-gabbro is very similar to that of the gabbroic rocks of the eastern Orvin Land, and accordingly it is considered to be a late-tectonic intrusion.

The unnamed islands to the southeast of Frostøyane are entirely composed of a gabbro similar to that in Nordmarka. The NE-SW flow trend is similar to that in the gneisses of Frostøyane.

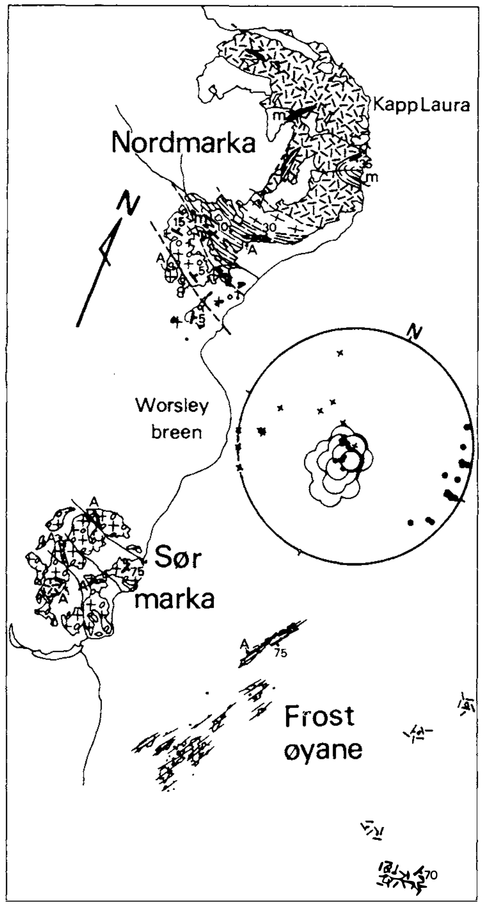


Fig. 4. *Geological map of NE edge of Nordaustlandet. The fabric diagram represents the mesoscopic structural elements from the gneisses and the porphyritic granite of Nordmarka. Contours: gneissosities of the gneisses (21, 0-10-20-30%), dots: foliations of the porphyritic granite, open circles: small fold axes of the gneisses, crosses: aplite dykes. Scale: 1:170 000.*

Porphyritic granite

This is a coarse-grained, faintly gneissose two-mica granite with many large idiomorphic potash feldspars. The granite occurs in the southern part of Nordmarka and in the whole area of Sørmarka; the two localities being separated by the 4 km wide Worsleybreen. The rock is homogeneous, it is cut by some basic dykes in Sørmarka, and includes small gneissose amphibolite blocks in Nordmarka. The structure is very gentle in Nordmarka, less than 15^g dip, while steep in Sørmarka. The strike chane sharply across a NW-SE striking fault in the southern part of Nordmarka. Porphyroblastesis of potash feldspar continues into the gneisses to the north as an augen gneiss zone of less than 50 m width. Thus the porphyroblastesis is later than the gneisses, but may be older than the gabbros if the basic dykes cutting this granite are of the same origin as the meta-gabbros. Two conventional Rb/Sr muscovite ages of pegmatite and aplite associated with this granite were reported: 378 ± 7 and 373 ± 10 m.y. (Hamilton and Sandford 1964).

Gneisses

A gneiss zone of WNW-ESE strike and shallow northerly dips occurs between the Nordmarka meta-gabbro and the porphyritic granite. The rocks are paragneisses, mostly biotite-garnet ones, some quartzitic gneisses, and thin marble beds with diopside-garnet-epidote skarn. Thin schistose amphibolite is also interbedded in the pelitic gneisses. Towards the south the gneisses become feldspar porphyroblastic and biotite is strongly replaced by muscovite. The contact between the gneisses and the augen gneiss facies of the porphyritic granite is sharp.

To the north of the gneisses a relatively homogenous quartz dioritic rock with shadows of gneisses occurs between the gneisses and the meta-gabbro. This rock may be a sub-concordant sheet cutting the gneisses, but the relation to the meta-gabbro is unknown.

A gneissose amphibolite and a meta-porphyrite layer occurs in the gneisses slightly oblique to the gneissosity. They are cut by the granitic metatect of the gneisses, but have preserved original igneous textures and are probably late-kinematic basic intrusions. The gneissose amphibolite resembles the Nordmarka meta-gabbro and the meta-porphyrite, being baked into hornfels, is certainly the same as those in Isispynten mentioned below.

The gneisses of Frostøyane are mainly biotite-muscovite gneisses, some contain garnet and cordierite. A schistose biotite amphbiolite has poikilitic plagioclase including garnet in the centre. Meta-dolerite dykes cut these rocks.

Structure

The gneisses show shallow north dips and the lineations swing from ESE to NE from the west to the east (Fig. 4, fabric diagram). This disturbance of the older regional structure may be related to the emplacement of the Nordmarka meta-gabbro and the porphyritic granite. The porphyritic granite to the north of the fault is conformable with the gneisses. The gneisses in Frostøyane constitute another zone trending ENE-WSW with steep ESE dips, separating the Sørmarka porphyritic granite from the meta-gabbro of the southeast islands. The trend of this zone is comformable with that of the Isispynten area to the south.

Only one fault is observed, in the southern part of Nordmarka, however airphotos reveal two distinct lineaments in Nordmarka, of NW-SE and N-S strike, which may represent faults with small displacements.

Isispynten and the islands to the north

The Isispynten area of about 2.5 × 1.5 km includes several small exposures along the eastern edge of the large Austfonna glacier. The nearest exposures to the north are about 9 km away; towards southwest the glacier front stretches for about 90 km without any known rock exposure.

Sandford (1954) presented a description of rocks from this area based on the material brought back by the Oxford expeditions of 1924, 1935—36, and 1949.

The main rock types distinguised are, in descending order (Fig. 4):

The present division:	SANDFORD's division (1954):
Pink aplite and quartz dioritic dykes	Pink granodiorite, diorite
Meta-porphyrite	Amphibolite
Homogeneous grey granite and augen gneiss	Grey granite
Coarse-grained pyroxene amphibolite	Amphibolite
Gneisses with marble and quartzite	Gneiss and schist

Gneisses

The gneisses are mainly of two-mica type with or without garnet, locally siliceous and with a relatively faint gneissosity. The grey granite penetrates into the gneisses to form banded and agmatitic structures. A 15 m thick banded marble occurs at the southern tip, including boudinaged skarn of diopside, garnet, hornblende, and epidote. Pyroxene-plagioclase symplectite with garnet rim occurs in this skarn. In the gneisses to the north muscovite replaces biotite and sillimanite overgrows cordierite; a gneissose amphibolite has been converted to syenetic amphibolite by introduction of microcline.

In the four small islands about 9 km NNE of Isispynten the main rock is a two-mica gneiss, with layers of schistose amphibolite and banded quarzite + marble with skarn. A fine-grained biotite gneiss has poikiloblastic rhombic pyroxenes and strongly myrmekitic mosaics of plagioclase and quartz.

Three conventional Sr/Rb ages were reported by Hamilton and Sandford (1964) on biotites from the gneisses of Isispynten: 358 ± 8, 417 ± 7 and 415 ± 10 m.y. All are in the range of the main Caledonian phase obtained by the K/Ar method so far and it is evident that the gneisses have been affected by the Caledonian event.

Amphibolite

Massive coarse-grained clinopyroxene-bearing amphibolite occurs to the east and north. The rock which contains biotite and includes gneissic xenoliths is frequently cut by white and pink aplitic dykes. In the northern exposure the amphibolite occurs as agmatitic xenoliths in the grey granite. The metamorphism of the amphibolite is similar to what has been observed in the amphibolite of Orvin Land.

Granite

The grey granite has intrusive contacts both to gneisses and to the amphibolite, and a zone of 10—20 m augen gneiss has develped along the border to the agmatized gneiss. The granite is a homogeneous biotite

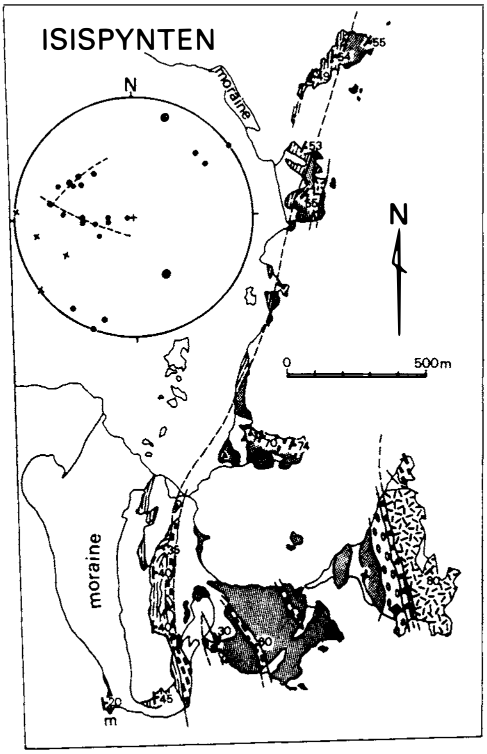


Fig. 5. Geological map of Isispynten. The fabric diagram. Dots: gneissosities of the gneisses, open circles with a dot in centre: foliations of the grey granite, girdles and open circles with cross: estimated older (gneisses) and younger (grey granite) folds and their axes, open circles: observed small fold axes, crosses: meta-porphyrite dykes.

granite with a large amount of microcline, and posessing a local faint gneissosity. A cubic joint system is well developed.

Dykes

Some zones, less than 25 m wide, containing basic xenoliths occur in the grey granite. The xenoliths consists of meta-porphyrite, with distinct long prismatic plagioclase phenocrysts with flow structure, and the zones indicate the original dyke trends. Thus the meta-porphyrite intruded in the granite as dykes before complete consolidation of the granite, and were brecciated into agmatitic blocks by later movement of the granite. These dykes occur along the border between gneiss and granite and cut the coarse-grained amphibolite. Apparently similar dykes 1—5 m wide were found in central Orvin Land (Fig. 2).

Numerous grey-white and pink dykes of less than 10 m thickness cut all rocks mentioned above with shallow to moderate dips. Contact relationships suggest these two types of dykes to be intruded almost simultaneously. The grey-white type is of quartz-dioritic composition and shows close similarities in lithology to parts of the grey granite. Accordingly the activities of the grey granite and the three kinds of dyke rocks are closely related in time.

The significance of this complex of intrusive and hypabyssal rocks rather unique in Svalbard, should be considered during future work in the area.

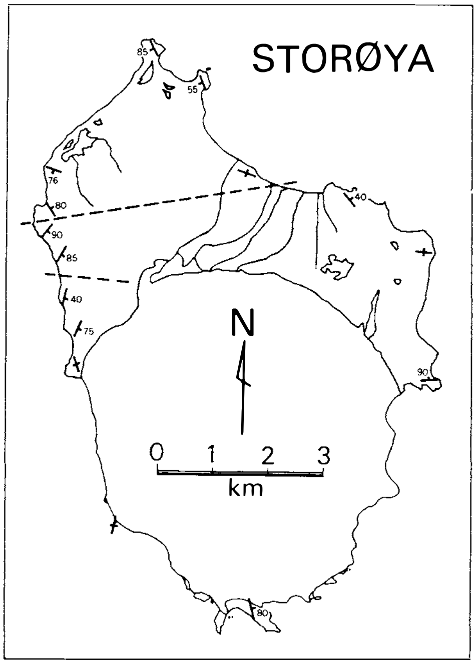


Fig. 6. *Structure of the Storøya gabbro and diorite. The island is composed of gabbros and diorites, descriptions are given in the text.*

Structure

The gneisses show a north-south trend in the southern part of the area, turning NE-SW in the northern part, the latter direction paralleling that of the Frostøyane gneisses further north (Fig. 5, fabric diagram). The calculated younger fold axis from the northern part of the area, and one observed younger fold, strike SSE with c. 50^{g} plunge. This deviation from the main trend of gneissosity and lineation suggest a later reorientation of the gneisses by the emplacement of the granite and amphibolite.

Storøya

The size of this island, off the northeastern corner of Nordaustlandet, is 11 x 7 km. Most of the southern part is occupied by a shield glacier, Storøyjøkulen, and the inner northern part is largely covered by glacial deposits. Thus the exposures are confined to the shores.

The rocks comprise various gabbros and diorites, ranging from olivine bearing anorthositic to quartz dioritic facies. The distribution of the different varieties is affected by shear zones and faults of mainly east-west strike (Fig. 6).

The northern coast

A large shear zone is estimated in the northern part of the island, separating the northern capes from the rest. The rocks on the northern side of this zone are layered gabbro with anorthositic and pyroxene-hornblende rich bands. A NNW-SSE striking flow structure with steep westerly dips is distinctly developed, and the thickness is calculated to about 600 m. Fine-grained hornfelsic dolerite dykes cut in two directions. An unaltered dyke of assumed Mesozoic age cuts the northernmost cape.

The western coast

The strike of the layered structure changes near the northwestern cape and serpentinization occurs, suggesting a fault. Southwards from this cape a relatively continuous succession of layered gabbro is exposed, although several zones of shearing cut across, from layered olivine-pyroxene gabbro in the west to dioritic facies in the east, near the glacier. The dioritic facies includes many sub-angular and layered inclusions of dark facies. The estimated thickness of this unit is about 1.5 km. Numerous dolerite dykes cut the layered gabbro around the northwestern cape in the E-W strike.

The southern coast

Small exposures along the southern ice edge consists of medium grained gabbro with olivine-bearing anorthositic bands, and a marble inclusion. At the southernmost cape layered gabbro occurs with pyroxene-hornblende pegmatite and dolerite dykes.

The eastern coast

Along the east coast a quartz dioritic facies dominates, excluding the exposure in the middle of the wide northeastern bay where massive and layered gabbro occurs. The quartz diorite includes many fine-grained dark blocks. The quartz has a characteristic milky blue opaly luster and forms pools of a few mm. Dense doleritic and white aplitic dykes cut the diorite. If the whole eastern area is considered as one unit, the thickness of the quartz dioritic facies may be estimated to 1—1.5 km.

The layered gabbro along the northern and western coast are presumably earlier differentiates of a magma, the eastern dioritic rocks are later. Thus the estimated total thickness of the Storøya basic complex, which contains a relatively large amount of later differentiates, is in the order of a few km.

Structure

The main trend of fractures, east-west, has resulted in inclusion-rich diorite zones and local zones of mylonite and schistose amphibolite. Some aplite dykes also follow this direction. No chloritization occurs in these rocks, and the mechanical deformation therefore took place at a temperature around that of the lower amphibolite facies. The mafic minerals in the white aplite were transformed into hornfelsic biotite, and actinolite was formed.

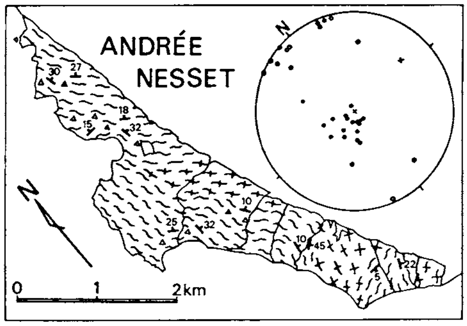


Fig. 7. *Geological map of Andréeneset, western Kvitøya. The fabric diagram. Dots: foliations, open circles: observed small fold axes, cross: aplite dyke.*

The dolerite dykes, which cut all other rocks, occur everywhere, having NW-SE and ENE-WSW directions and almost vertical dips. The direction of maximum compressive stress during the intrusion of the dolerite is estimated from this conjugated set in WNW-ESE direction. This direction is conformable with the main Caledonian stress field. The dolerite has a well preserved igneous texture of the plagioclase, but hornblende is decomposed into brown biotite and actinolite, and a pre-Mesozoic intrusion age is evident.

Kvitøya

This island located about 55 km east of Storøya, is almost entirely covered by an ice dome. Recent satellite pictures have greatly improved the knowledge of the shape, size, and position of the island (new preliminary map 1:100 000 Kvitøya, Norsk Polarinstitutt 1977 and Fig. 1). The former estimated area of Kvitøya was about 250 km^2, the revised figure is about 750 km^2. Among five small exposures along the edge of the ice cap, the three main ones were visited: Andréeneset, Kræmerpynten, and Hornodden.

Andréeneset

This is a 1 × 6 km exposure along the southwestern edge of Kvitøyjøkulen (Fig. 7). The main rocks are banded and nebulitic granitic migmatites with discontinuous biotite gneiss layers, with or without garnet, and a small amount of amphibolite paleosomes. The metatect is pink gneissose two-mica granite and grey biotite granite. The amphibolite paleosomes are fine-grained, hornfelsic with ophitic plagioclase remnants and poikilitic hornblende. A peculiar lamprophyre-like rock also occurs as paleosomes: idiomorphic clinopyroxene occurs in a fine-grained plagioclase matrix which contains large amounts of carbonate and idiomorphic biotite. Its lithology is similar to alnöite and damtjernite of the alkaline suite.

Grey and pink two-mica granites dominate in the southern part of the exposure and cut the migmatite elsewhere as dykes.

The gneissosities show large variations, with a maximum around N-S to NW-SE with gentle to moderate dips towards E and NE. The observed fold axes concentrate along N-S with very gentle plunges. Younger undulation axes occur around E-W.

Kræmerpynten

This semicircular exposure, 500 m across, along the eastern edge of the ice cap, is composed of medium- to coarse-grained basic rocks of apparently noritic to dioritic composition. Layered and inclusion structures occur locally; fine-grained dark sub-angular inclusions occur in a leucocratic dioritic rock with weak flow structure. White aplites cut the gabbros and diorites. Inclusions of quartzite and calcareous skarn are found and pink muscovite-tourmaline pegmatite cuts all other rocks.

All the basic rocks show signs of recrystallization, and the fine-grained blocks have a granoblastic texture of hornblende and pyroxene without preferred orientation. No epidote, sphene or actinolite were seen and a relatively high temperature of recrystallization is assumed. The degree of recrystallization is stronger than in the gabbros of Storøya.

The layered structures strike E-W to NW-SE with almost vertical dips, the white aplite dykes follow this direction, while the pink pegmatites have N-S strikes with shallow easterly dips.

Hornodden

A 100 m rocky exposure occurs at the southeastern edge of the ice cap. The main rock here is a coarse-grained gneissose gabbro containing blocks and schlieren of fine-grained dense rocks. Gabbro pegmatite occurs as network veins grading into gneissose gabbro. The gneissose structures of the gabbro are of NW-SE to E-W strike with steep northerly dips. Pink aplite and pegmatite dykes cut the gabbro in two directions: N-S and WNW-ESE.

Conclusion

The main exposures of NE Nordaustlandet and the islands to the north and east were covered by geological mapping in 1976 and a comprehensive knowledge has been established. A large migmatite terrain is confirmed in Orvin Land, and the distribution of various paleosomes of supracrustal origin suggest a preliminary stratigraphical division: the upper part including amphibolite, quartzite and marble, and the lower part mainly of pelitic composition. The gneisses distributing along the eastern side of Austfonna belong to the upper division. Comparing with the lithostratigraphy already known from other parts of Svalbard these two divisions might be correlated to the lower part of Hecla Hoek, i.e., the Finnlandveggen Group of the Stubendorffbreen Supergroup of Ny Friesland (Harland et al. 1966).

The rocks are metamorphosed under the conditions of low pressure-high temperature facies series, with the mineral assemblages of the paleosomes being sillimanite-cordierite-garnet-two micas in the pelitic rocks and ortho- and clinopyroxene-hornblende-biotite in the basic rocks. The occurrence of orthopyroxene (of diallage composition) demonstrates that the highest grade was of the granulite facies. During the migmatization most para-gneisses underwent hydrous retrogressive metamorphism of lower amphibolite facies.

The general structural trend of the gneisses and migmatites is N-S deviating NE-SW and NW-SE (the D-1) paralleling the main Caledonian direction of Svalbard, while a later gentle deformation associated with the emplacement of granites and gabbros occurs as an axial trend around E-W (D-2). The pattern of block faults in Orvin Land indicates a N-S compression which conforms with the D-2 stress field.

Various basic rocks occur, especially in the eastern part of the area and their occurrences and petrography show that they emplaced at different stages during the orogeny. Besides amphibolites of geosynclinal origin, two types of meta-gabbros and a meta-porphyrite are distinguished, all being more or less metamorphosed. The meta-porphyrite occurs as dykes, closely assosiated with late-tectonic grey granite. This association is unique in the Svalbard Caledonides. The gabbro-diorite complex of Storøya has kept its primary layered structure, and is considered as a stratiform basic complex (for detailed description of the gabbroic rocks, see Ohta 1978, this volume). A peculiar lamprophyre-like alkalic basic rock occurs as paleosomes in the migmatites of Andréeneset.

The occurrence of a large amount of syn- to late-tectonic basic igneous rocks is distinctive and not known from other metamorphic terrains of the Svalbard Caledonides. The stratiform basic complex suggests crustal conditions similar to that of a stable continent. The existence of basement rocks in this area is not yet confirmed, however, the occurrence of hypersthene gneiss as migmatitic paleosomes encourages further studies along this line.

Acknowledgement

The authors are greatly indebted to the officers and crew on board M/S «Polarstar», the helicopter crew, and field assistants Dag Elgvin, Jens Halvorsrud, Jostein Nordland and Stein Nybakken for their valuable assistance.

References

FLOOD, B., D. G. GEE, A. HJELLE, T. SIGGERUD, and T. S. WINSNES, 1969. The geology of Nordaustlandet, northern and central parts. *Norsk Polarinstitutt Skrifter* Nr. 146. 139 pp.

HAMILTON, E. I., and K. S. SANDFORD, 1964. Rubidium-strontium ages from North-East Land (Spitsbergen). *Nature* 201: 1208—1209.

HARLAND, W. B., R. H. WALLIS, and R. A. GAYER, 1966. A revision of the Lower Hecla Hoek Succession in central north Spitsbergen and correlation elsewhere. *Geol. Mag.* 103 (1): 70—97.
NATHORST, A. G., 1910. Beiträge zur Geologie der Bären-Insel, Spitzbergens und des König-Karl-Landes. *Bull. Geol. Inst. Upsala* 10: 261—416.
NORDENSKIÖLD, A. E., 1875. Redogörelse för den svenska polarexpeditionen år 1872—73. *Bih. Kungl. svenska Vetensk. Akad. Handl.* 2 (18). Stockholm.
OHTA, Y., 1978. Caledonian basic rocks of Storøya and Kvitøya, NE Svalbard. *Norsk Polarinstitutt Årbok* 1977 (this volume): 25—42.
ORVIN, A. K., 1940. Outline of the geological history of Spitsbergen. *Skrifter Svalbard og Ishavet* Nr. 78, Oslo.
SANDFORD, K. S., 1926. The geology of North-East Land (Spitsbergen). *Quart. J. Geol. Soc. London* 82: 615—665.
— 1954. The geology of Isis Point, North-East Land (Spitsbergen). *Quart. J. Geol. Soc. London* 110: 11—18.

Appendix

In August 1978, after this paper was written, A. Hjelle made a brief visit to Karl XII øyane (Fig. 1). This area consists of only one main island and some minor adjacent islets; some earlier maps show two main islands.

The northern, highest part of the island is composed almost entirely of finely laminated siliceous beds, possibly of more than 300 m thickness, which are intruded by gabbroic sills and dykes. The amount of gabbroic rocks increase towards the south of the island, and the intrusions do locally disturb the beds which in general dip 30 to 60^g towards the NNW.

Two generations of gabbroic rocks occur: 1) Medium grained massive with 2) agmatitic inclusions of dense dark varieties, both somewhat metamorphosed. In the middle part of the island gabbroic rocks are locally intruded by dioritic material, forming agmatites. In the same area all the rocks mentioned above are cut by minor (cm) muscovite pegmatite joint filling veins.

Due to the similarities with the basic rocks in Storøya and Kvitøya, Karl XII øyane is regarded as part of the northeasternmost complex of Nordaustlandet, which is characterized by relatively large amounts of syn- to late tectonic basic rocks.

Caledonian basic rocks of Storøya and Kvitøya, NE Svalbard

By YOSHIHIDE OHTA

Abstract

Petrographic and petrochemical studies of the basic rocks from Storøya and Kvitøya, NE Svalbard are presented in this paper.

The Storøya gabbro-diorite complex consists of olivine-plagioclase cumulatives and quartz dioritic rocks which are the modified products of the gabbros by large amounts of sodic plagioclase and quartz. The Kvitøya gabbros are hypersthene-bearing ones without olivine, and the earlier cognate derivatives were included in the main gabbros to convert into pyroxene hornfels.

The bulk compositions indicate that the rocks from both islands are primarily of the tholeiitic rock series of moderate iron concentration; the Kvitøya rocks show stronger iron concentrations than the Storøya ones. All rocks were strongly modified by late magmatic Sodium rich material and were converted into calc-alkalic rocks. The non-oceanic nature of these tholeiites is suggested from the minor element ratios and the differentiation trends of some major oxides.

The assemblage of abundant calc-alkalic rocks and some tholeiites in these islands suggest that the area might have been of a well developed island-arc setting with a thick continental crust during the late period of Caledonian orogeny.

Introduction

The distribution of gabbro-diorites in Storøya and Kvitøya, the two islands NE of Nordaustlandet, Svalbard, was first shown in the geological map of Orvin (1940) based on reports of Nathorst (1910) and Horn (1932). However, due to the remote location of these islands in ice-packed waters, no proper geological study has been carried out on these rocks. From NE Nordaustlandet, some amphibolites were reported from Isispynten (Sandford 1954) and eastern Orvin Land (Flood et al. 1969).

During the Norsk Polarinstitutt 1976 Svalbard Expedition, three geologists carried out geological mapping in these areas, the results of which are presented in a separate paper in this volume (Hjelle et al. 1978). The present paper presents petrographic and petrochemical studies of the gabbros and related rocks from Storøya and Kvitøya and their relations to the amphibolites and migmatites of NE Nordaustlandet.

Geological settings

NE Nordaustlandet, east of Duvefjorden, makes a large migmatite complex with gentle undulating structures. Along the eastern coast, the syn- to late-tectonic structures can be divided into two phases: D-1: the formation of regional metamorphic rocks and migmatites represented by the N-S to NE-SW striking foliations, and D-2: structures related to the syn- to late-tectonic intrusions. Actually in the Nordmarka area, the gneisses situated between porphyritic granite and gabbro have E-W strikes and the lineations on the foliation surfaces tend to be rotated by the later movement caused by the granite and gabbro (Hjelle et al. 1978).

Five different types of basic rocks occur in NE Nordaustlandet and the islands to the east. Their locations are shown in Fig. 1 by numbers corresponding to the following description.

(1) Amphibole- and pyroxene gneisses

These are layered paleozomes concordantly included in the migmatites, and occur as hornblende schists in Nordmarka and Frostøyane, hornblende gneiss and garnet-hypersthene-hornblende gneiss at Tschuknovskyodden, eastern Orvin Land, and the islands about 10 km north of Isispynten. These paleozomes are evidently derived from geosynclinal piles. Small agmatitic paleozomes containing hornblende occur commonly in the migmatites elsewhere.

(2) Massive amphibolites

These are mostly pyroxene-hornblende gabbros and diabasic rocks, discordantly emplaced in the migmatites. The rocks were strongly affected by migmatization, with development of biotite and quartz. The cracks were penetrated by granitic-, aplitic- material and agmatitic structures are partly represented. The gabbro reported from Béhounekodden, eastern Orvin Land, by Flood et al. (1969) and the coarse-grained amphibolite of Isispynten described by Sanford (1954), belong to this type.

A gabbro of this type, 3 × 5 km in size, occurs in the northern part of Nordmarka, showing a synform structure with an E-W axial trend. Large inclusions of crystalline schists and marble are involved, and a coarse-grained syenitic amphibolite has developed due to strong idioblastesis of gray microcline. The gabbro in the islands in the southern part for Frostøyane are also of this type and may be a large mass. Several coarse-grained granoblastic amphibolites of similar type occur as xenolithic masses in the porphyritic granite of Nordmarka and Sørmarka.

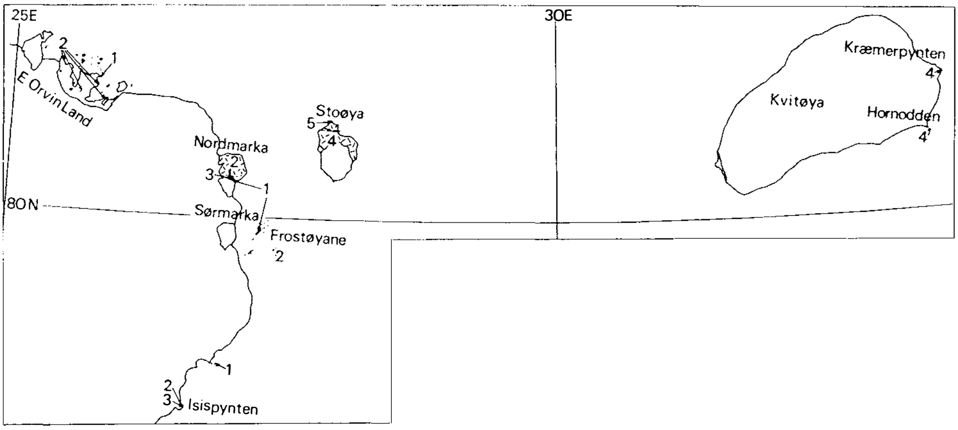


Fig. 1. *Location of various basic rocks in NE Svalbard. 1: basic rocks of geosynclinal pile origin; 2: syn-tectonic massive amphibolites; 3: meta-porphyrite dykes; 4: late-tectonic gabbros and associated basic rocks; 5: Mesozoic dolerites.*

(3) Meta-porphyrite dykes

Large long prismatic plagioclase phenocrysts in a dark matrix are distinct in this rock. The dykes lineally cut the gneisses and massive late-tectonic grey granite, but show agmatitic structures in the granite. The primary mafic constituents were totally recrystallized into small-grained granoblastic polygones. The dykes cut the Type (2) amphibolite in Isispynten.

(4) Gabbros and related basic rocks in Storøya and Kvitøya

The gabbroic rocks of these islands have definite igneous textures, the composition ranging from anorthositic olivine gabbro to quartz diorite in Storøya and noritic gabbro to diorite in Kvitøya. Some basic rocks from Kræmerpynten, eastern Kvitøya (Fig. 1), have granoblastic texture. Dolerite dykes cut the gabbro-diorites of Storøya and the rocks are hornfelsed. Pink pegmatite-aplites and grey granite dykes cut the gabbros of both islands, thus, these rocks might be of a late-tectonic origin. Rocks of this type will be described in detail below.

(5) The fresh dolerites

A dyke observed on the northern tip of Storøya shows almost no secondary alteration and has a petrography very similar to the Mesozoic dolerites occurring elsewhere in eastern Svalbard.

The basic rocks of Types (2) and (3) are evidently syn- to late-tectonic instrusions, having close association with specific granite: Type (2) with various migmatites of the D-1 tectonic phase, and Type (3) with the late-tectonic (D-2) massive grey granite. The conventional Rb/Sr ages of muscovite and biotite from the gneisses of Isispynten and the porphyritic granite of Sørmarka, range from 358 to 415 m.y. (Hamilton and Sandford 1964).

Petrography

The Storøya gabbro-diorites

Storøya, about 7 × 11 km in size, is completely composed of gabbros and diorites, but the exposures are restricted around the shore and the structure of the whole mass has not been established yet. A primary layering due to marked contrast in modal composition characterizes the gabbros. An orthocumulative texture of olivine and plagioclase with platy parallelism are detected, and intercumulous poikilitic pyroxene, totally uralitized, is observed. The layered structures were obliterated by numerous E-W striking shear zones which separate the northern part of the island from the rest. The rocks along the western shore have a gentle swing structure with a NE convex, while those of the eastern coast show a SW convex. The northern block has anorthositic, olivine- and/or clinopyroxene-bearing gabbros with a few inclusions of marble, the western one consists mainly of clinopyroxene-hornblende gabbros and the eastern one is composed of quartz dioritic rocks. Scattered exposures around the southern ice edge have pegmatitic gabbros and a small marble inclusion. The estimated thickness of the cumulative and layered rocks in the northern and western blocks is about 1.5 km, and of the eastern quartz diorite about 1.7 km. All varieties of gabbros underwent retrogressive metamorphism: uralitization of pyroxene and formation of actinolite around hornblende.

Numerous dolerite dykes cut the gabbro-diorites roughly in the E-W strike. The plagioclase laths, partly showing flowage and of An 50-55 with normal zoning, have retained a primary doleritic texture, while the mafic constituents were totally decomposed into actinolite, sphene and opaques, occasionally with biotite, but epidote and chlorite are very rare. Randomly orientated actinolite-biotite nematoblasts replaced all primary mafics in some dolerites.

The complete shape of the gabbro-diorite complex is unknown. However, the following evidences are in favour of a stratiform basic body of this complex: cryptic layering and regular variation in composition of constituent minerals (for example, the plagioclase in Table 1), the foliation is parallel to the compositional layering, major lithologic units are represented by groups of layers, orthocumulative textures with poikilitic pyroxene, and a relatively uniform grain size. On the other hand, the evidences below support the idea of an alpine type: the borders of lithologic units may be tectonic, the cm size of the anorthosite layers alternate with the same size of ultra-mafic layers in thick gabbros, the transitional facies between ultra-mafic and intermediate differentiates is troctolitic olivine gabbro having double reaction rims of orthopyroxene and plagioclase symplectite around the olivine, possible cataclastic dunite is now completely converted into blasto-porphyritic actinolite schist, inclusion-relation among different lithologic facies, and the association of numerous dykes.

Thus, the present complex exhibits the nature of both the stratiform and the alpine types of Thayer (1960). The stratiform basic intrusions are not restricted to occur only in stable tectonic areas, but are also reported from orogenic provinces as in Seiland, Finnmark, northern Norwegian Caledonides (Robins and Gardner 1974). The Storøya gabbro-diorite complex can be considered a stratiform type, strongly influenced by orogenic conditions.

No major ultra-mafic mass is recorded, on the contrary, the association of a large amount of quartz diorite is characteristic in this complex. The quartz in the dioritic rocks has a characteristic milky-blue colour. The dioritic facies often includes many sub-angular blocks with some amount of secondary quartz, saussuritized plagioclase, actinolitic amphiboles, epidote and chlorite. Blasto-porphyritic actinolite schist occurs as xenolithic blocks. The plagioclase grains of the dioritic rocks have a strong disharmonic mantle of oligoclase composition around the labradorite-andesine cores which show cracks resolved by the mantle. The mantle sometimes shows strong oscillatory zoning in the oligoclase composition range. A large amount of quartz was introduced simultaneously with the mantle oligoclase and hornblende was actinolitized, while no strong hydration to form chlorite and saussurite was associated. Since no biotite nor potash feldspar were formed during this stage, the introduced material can be considered as the acidic residuals of the latest differentiation of basic magma. The mobilization of already consolidated rocks by this introduction caused the intrusive blocky structures commonly seen in the dioritic rocks.

Regional metamorphism followed the consolidation of the dioritic rocks. The quartz was granulated into mylonitic mortar, biotite replaced the granulated hornblende, and epidote and chlorite were formed. At the same time, some ultra-mafic layers were altered into serpentinite. These phenomena are closely associated with the E-W striking shearing. Sharp-cut dolerite dykes, being hornfelsed, occur in the same direction. This movement can be correlated to the late stage of the D-2 tectonic phase.

The basic rocks of Kvitøya

The lithology of the basic rocks of Kvitøya is more complicated than that of Storøya, in spite of the small exposures. A transition from igneous to metamorphic textures is seen in these rocks. There are three groups of igneous-textured rocks:

(1) Relatively leucocratic, medium-grained rocks. — Orthopyroxene is common in these rocks, being often hydrated, and has actinolite rims, the outer part of which is distinctly green. These rims suggest primary clinopyroxene rims around the orthopyroxene. Clinopyroxene is rare and hornblende includes both pyroxenes. Skeletal opaque minerals and granular apatite are included in the hornblende. Plagioclase has an An content of 40-50 and shows shadow-like irregular zoning with margins of An 30-35.

(2) Melanocratic rocks of various grain sizes. — Clinopyroxene, strongly converted into actinolite-biotite aggregate, is always included in large hornblende grains in these rocks. Opaques are relatively abundant in most rocks, the hornblende having spewed out opaque films along cleavages during actinolitization. Apatite occurs in a considerable amount. Irregular zoning of plagioclase is very strong with An 45-50 cores and An 35 rims.

(3) Pegmatitic rocks and white aplites. — The pegmatitic rocks have large hornblende crystals including skeletal opaques and clinopyroxene being decomposed into aggregates of actinolite-epidote-opaque. Large idiomorphic apatite is abundant locally. Plagioclase shows irregular zoning in the composition range of An 33-40. The aplites consist of plagioclase (An 30) and quartz in the texture of granoblastic polygones with scattered small aggregates of poikilitic granular actinolite.

In contrast to the Storøya gabbros, no olivine has been found, instead, orthopyroxene is common in the Kvitøya gabbros. Considerable amounts of opaque minerals and apatite crystallized parallel to the hornblende. All rocks show signs of later hydration, locally associating a small amount of biotite.

Two types are distinguished among rocks of transitional textures between igneous and metamorphic ones. The first type is a fine-grained, melanocratic rock with granoblastic clinopyroxene and hornblende, and prismatic plagioclase of doleritic texture. Orthopyroxene rimmed by clinipyroxene also occurs. These rocks occur as dark inclusions in leucocratic noritic rocks of igneous texture. The second type is mainly composed of decussate hornblende and granoblastic plagioclase; the latter occasionally remains as relatively large sub-prismatic grains. One rock has a notable amount of idioblastic epidote. Retrogressive conversions, i.e., formation of actinolite and hydration commonly seen in the igneous-textured rocks, have not been seen in any of the two types of transitionally-textured rocks.

Rocks having metamorphic textures are characterized by a typical granoblastic polygonal texture without preferred orientation. They are mostly hornblende-plagioclase rocks, but some rocks have clinopyroxene and occasional orthopyroxene rimmed by clinopyroxene. No essential retrogressive change occurs, but small amounts of actinolite and biotite were formed along fractures. The plagioclase composition ranges from An 33-55 and no zoning has been seen.

Rocks with transitional and metamorphic textures are most likely to be hornfels. The pink pegmatite and aplite cutting these rocks might produce the retrogressive alterations in the igneous-textured rocks, but they are not responsible for the pyroxene hornfels. The regional migmatites, the nearest occurrence is about 40 km west, were formed below the sillimanite isograde, and are too low a temperature for the hornfels. Consequently, the thermal effect of the igneous-textured later gabbros seems to be most reasonable in the present case. The possibility of a basement origin of these metamorphic-textured rocks can not be excluded.

The igneous-textured gabbros of Kvitøya can be correlated to the Storøya gabbro-diorites.

Petrochemistry

30 rocks from Storøya and Kvitøya were analysed for major and minor elements by the fluorescence, flamephotometry and titration methods. The results are shown in Tables 1-4, with some petrographic remarks.

The Storøya gabbro-diorites

14 rocks were analysed from this complex, including two blocky inclusions which can be regarded as cognate rocks (Nos. 2 and 7, Tables 1 and 3), and one cross-cutting dyke rock (No. 8, Tables 1 and 3). Petrographically, these rocks, excluding No. 8, can be grouped into three: (1) layered pyroxene-hornblende gabbros with or without olivine (Nos. 1 to 6); (2) quartz dioritic rocks with distinct oligoclase mantle and quartz (Nos. 7 and 9-11); and (3) quartz diorites with mylonitic texture and containing biotite and chlorite (Nos. 12-14). These groups are shown by different symbols in the figures.

All rocks are sub-alkalic in the alkali-SiO_2 diagram (Fig. 2). Only the dolerite dyke (No. 8) is relatively alkalic, mainly due to a high content of K_2O and some Na_2O. The former was introduced later as hornfelsic biotite partly replacing hornblende, resulting in the deviations of FeO + Fe_2O_3, TiO_2, and CaO on the variation diagrams (Fig. 3).

The Group (1) rocks show SI values (= solidification indices) higher than 40, indicating their cumulative nature. The SI-variation diagrams (Fig. 3) show relatively smooth curves for each oxide, except for No. 1

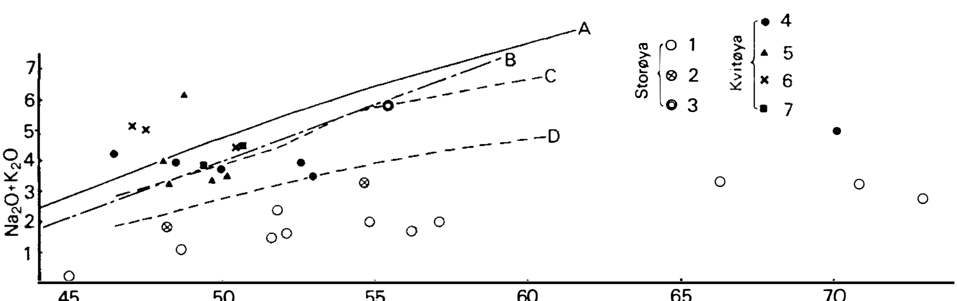


Fig. 2. *Alkali-SiO_2 diagram of the basic rocks from Storøya and Kvitøya (all figures are on unhydrous base). A and B: alkalic-subalkalic border of Irvine and Baragar (1971) and Mac Donald (1964), respectively; C and D: borders of the high-alumina basalt of Kuno (1960). Symbols: 1: gabbro-diorites; 2: inclusions in the quartz dioritic rocks; 3: hornfelsed dolerite dykes; 4: igneous-textured rocks; 5: rocks of transitional textures; 6: rocks with metamorphic textures; 7: rocks from Hornodden. These symbols are common in all figures.*

Table 1

Normative composition and some petrographic remarks of the Storøya gabbro-diorites. The symbols refer to the figures.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
NORM COMPOSITION	Q				2.29	1.61		5.80	0.08	9.07	14.95	13.03	25.49	34.92	41.25
	Or		1.25	0.06	0.48	0.41	1.87	3.54	14.84	1.42	0.99	1.02	4.17	1.89	1.02
	Ab	1.86	13.01	9.01	13.42	12.55	17.80	23.55	28.47	15.33	16.42	13.74	23.67	26.72	23.55
	An	22.80	25.41	41.73	41.03	33.19	36.94	38.15	23.16	38.90	35.05	36.64	21.95	23.83	23.15
	Ne		0.38												
	C												0.66	1.67	1.53
	Hy	19.90		6.47	31.57	22.39	23.74	25.04	23.68	21.64	23.41	22.38	22.67	10.20	7.90
	Di	7.36	28.54	28.41	9.68	27.66	18.40	1.98	7.07	10.99	5.84	10.58			
	Ol	45.97	29.79	13.56			0.22								
	Mt	2.00	1.45	0.37	0.96	0.88	0.47	1.27	0.77	2.13	2.13	1.98	0.79	0.39	1.04
	Il	0.10	0.15	0.35	0.54	1.28	0.50	0.59	1.43	0.43	1.14	0.58	0.49	0.28	0.44
	Ap	0.02	0.02	0.04	0.04	0.04	0.06	0.06	0.50	0.03	0.07	0.04	0.11	0.10	0.13
Norm An%		93	66	82	75	73	68	62	45	72	68	73	48	47	50
Obs. An				50-75	28,55	60-70	45-50 25-30	Olig. sauss.	20,50	50-65 25-28				28-35 40-43	20-28 30-43
$\frac{Fe_2O_3}{FeO+Fe_2O_3}$		0.20	0.20	0.08	0.14	0.11	0.06	0.15	0.11	0.26	0.19	0.21	0.11	0.10	0.26
SI		73.7	66.0	68.1	55.0	50.9	44.8	29.9	36.4	42.0	29.9	37.7	31.5	21.9	19.5
Main primary miner.		Ol. cpx.	Act.	Ol.Pl cpx.	cpx. Pl.	cpx.Pl Hb.	Hb. Pl.	Hb.Pl	Hb.Pl	Hb.Pl Qz	Hb.Pl Qz	Hb.Pl Qz	Hb.Pl Qz	Hb.Pl Qz	Hb.Pl Qz
Symbol in Figures		○	⊗	○	○	○	○	⊗	◎	○	○	○	○	○	○

Table 2

Normative composition and some petrographic remarks of the Kvitøya gabbros and related basic rocks. The symbols refer to the figures.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
NORM COMPOSITION	Q																28.50
	Or	2.37	2.42	2.17	2.24	3.39	0.53	2.99	3.64	2.44	0.68	1.77	1.23	1.08	1.51	1.04	1.42
	Ab	33.06	21.35	35.08	23.16	30.25	35.42	25.29	24.51	29.79	33.27	34.82	29.21	32.43	32.80	20.13	42.38
	An	23.04	18.83	29.57	38.68	32.51	27.30	37.69	55.74	27.92	19.19	42.14	36.57	31.87	34.71	36.26	23.53
	Ne	1.15	11.68	4.96	1.30				2.13		12.16	1.16		3.42			
	Hy					1.06	3.60	13.91		10.52			2.40		17.87	24.71	1.45
	Di	16.65	20.03	9.00	15.61	10.56	16.41	9.27	3.32	17.78	17.75	6.71	17.84	18.28	4.86	6.16	0.65
	Ol	13.33	21.34	9.76	16.01	16.91	7.70	6.54	9.56	5.47	10.69	10.93	9.08	9.19	6.07	0.75	
	Mt	4.47	2.65	4.71	2.11	2.16	4.60	3.24	0.65	2.28	3.06	1.24	2.71	2.78	1.31	1.19	1.26
	Il	5.03	1.54	3.26	0.85	2.61	3.91	0.80	0.37	3.63	2.65	0.64	0.79	0.78	0.63	0.56	0.76
	Ap	0.90	0.16	1.49	0.04	0.54	0.52	0.25	0.08	0.17	0.54	0.58	0.17	0.18	0.25	0.20	0.04
Norm An%		41	47	46	63	52	44	60	70	48	36	55	56	50	50	55	36
Obs. An		35			38-40	35	45-50	35-45	78		35		40-43	50	40	45	30
$\frac{Fe_2O_3}{FeO+Fe_2O_3}$		0.29	0.24	0.38	0.23	0.21	0.33	0.32	0.22	0.20	0.26	0.20	0.33	0.32	0.18	0.17	0.79
SI		24.7	40.7	21.0	38.7	34.3	24.2	35.7	39.1	31.1	24.0	28.7	35.7	29.5	40.0	43.4	7.4
High Al bs.					X			X	X			X	X	X			
Main primary minerals		cpx.Hb Pl.	Hb.Ol	Hb.Pl	Hb.Pl	Hb.Pl	Opx.Hb cpx.Pl	Hb.Pl	Hb.Pl	cpx. Hb.Pl	Opx.Pl cpx.Hb	Hb.Pl	cpx. Hb.Pl	opx.Pl cpx.Hb	opx.Pl cpx.Hb	opx.Pl cpx.Hb	Act. Pl.Qz
Symbol in Figures		●	✕	✕	▲	●	▲	▲	■	●	▲	■	▲	✕	●	●	●

Table 3

Chemical composition of the Storøya gabbro-diorites. The numbers refer to Table 1.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	42.89	48.35	48.88	50.63	51.59	52.00	53.15	53.19	54.85	55.52	56.14	64.84	71.91	73.52
TiO_2	0.07	0.11	0.26	0.38	0.92	0.36	0.41	1.00	0.31	0.78	0.41	0.34	0.20	0.31
Al_2O_3	8.81	12.52	17.40	17.29	14.56	17.29	18.34	15.95	17.25	15.25	15.81	13.25	15.47	14.15
Fe_2O_3	1.94	1.44	0.36	0.90	0.84	0.45	1.18	0.72	2.03	1.94	1.86	0.73	0.37	0.98
FeO	7.60	5.76	4.30	5.78	7.08	7.35	7.78	5.84	5.82	8.33	7.09	6.22	3.34	2.82
MnO	0.16	0.13	0.10	0.13	0.17	0.17	0.19	0.13	0.16	0.18	0.18	0.17	0.08	0.10
MgO	27.32	17.45	12.16	10.07	9.75	8.22	5.16	6.91	7.10	5.18	6.42	4.68	1.96	1.58
CaO	6.55	12.82	16.01	10.56	13.71	12.23	7.97	6.57	10.62	8.16	9.88	4.33	4.86	4.67
Na_2O	0.21	1.58	1.03	1.47	1.40	2.00	2.54	3.08	1.70	1.74	1.50	2.54	2.97	2.58
K_2O	nd	0.22	0.01	0.08	0.07	0.32	0.58	2.44	0.24	0.16	0.17	0.68	0.32	0.17
P_2O_5	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.23	0.04	0.03	0.02	0.05	0.05	0.06
ig.	5.13	1.42	0.15	1.78	0.98	0.95	1.68	2.22	1.17	2.26	1.16	1.45	1.26	0.72
Total	100.69	101.81	100.68	99.09	101.09	101.37	99.01	98.28	101.29	99.53	100.64	99.28	102.79	101.66
Ni	550	315	152	52	65	28	13	106	21	5	10	21	24	nd
Cr	304	278	398	116	191	119	76	203	61	89	121	111	140	89
Co	82	55	33	34	36	33	33	25	25	104	38	27	27	12
V	37	43	75	110	213	150	230	122	135	220	154	171	52	50
Zr	3	3	22	30	25	22	35	265	37	39	30	66	72	74
Sr	nd	30	60	85	70	90	105	560	75	85	120	83	135	100
Rb	10	10	22	<5	<5	35	34	140	<5	<5	10	49	38	15
Ba	<65	<65	<65	<65	<65	<65	100	850	<65	<65	65	110	<65	<65

Table 4

Chemical composition of the Kvitøya gabbros and related basic rocks. The numbers refer to Table 2.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO_2	45.72	47.40	47.48	48.00	48.65	48.73	48.83	49.46	49.78	49.85	49.97	50.13	51.93	52.63	53.37	73.15
TiO_2	3.50	1.13	2.36	0.61	1.89	2.81	0.57	1.27	2.58	1.97	0.46	0.57	0.58	0.46	0.41	0.04
Al_2O_3	14.83	15.19	19.34	19.29	18.24	16.61	18.74	26.85	16.00	17.58	22.53	19.13	19.63	19.35	19.25	17.28
Fe_2O_3	4.15	2.60	4.55	2.03	2.09	4.41	3.06	0.64	2.16	3.03	1.19	2.61	2.77	1.28	1.17	2.31
FeO	10.28	8.13	7.41	6.74	8.10	8.78	6.42	2.26	8.60	8.42	4.91	5.39	6.00	6.05	5.63	0.60
MnO	0.21	0.17	0.19	0.17	0.17	0.21	0.21	0.07	0.18	0.20	0.11	0.17	0.16	0.16	0.15	0.03
MgO	6.10	10.85	4.47	7.54	7.40	5.49	7.09	4.33	6.51	5.60	4.22	6.38	5.60	7.54	7.93	0.65
CaO	9.13	9.17	9.25	11.80	9.64	9.98	9.96	12.41	10.13	9.00	10.57	12.07	11.60	8.53	9.20	5.12
Na_2O	3.78	4.66	4.87	2.83	3.40	3.95	2.78	3.20	3.29	6.18	4.10	3.28	4.42	3.72	3.32	4.90
K_2O	0.39	0.42	0.37	0.38	0.58	0.09	0.50	0.63	0.41	0.12	0.30	0.21	0.19	0.26	0.18	0.25
P_2O_3	0.42	0.08	0.72	0.02	0.26	0.25	0.12	0.04	0.08	0.27	0.28	0.08	0.09	0.12	0.10	0.02
ig.	0.82	1.35	0.57	0.84	0.10	0.24	0.85	1.48	0.64	0.10	0.74	0.34	0.11	0.79	0.99	0.68
Total	99.33	101.15	101.58	100.25	100.52	101.55	99.12	101.64	100.36	102.32	99.38	100.36	103.08	100.89	101.70	105.03
Ni	27	220	8	18	46	19	23	33	38	27	27	15	16	94	99	15
Cr	53	320	50	65	59	55	107	70	65	72	50	64	59	81	92	107
Co	57	50	38	42	44	42	36	11	41	36	26	35	30	29	27	nd
V	405	186	190	195	200	270	159	43	302	228	138	145	139	74	66	5
Zr	154	95	132	90	207	102	77	133	124	135	129	114	140	97	92	136
Sr	800	280	635	1175	383	525	750	1380	314	540	1020	935	925	580	565	1025
Rb	<5	12	<5	5	<5	<5	35	165	<5	5	52	9	<5	31	35	83
Ba	110	<65	<65	105	90	<65	170	115	65	120	100	<65	<65	175	125	150

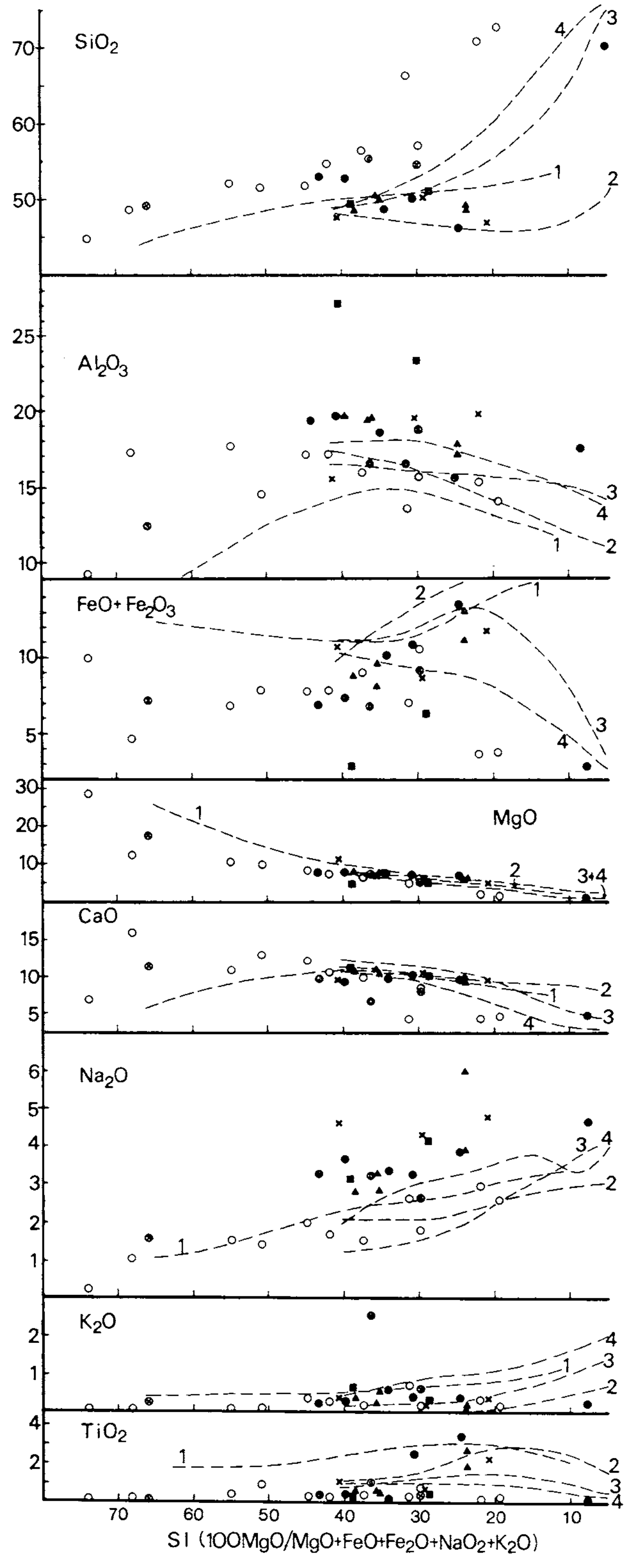


Fig. 3. *SI-variation diagrams of the oxides. 1: oceanic tholeiites, Hawaii; 2: tholeiitic rock series of a high iron concentration type, Skaergaard; 3: tholeiitic rock series of a moderate iron concentration type; 4: calc-alkalic rock series (3 and 4 are from Izu-Hakone, central Japan). All curves were simplified after Kuno (1968).*

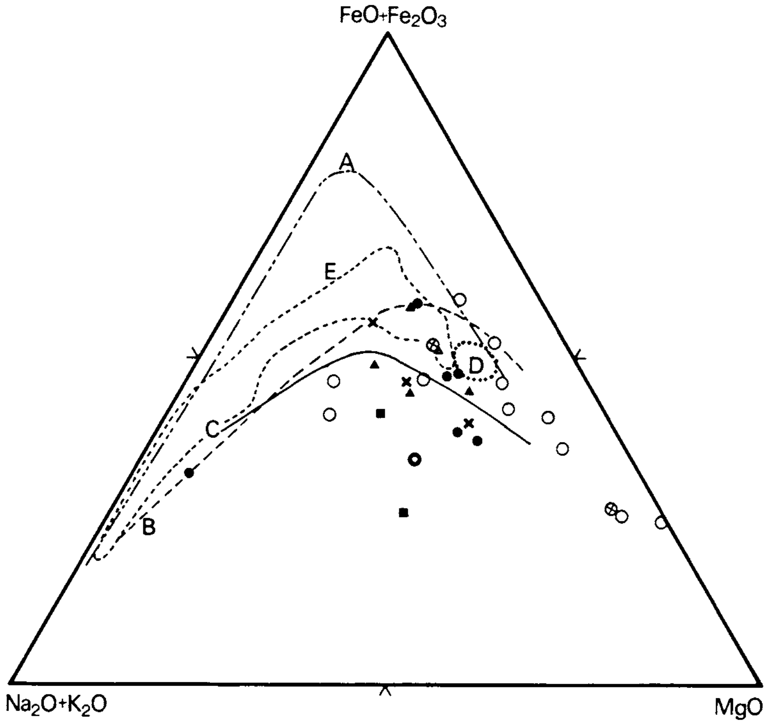


Fig. 4. *MFA diagram of the basic rocks from Storøya and Kvitøya. A: Skaergaard intrusion; B: the border between the pigeonitic (above) and the hypersthenic (= calc-alkalic) rock series of Kuno (1959); C: the border of tholeiites and calc-alkalic rocks by Irvine and Baragar (1971); D: parental magmas of various rock series (Kuno 1968); E: Scottish Tertiary tholeiites as an example of high-alumina basalts (Bailey et al. 1924).*

which is notably modified by selective serpentinization. Two trends can be distinguished on the Al_2O_3-variation diagram, the higher Al_2O_3 trend consisting of leucocratic basic plagioclase-rich cumulatives.

The Group (2) rocks are in the field of the hypersthenic rock series (= calc-alkalic rocks) (Kuno 1959) (Fig. 4), however, they can be in the field of the pigeonitic rock series, when the oligoclase mantle added later is subtracted. These rocks are in the field of tholeiites of Irvine and Baragar (1971). Since strong iron concentration did not occur during the middle stage of differentiation and no rock has more than 15% total iron, these rocks belong to the tholeiitic rock series of the moderate iron concentration type. Although all rocks were covered by later hydration, no occurrence of orthopyroxene support the tholeiitic nature.

The Group (3) rocks are of the calc-alkalic series due to their bulk composition. Rocks of Group (2) and (3), the former also tend to be calc-alkalic, are characterized petrographically by the later addition of a large amount of oligoclase and quartz, without biotite and chlorite which were associated only with the latest cataclastic movement of shearing to affect the Group (3) rocks. The introduced material consists mainly of Na_2O, SiO_2, and H_2O, and is responsible for the transformation into calc-alkalic rocks. A high SiO_2 trend is distinct in the variation diagrams of both SI and FeO^*/MgO bases (Figs. 3 and 6). No association of K_2O with this later introduction suggests that the material is of a magmatic residual, and is not of migmatitic origin, since the acidic mobilisates derived from the migmatites are always rich in potash feldspar, biotite and muscovite, besides quartz.

It is a strange fact that the $Fe_2O_3/FeO + Fe_2O_3$ ratios are very small in the present rocks (Table 1), in spite of the strong hydration of the primary mafic minerals. If these ratios are really indicative of a low oxygen pressure, decomposition of H_2O was prevented for unknown reasons.

The non-oceanic type of the present tholeiitic rocks is represented in the SI-variation diagrams in the range of $60>SI>30$, i. e., high SiO_2 and Al_2O_3, low $FeO + Fe_2O_3$ and TiO_2, in comparison with the Hawaiian tholeiites (Fig. 3). This conclusion is also supported by the minor element ratios as shown in Figs. 5-A, -B, -C, and -D.

The Kvitøya gabbros and related rocks

16 rocks were analysed, 14 from Kræmerpynten and 2 from Hornodden (Fig. 1). The rocks from Hornodden (Nos. 8 and 11, Tables 2 and 4) have extremely high Al_2O_3 and very low $FeO + Fe_2O_3$ contents, reflecting their leucocratic nature with basic plagioclase (An 78), and making them a separated group.

The rocks from Kræmerpynten are petrographically grouped into three: (1) those with igneous textures (Nos. 1, 5, 9, 14, 15, 16, Tables 2 and 4); (2) those with transitional textures (Nos. 4, 6, 7, 10, 12); and (3) those having metamorphic textures (Nos. 2, 3, 13). They are shown with different symbols in the figures.

Most rocks show relatively smooth curves on the SI-variation diagrams in the range of $45>SI>7$ (Fig. 3). The Group (3) rocks have relatively large deviations from the smooth curves in the Al_2O_3, $FeO + Fe_2O_3$, and Na_2O variations, reflecting their metamorphic modifications. All Group (3) rocks and some Group (2) rocks have normative Ne, while most Group (1) rocks are saturated by SiO_2, except for No. 1, a pegmatite (Table 2).

A steady increase of $FeO + Fe_2O_3$ with decreasing SI, but all with less than 15% total iron, and a weak decrease of SiO_2 in Groups (1) and (2) rocks, suggest a moderately iron concentrated tholeiitic rock series. However, in the alkali-SiO_2 diagram (Fig. 2), a nearly constant total alkali, except for a few high alkali rocks of Groups (2) and (3), is characteristic in most rocks. The projected trend traverses the border between the alkalic and sub-alkalic field, and about half of the analysed rocks are in the field of the high-alumina basalt series of Kuno (1960). In the MFA diagram (Fig. 4), all rocks are in the area of Kuno's hypersthenic rock series (=calc-alkalic rocks), while about half are in the tholeiite field of Irvine and Baragar (1971). The rocks with high Al_2O_3 have a smaller iron concentration than common high-alumina basalts as Scottish Tertiary tholeiites. Considering the

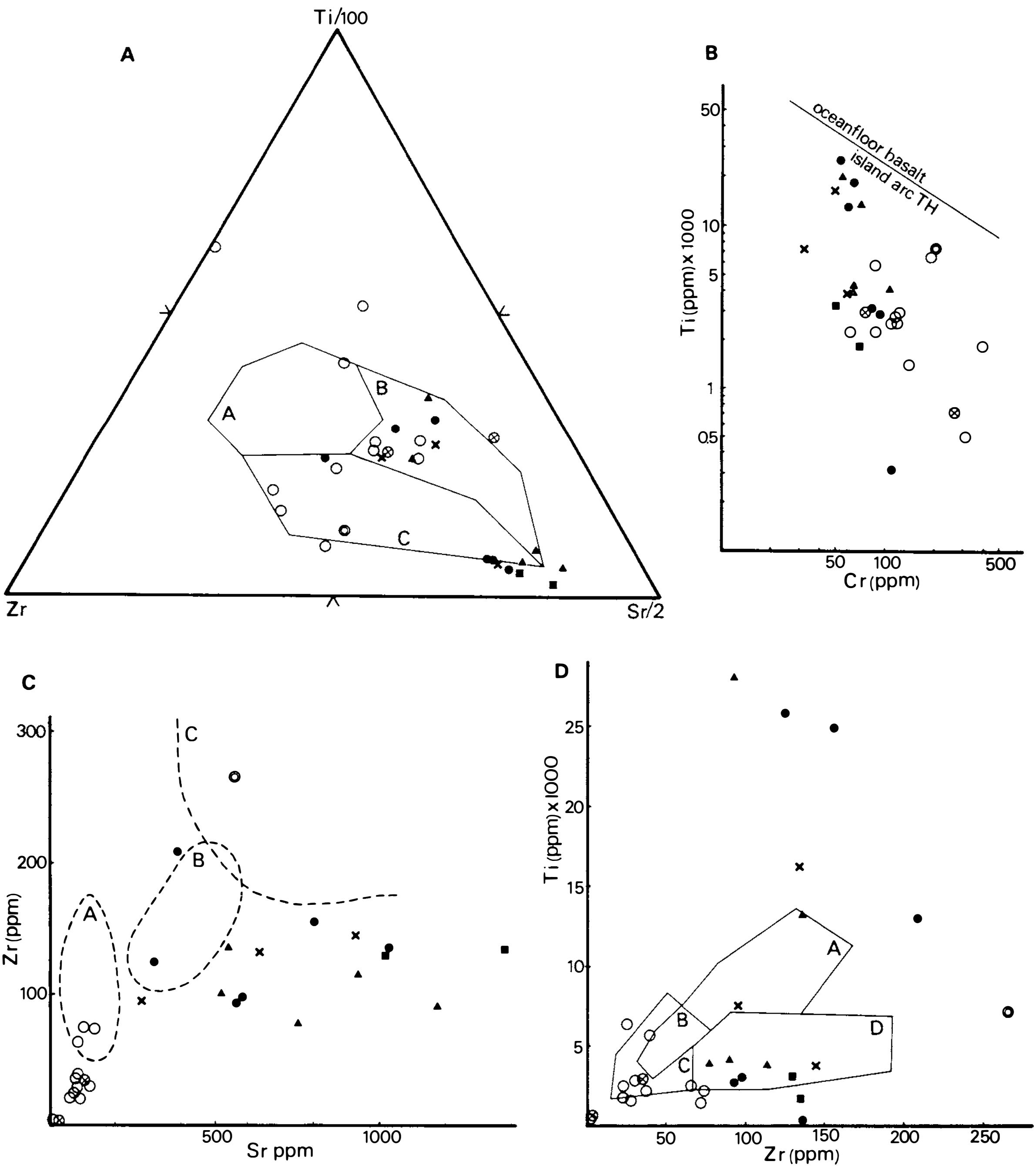


Fig. 5. *Minor element ratios representing a non-oceanic nature of the present rocks. 5-A: Ti-Zr-Sr ratios (after Pearce and Cann 1973). A: ocean floor basalts; B: low potash basalts of island-arcs; C: calc-alkalic basalts. 5-B: Ti-Cr ratios (after Pearce 1975). 5-C: Zr-Sr ratios (after Bass et al. 1973); A: ocean ridge basalts; B: ocean islands tholeiites; C: alkalic basalts. 5-D: Ti-Zr ratios (after Pearce and Cann 1973). A+B: ocean floor basalts; B+C: low potash island-arc basalts; D: calc-alkalic basalts.*

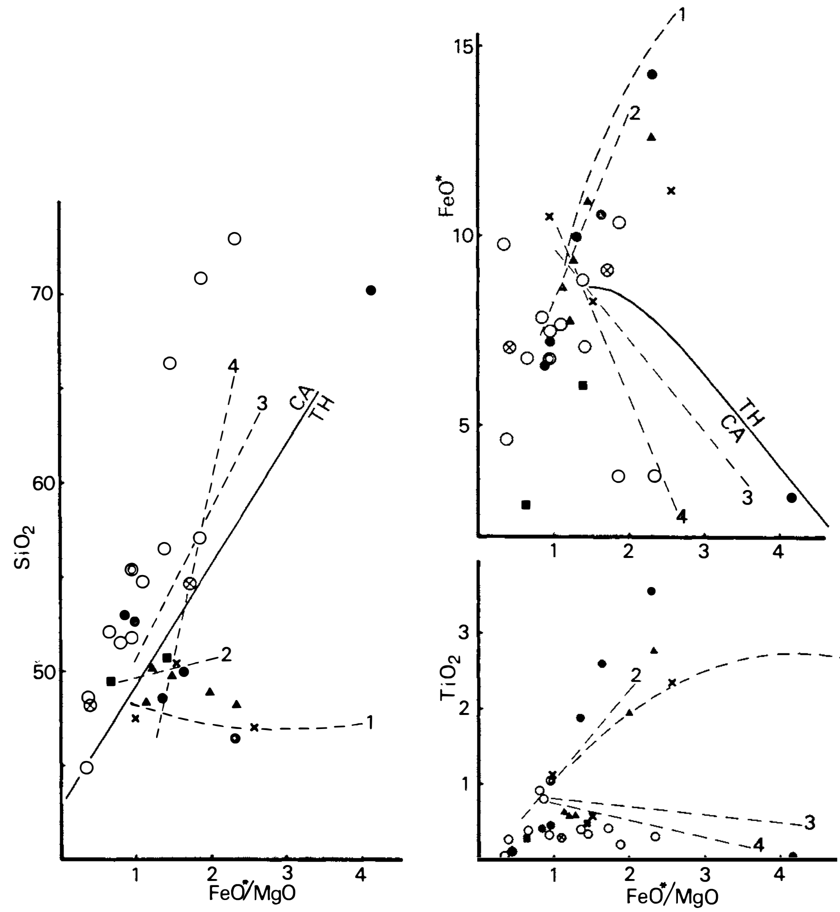


Fig. 6. *FeO*/MgO differentiation diagrams of SiO_2, FeO* and TiO_2. 1: Skaergaard; 2: abyssal basalts; 3 and 4: calc-alkalic rocks of central Japan, Asama and Amagi, respectively. All curves are after Miyashiro (1974).*

late- and post-magmatic modifications observed under microscope, the primary nature of the present rocks can be assumed to be tholeiitic with moderate iron concentration, and the later modifications changed most rocks into a calc-alkalic nature.

However, in the FeO*/MgO-variation diagrams (Fig. 6), a similarity between the present differentiations of SiO_2, FeO* and TiO_2 and those of the Skaergaard intrusion, a high iron concentration type tholeiite series, is demonstrated. The possibility of a high iron type can not be excluded since the observed exposure was only $^1/_4$ km^2 in width.

The non-oceanic nature of the Kræmerpynten rocks is represented by the Al_2O_3 and FeO + Fe_2O_3 differentiations in the SI-variation diagrams and the SiO_2 in the FeO*/MgO-variation diagram. The minor element ratios (Fig. 5) also confirm this conclusion.

The rocks of Hornodden are definitely different from those of Kræmerpynten and the relation between them is yet unknown.

Conclusion

Intrusions of pink pegmatite and aplite elsewhere in the gabbros and the formation of biotite hornfels in the latest dolerite dykes of Storøya reveal the late-tectonic emplacement of the gabbro-diorite in both islands in relation to the Caledonian migmatites.

The Storøya rocks include varieties of cumulatives, indicating a stratiform basic body strongly obliterated by the orogenic conditions. The structural situation of the Kvitøya rocks is unknown due to the small isolated occurrences, however, they are most likely to be earlier intrusions related to the same basic activity as the Storøya rocks.

The rocks of both islands belong primarily to the tholeiitic rock series of a moderate iron concentration type, the Kvitøya ones having a higher iron concentration than the Storøya rocks. All rocks were modified by later introduction of Na_2O-rich material and were converted into a calc-alkalic nature. Large additions of Na_2O to the Kvitøya rocks made SiO_2 undersaturation in the early derivatives which are included in the later igneous-textured rocks. Some of these rocks even tend to be alkalic in nature. The Na_2O-rich material can not be derived from the migmatitic country rocks and a late magmatic origin is most plausible. The granoblastic polygonal texture of the Kvitøya rocks was a result of the thermal effect of the igneous-textured gabbros on the earlier derivatives of the cognate origin.

The assemblage of abundant calc-alkalic rocks and some tholeiites is typical in the orogenic belts of well developed island-arc types, having a relatively thick continental crust (Miyashiro 1974 and 1975). A large amount of quartz dioritic rocks, chemical equivalents of andesite and dacite, in the Storøya complex and the high-alumina rocks in Kvitøya, confirm this idea.

The Caledonian foreland of eastern Nordaustlandet has been inferred from large-scale tectonic considerations of the Caledonian orogeny of Svalbard by many authors (Orvin 1940; Sokolov et al. 1968; and Harland and Gayer 1972). The chemical characteristics of the Storøya and Kvitøya basic rocks present a positive evidence for this idea.

Acknowledgements

The author is very much indebted to Mr. A.O. Larsen, Geological Institute of the University of Oslo, for the chemical analyses of rocks. He wishes to thank his colleagues T.S. Winsnes and A. Hjelle for close cooperation both in field work and critical discussions.

References

BAILEY, E.B., C.T. CLOUGH, W.B. WRIGHT, J.E. RICHEY, and G.V. WILSON, 1924: Tertiary and post-Tertiary geology of Mull, Loch Aline, and Oban. *Geol. Surv. Scotland Memor.* 445 p.

BASS, M.N., R. MOBERLY, J.M. RHODES, C. SHIH, and S.E. CHURCH, 1973: Volcanic rocks cored from the central Pacific, Leg. 17, Deep Sea Drilling Project. *Trans. Am. Geophy. Union.* 54: 991—995.

BØE, P., 1976: Geology of the troctolitic complex of Raisduodden-Hal'di, Troms, Northern Norway. *Norsk Geol. Unders.* Nr. 324: 29—46.

FLOOD, B., D.G. GEE, A. HJELLE, T. SIGGERUD, and T.S. WINSNES, 1969: The geology of Nordaustlandet, northern and central parts. *Norsk Polarinstitutt Skrifter.* Nr. 146: 1—139.

HAMILTON, E.I., and K.S. SANDFORD, 1964: Rubidium-strontium ages from North-East Land (Spitsbergen). *Nature* 201: 1208—1209.

HARLAND, W.B., and R.A. GAYER, 1972: The arctic Caledonides and earlier oceans. *Geol. Mag.* 109: 289—314.

HJELLE, A., Y. OHTA, and T.S. WINSNES, 1978: Geology of northeastern part of Svalbard. *Norsk Polarinstitutt Årbok* 1978 (this volume): 7—24.

HORN, G., 1932: Some geological results of the Norwegian Expedition to Franz-Josef Land, 1930. *Norsk Geol. Tidskr.* 11: 482—489.

IRVINE, T.N., and W.R.A. BARAGAR, 1971: A guide to the chemical classification of the common volcanic rocks. *Canadian Jour. Earth Sci.* 8: 523—548.

KUNO, H., 1959: Origin of Cenozoic petrographic provinces of Japan and surrounding areas. *Bull. Volcanol.* ser. II, 9: 241—265.

— 1960: High-almina basalt. *Jour. Petrol.* 1: 121—145.

— 1968: Differentiation of basaltic magmas. In HESS, H.H., and A. POLDERVAART ed., *Basalts* 2: 623—688.

MACDONALD, G.A., 1964: Chemical composition of Hawaiian lavas. *Jour. Petrol.* 5: 82—133.

MIYASHIRO, A., 1974: Volcanic rock series in island arcs and active contineltal margins. *Am. Jour. Sci.* 274: 321—355.

— 1975: Volcanic rock series and tectonic setting. *Earth Planet. Sci. Rev.* 3: 251—269.

NATHORST, A.G., 1910: Beiträge zur Geologie der Bären-Insel, Spitzbergen und des König-Karl-Landes. *Bull. Geol. Inst. Upsala* 10: 261—416.

ORVIN, A.K., 1940: Outline of the geological history of Spitsbergen. *Skr. Svalbard og Ishavet* Nr. 78: 1—57.

PEARCE, J.A., 1975: Basalt geochemistry used to investigate past tectonic environments Cyprus. *Tectonophy.* 25: 41—67.

PEARCE, J.A., and J.R. CANN, 1973: Tectonic setting of basic volcanic rocks determined using trace element analyses. *Earth Planet. Sci. Lett.* 19: 290—299.

ROBINS, B., and P.M. GARDNER, 1974: Synorogenic layered basic intrusions in the Seiland petrographic province, Finnmark. *Norsk Geol. Unders.* Nr. 312: 91—130.

SANDFORD, K.S., 1926: The geology of North-East Land (Spitsbergen). *Q.J.G.S. of London.* 82: 615—665.

— 1954: The geology of Isispynten, North-East Land (Spitsbergen). *Q.J.G.S. of London.* 110: 11—20.

SOKOLOV, V.N., A.A. KRASILTCHIKOV, and Ju. Ja. LIVSHITZ, 1968: The main features of the tectonic structure of Spitsbergen. *Geol. Mag.* 105: 95—115.

THAYER, T.P., 1960: Some critical differences between alpine-type and stratiform peridotite-gabbro complex. *Proc. 21st. Geol. Congr.* pt. 13: 247—259.

WAGER, L.R., 1968: Rhythic and cryptic layering in mafic and ultramafic plutons. In HESS, H.H., and A. POLDERVAART ed., *Basalts.* 2: 573—622.

The Triassic stratigraphy of southern Spitsbergen

By DAVID WORSLEY[1] and ATLE MØRK[1]

Abstract

Stratigraphical sections through the Triassic succession of the Hornsund and Sørkapplandet areas are presented. Most of the localities studied have not been described previously, and this new information demonstrates the continued existence of the Hornsund-Sørkapp High as a positive structural feature throughout the Triassic. The lithological units observed are compared with the Triassic sequence of central Spitsbergen and recent proposals for the establishment of new lithostratigraphical units in the Hornsund area are reviewed.

Introduction

The Triassic succession of central Spitsbergen has been the object of study for over 100 years and its development is relatively well documented. Outcrops in other parts of the Svalbard archipelago are still poorly known, although great advances have been made since the review paper by Buchan, Challinor, Harland, and Parker (1965). These workers proposed a comprehensive lithostratigraphical scheme for the Triassic based on their own studies in central Spitsbergen, but they also incorporated evidence from earlier work in other parts of Svalbard. At that stage little was known about the extensive Triassic outcrops in eastern Svalbard, but investigations in the last decade (e.g. Flood, Nagy, and Winsnes 1971a) have confirmed the lateral persistence and applicability of most of the units proposed by Buchan et al. (1965) in these eastern areas. This subsequent work has produced some modifications in unit rank (see Harland et al. 1974: Table 2) and there has been some discussion of alternative schemes for the division of the Upper Triassic succession (e.g. Smith et al. 1976; Edwards et al. 1978). Our interpretation of present status in central and eastern Svalbard is shown in Figure 1. The ages of the various units have been discussed in the biostratigraphical reviews of Tozer and Parker (1968) and Korčinskaja (1972); dating of the De Geerdalen and Wilhelmøya Forma-

[1] Paleontologisk Museum, Sarsgate 1, Oslo 5.

GP	FM	thickness m	age	
KAPP TOSCANA	WILHELMØYA	15/240	Rhaetoliassic	marg.marine ssts
	DE GEERDALEN	30/400+	Norian Carnian	marine to fluviodeltaic sandstones & shales
	TSCHERMAKFJELLET	12/150	Ladinian	
SASSENDALEN	BOTNEHEIA	20/260	Ladinian Anisian	open marine shales, siltstones & sandstones
	STICKY KEEP	25/310	Spathian Smithian	
	VARDEBUKTA	15/255	Dienerian Griesbachian	

Fig. 1. *A review of the Triassic stratigraphy of central and eastern Svalbard. Thickness values refer to minimum/maximum known thicknesses of the various formations throughout Svalbard.*

tions has been improved in recent years by palynological studies (Bjærke 1977; Bjærke and Manum 1977).

Information from southern Spitsbergen is still limited, and existing descriptions are confined mostly to reconnaissance studies of coastal exposures. Buchan et al. (1965) figured a section from Treskelen logged by Lowell and indicated a lithostratigraphical division which in general corresponds to our interpretations. Work by Sokolov and Pčelina (1967) in the Sørkapp area gave important biostratigraphical information, but their lithological section was too generalised to permit any precise comparison with other areas. An important contribution by Birkenmajer (1977) presented data from NW Sørkapplandet and from the area between Hornsund and Bellsund; however some of Birkenmajer's nomenclatorial proposals and interpretations are somewhat unfortunate as they suggest greater differences in the development of Triassic units between central and southern Spitsbergen than exist in reality.

Better knowledge of southern Spitsbergen is essential for any coherent interpretation of the Triassic palaeogeography of Svalbard — not least because of the postulated existence of the fault-bounded Hornsund-Sørkapp High in this area in Upper Palaeozoic times (e.g. Cutbill and Challinor 1965). The continued influence of this block structure upon Triassic sedimentation is implied by earlier work, and this contribution presents new information from exposures on and adjacent to the high. Our work represents a part of current investigations by the Svalbard project group at the University of Oslo. The group's programme includes an integrated interdisciplinary reappraisal of the Triassic succession of Svalbard aimed at a synthesis of depositional patterns throughout the archipelago and in adjacent shelf areas. An expedition to Hornsund organised by Statoil (The Norwegian State Oil Company) in 1977 enabled members of the project group to study Triassic sections along a north-south traverse through Sørkapplandet. Helicopter support made it possible to visit nunataks in the middle of Sørkapplandet, and the results shed new light on this little known area. A comprehensive report on the results of this and other studies now in progress will be presented elsewhere. This contribution will merely outline the general stratigraphy of the Triassic succesion along the traverse noted above; we will also compare our conclusions with the lithostratigraphical scheme proposed by Birkenmajer (1977).

Regional setting

The general geology of Sørkapplandet is well illustrated by the geological map of southern Spitsbergen compiled by Flood, Nagy, and Winsnes (1971b). The eastern part of Sørkapplandet contains flatlying to gently dipping Cretaceous and Tertiary sediments which comprise the southwestern margins of the main Tertiary basin of central Spitsbergen. These beds show increasing tectonical disturbance westwards towards the NNW-SSE trending Tertiary fold belt where thrusting has produced both vertical and overturned sequences of Upper Palaeozoic and Mesozoic rocks. The fold belt also marks the eastern margin of the Hecla Hoek terrain characteristic of western Sørkapplandet. Relatively flatlying attenuated Triassic sequences rest directly on the Hecla Hoek in the central parts of this complex, and the area thus corresponds generally to the Permian Hornsund-Sørkapp High. However, it is evident that varying block/trough configurations throughout the Upper Palaeozoic produced a complex facies mosaic of Devonian, Carboniferous and Permian sediments on and adjacent to the present horst structure. This mosaic has subsequently been further complicated by Tertiary deformation which has produced crustal shortening in the order of 15 km (Birkenmajer 1972). Tertiary faults evidently reactivated earlier lines of weakness created by the Upper Palaeozoic block boundaries.

Tertiary faults also mark the western edges of the horst structure, and the extreme northwestern and southwestern corners of Sørkapplandet apparently represent depositional troughs developed in the Lower Carboniferous and Permian respectively. The area around Hornsundneset contains a 950 m thick sequence of fluvial sediments assigned to the Billefjorden Group; these are directly overlain by a Triassic succesion now being studied by Dr. E. Nysæther, University of Bergen. The Øyrlandet and Sørkappøya areas show a thick (300 m+) Permian marine succession assigned to the Tokrossøya Formation. Overlying Triassic rocks, like those of Hornsundneset, show a somewhat thicker development than the sequences preserved in the central parts of the Hornsund-Sørkapp High.

Triassic sections studied by us in 1977 are representative of the three structural elements of Sørkapplandet which contain Triassic exposures, viz.

i. the Tertiary fold belt: Exposures were studied in the Treskelen area (north of Hornsund), and along the mountain ridge which extends southwest from Bautaen on the south coast of the fjord through Smalegga and Bjørnskardet to the most southerly Triassic exposures at Austjøkeltinden (12 km south of Bautaen). Triassic sequences in this region are steeply dipping to overturned.

ii. The Hornsund-Sørkapp High: Gently dipping Triassic sequences resting directly on the Hecla Hoek were studied on the mountains of Kistefjellet and Keilhaufjellet in southern Sørkapplandet.

iii. The western margins of the high: A partial section was measured through the steeply dipping but poorly exposed Triassic succession of Sørkappøya.

Sections were measured on a scale of 1:200 using standard log sheets which facilitate the registration of all sedimentological and palaeontologcial features of the succession. Interpretative sections prepared from the field logs are presented in Fig. 2.

Stratigraphy

The stratigraphical interpretations presented on our sections reflect our conclusions while in the field that formational units recognised elsewhere in Svalbard can be used for mapping in the Sørkapplandet area (conclusions which are also based on comparative studies both in the central and eastern areas of Svalbard). Our investigations were completed prior to the publication of the work by Birkenmajer (1977): this work was based mainly on areas to the north of Hornsund but both our studies include the area around Treskelen. Birkenmajer introduced three new units of formational and higher rank, viz. the Torell Land Group, the Storbreen Subgroup and the Drevbreen Formation. He also introduced 4 new members and two new beds within the Vardebukta and Drevbreen Formations. The reason stated for these proposals was that the standard of Buchan et al. (1965) «proved to be impractical during the field work south of Bellsund». As indicated by our formational descriptions, this argument is reasonable when applied to the members and beds proposed by Birkenmajer, but acceptance of his higher rank units would in our opinion produce unnecessary complications in what is at present a relatively coherent lithostratigraphical scheme. In the following section we will briefly describe the characteristic features of the various formations mapped between Hornsund and Sørkappøya. We will then briefly review our reasons for rejecting Birkenmajer's proposed Drevbreen Formation, Storbreen Subgroup and Torell Land Group.

Vardebukta Formation

Complete sections through the unit were logged at Treskelen (83 m) and Austjøkeltinden (71 m). Poor exposures between these localities (at Smalegga and Bjørneskardet) show the upper parts of the formation resting directly on the Lower Permian Treskelodden beds. The absence of the Kapp Starostin Formation in these localities (Hellem and Worsley 1978) is thought to be a tectonic phenomenon rather than the primary depositional feature suggested by Birkenmajer (1964, 1977) for exposures on the NE slopes of Bautaen. The basal 15 m of the Kistefjellet section are somewhat arbitrarily assigned to this formation; as in other localities on the Hornsund-Sørkapp High, Triassic conglomerates rest directly on the Hecla Hoek.

In complete exposures marginal to the high the base of the unit is marked by soft dark grey shales which directly overlie the massive uppermost bench of the Kapp Starostin Formation. Thin siltstone interbeds appear a few metres above the base and become increasingly common upwards; the siltstones have sharp (often clearly erosive) bases and rippled tops (wrinkle marks are common in the sections at Smalegga). This lower part of the formation, the Urnetoppen Member of Birkenmajer (1977), culminates in fine-grained sandstones which occur 20 to 30 m above the base of the formation; these are cross-bedded, often contain bivalves (e.g. *Myalina* sp) and have lag tops with both intraformational and extraformational clasts (among the latter are Permian cherts).

These sandstones and equivalent units have a widespread occurrence throughout exposures marginal to the high both north and south of Hornsund. The conglomerate lags suggest a period of winnowing with possible emergence; beds at Smalegga and Bjørnskardet contain large angular intraformational carbonate clasts in a sand matrix. The term «Brevassfjellet *Myalina* Beds» has been applied by Birkenmajer both to these units and to the basal conglomerates overlying the Hecla Hoek on the high. This name was apparently prompted by the widespread occurrence of *Myalina* sp. in the sandstone units and by the single occurrence of a coquina with this bivalve within such a basal conglomerate at Brevassfjellet (NW Sørkapplandet). The inclusion in one unit of such a mixture of bio- and lithostratigraphical concepts seems unfortunate, and we suggest:

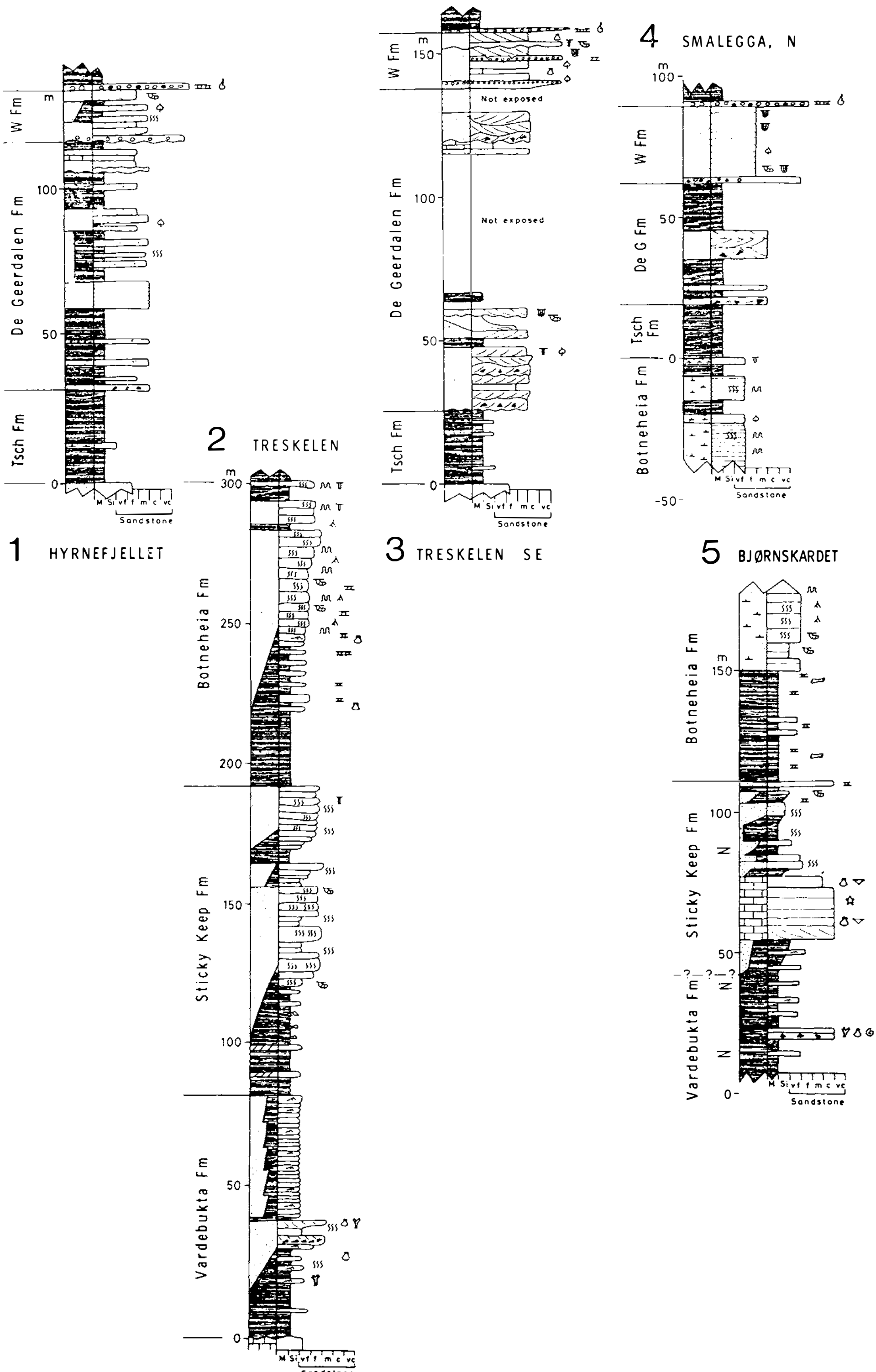
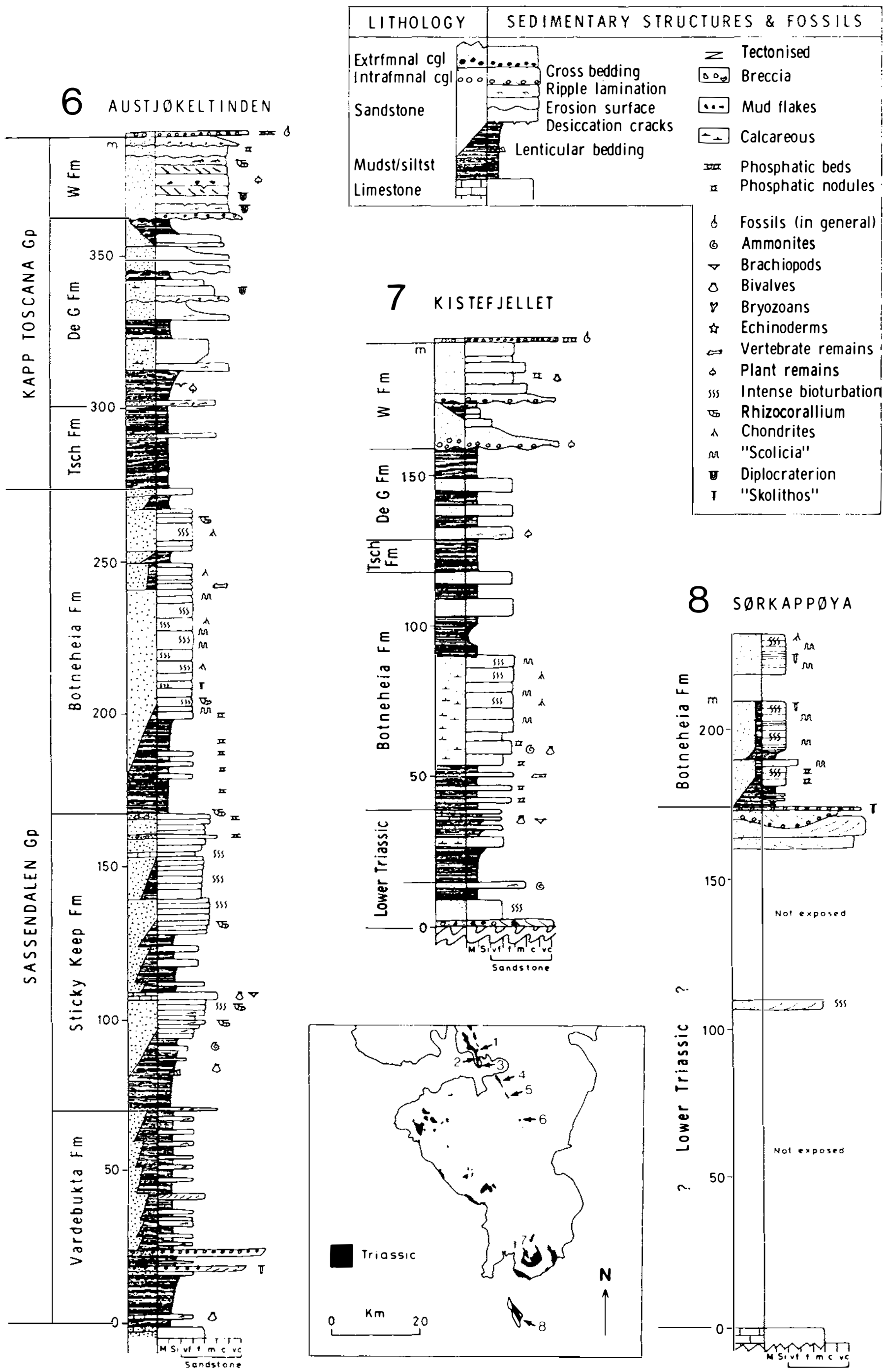


Fig. 2. *Interpretative sections along a N-S traverse from Hornsund to Sørkappøya. Sections are arranged taking a horizontal tie-line through the base of the Botneheia Formation.*


LITHOLOGY
SEDIMENTARY STRUCTURES & FOSSILS
Extrfmnal cgl
Intrafmnal cgl
Sandstone
Mudst/siltst
Limestone
Cross bedding
Ripple lamination
Erosion surface
Desiccation cracks
Lenticular bedding
Tectonised
Breccia
Mud flakes
Calcareous
Phosphatic beds
Phosphatic nodules
Fossils (in general)
Ammonites
Brachiopods
Bivalves
Bryozoans
Echinoderms
Vertebrate remains
Plant remains
Intense bioturbation
Rhizocorallium
Chondrites
"Scolicia"
Diplocraterion
"Skolithos"
6 AUSTJØKELTINDEN
KAPP TOSCANA Gp
SASSENDALEN Gp
W Fm
De G Fm
Tsch Fm
Botneheia Fm
Sticky Keep Fm
Vardebukta Fm
7 KISTEFJELLET
Lower Triassic
8 SØRKAPPØYA
Not exposed
M Si vf f m c vc
Sandstone
Triassic
Km
0 20
N

use of the term Brevassfjellet Bed to embrace basal conglomerates of the Triassic on the Hornsund-Sørkapp High,

and

assignment of sandstone sequences on the eastern margins of the high to a new unit, viz. the Bautaen Bed. with its type section on the SW tip of Treskelodden, as figured by Birkenmajer 1977: Fig. 21).

Sandstones assigned to the Bautaen Bed on the eastern margins of the high are overlain by irregular small scale rhythms of thin siltstones and shale interbeds corresponding to the lower parts (units a and b) of the Wibebreen Member proposed by Birkenmajer. We here place the junction with the Sticky Keep Formation at the contact between these beds and the overlying dark grey thinly laminated silty shales assigned by Birkenmajer to unit c of the same member. This decision will be discussed further below; it necessitates redefinition of the Wibebreen Member.

There is no direct evidence for the age of the Urnetoppen Member. Conodonts found in the Bautaen Bed at Treskelen (Birkenmajer and Trammer 1975) and our find of *Otoceras* cf. *boreale* in the bed at Bjørneskardet suggest a Lower Dienerian age for this unit. Sandstones directly above the Brevassfjellet Bed on Kistefjellet contain *«Terebratula» margaritovi* and *Myalina* sp., an association which elsewhere occurs with typical Dienerian species (Sokolov and Pčelina 1967). These datings suggest the establishment of shallow marine conditions in areas marginal to the high at some time in the Griesbachian. Renewed transgression in the Dienerian drowned the ?locally emergent Bautaen Bed in these marginal areas and covered the central areas of the high, producing the basal conglomerates of the Brevassfjellet Bed. In the Kistefjellet section this bed is overlain by a thin sandstone and shale sequence which culminates in the local development of sandstone shoals underlying the dark shales at the base of the Sticky Keep Formation.

Sticky Keep Formation

Complete sections through the unit were logged at Treskelen (112 m), Austjøkeltinden (96 m) and Kistefjellet (23 m). Tectonised exposures at Smalegga and Bjørnskardet indicate thicknesses of approximately 75 m in these areas. Sandstones at the base of the measurable section on Sørkappøya may represent a local development of the top of the formation.

The base of the formation is marked by the appearance of dark grey planar laminated silty shales which contrast with the underlying interbedded siltstones and shales. Silt laminae become increasingly abundant upwards in the sequence, producing a continuous gradation into cliff-forming siltstones. The massive nature of the latter is caused by intensive bioturbation accompanied by calcite cementation, both features first appearing when a certain «critical» silt content is attained in this coarsening upwards motif. Such large scale rhythms are repeated several times within this formation; our base at the bottom of the first such rhythm reflects a basic change in depositional style and can be mapped regionally. Birkenmajer's junction at the base of the first cliff-forming siltstone in the middle of a continuously coarsening upwards rhythm is in our opinion somewhat arbitrary and little suited to regional correlation. Our proposed boundary can be identified on all of Birkenmajer's detailed sections from Torell Land.

Our definition of the boundary between the Vardebukta and Sticky Keep Formations would appear to correspond with the boundary defined in Isfjorden by Buchan et al. (1965) «at the soft shales overlying the topographical ledge formed by siltstones and sandstones of the uppermost Vardebukta Formation». This junction clearly marks a regional transgressive episode which can be traced throughout the western exposure belt of the Triassic.

The situation is, however, complicated by the intermittent local development of brachiopod bearing limestones — the «Retzia limestone» of Lundgren (1887) in Bellsund, the «Skilisen Retzia Bed» of Birkenmajer (1977) from localities in central Torell land, and a biosparite seen by us at Bjørnskardet south of Hornsund. Common to all of these are the occurrence of the spiriferid brachiopod ?*Hustediella nathorsti,* previously identified as *Retzia nathorsti.*

The «Retzia Limestone» of Bellsund was originally thought to represent the top of a 300 m thick Permian succession overlying fossiliferous cherty limestones now assigned to the Kapp Starostin Formation. Frebold (1939) reassigned these beds to the «Eotriassic» (i.e. Griesbachian and Dienerian stages) and suggested that the Retzia Limestone marked the top of this unit; he also indicated a tentative correlation with Isfjorden where such limestones are not seen. Buchan et al. (1965) suggested that the Retzia Limestone of Bellsund should be included in the uppermost Vardebukta Formation and Birkenmajer (1977) also followed this practice. This use of a tentative chronostratigraphical correlation in the definition of a lithostratigraphical unit is debatable, especially when we compare sections from Bellsund presented by earlier workers (Fig. 3). The Retzia Limestone as such was not identified by Lowell (Buchan et al. 1965: Fig. 19), but comparison with Lundgren (1887) suggests that the calcarenite noted by Lowell at 303 m over the base of the Triassic (within the Sticky Keep Formation) is more likely to represent this unit than the calcarenite lower in the section at the top of the Vardebukta Formation. This interpretation will be investigated as part of our programme in Bellsund in 1978; meanwhile we suggest that the base of the Sticky Keep Formation be recognised in Sørkapplandet and Hornsund as defined by Buchan et al. (1965) in Isfjorden. The Retzia Limestone and its equivalents should however be placed within this formation and not, as suggested previously, at the top of the Vardebukta Formation. We provisionally rename Birkenmayer's unit

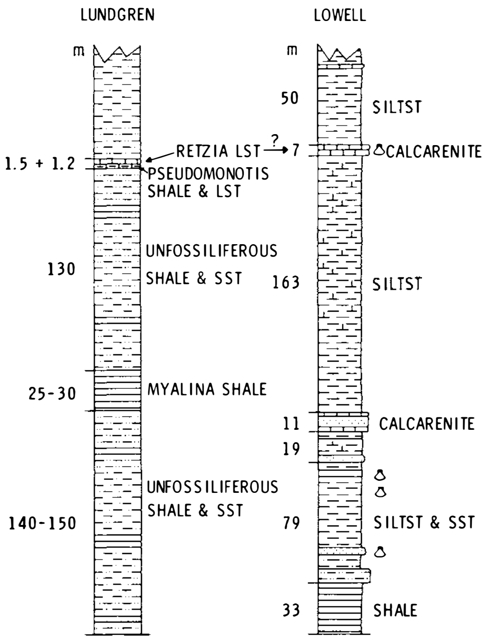


Fig. 3. *Lower Triassic sections from Bellsund presented by Lundgren (1887) and Lowell in Buchan et al. (1965). These sections suggest that the «Retzia Limestone» should be placed within the Sticky Keep Formation.*

as the «Skilisen Limestone Bed» and apply this term to the limestone which occurs at Bjørnskardet in Sørkapplandet.

This unit consists of a thickly bedded crinoidal biosparite which thins rapidly laterally, and only thin equivalents are seen at Austjøkeltinden. Brachiopods (*?Hustediella nathorsti, ?Sulcatinella wittenburgi* and *Orbiculoides* sp.) and a few bivalves (*Aviculopecten* sp.) have been found. Body fossils are otherwise rare in the Sticky Keep Formation in most localities, but evidence for the age of the unit is provided by exposures on Kistefjellet. The formation here consists of 1 large and 3 small coarsening upwards rhythms. The lowermost shales were noted by Sokolov and Pčelina (1967) as containing *Arctoceras* cf. *oebergi* and *Posidonia* cf. *mimer*. These fossils, and our finds of *Arctoprionites* cf. *nodosus* are typical for the Smithian stage. The uppermost rhythm contains the brachiopod *Punctospirella stacheyi,* a species considered by Dagys (1974) to be typical for the Lower Anisian.

Botneheia Formation

Complete sections through the unit were logged at Treskelen (108 m), Smalegga (87 m), Austjøkeltinden (106 m) and Kistefjellet (79 m). A partial section was also studied on Sørkappøya. It should be noted that this unit shows less variation in thickness along the studied traverse than any other Triassic formation.

The formation consists essentially of a single large scale coarsening upwards sequence. Basal dark shales with phosphatic nodules and interbeds (the Passhatten Member of Birkenmajer 1977) rest with a sharp contact upon the uppermost massive siltstones and sandstones of the Sticky Keep Formation. The shales grade up through increasingly common siltstone interbeds into massive cliff forming siltstones with both carbonate and silica cements (the Somovbreen Member of Birkenmajer op. cit.). This major sequence is overlain by two to three small shale-siltstone rhythms in all sections studied. These are lithologically similar to the underlying beds and differ markedly from the overlying shales and sandstones of the Tschermakfjellet and De Geerdalen Formations. They are therefore included in the upper part of the Somovbreen Member.

Regional variation from Treskelen to Sørkappøya is marked by the increasing proportion of siltstone in the formation; this is accompanied by a progressive increase in grain size, siltstones grading southwards into very fine to fine sandstones. The uppermost small rhythms are also more prominent in the Kistefjellet area than elsewhere.

Both vertebrate bones and ammonites are occasionally seen in the formation; an interesting find on Kistefjellet of *Nathorstites mcconnelli* in the middle of the Somovbreen Member suggests an Upper Ladinian age for this unit (i.e. somewhat younger than otherwise suggested for the Botneheia Formation elsewhere on Svalbard, but clearly in agreement with the section of Sokolov and Pčelina 1967). The most notable feature of the Somovbreen Member is however the striking succession of trace fossil associations which can be traced throughout Sørkapplandet. The lower parts of the member are intensely bioturbated by *Chondrites,* and *Scolicia*-like grazing trails are common (the latter were first figured by Frebold 1930 as «wurmähnlichen Abdrücken» from exposures in Stormbukta). These two ichnogenera are supplemented upwards by horizontal U-tubes with parallel sides up to 55 cm long. Spreiten are seen occasionally and suggest that these traces represent a variety of *Rhizocorallium* (these were probably identified by Birkenmajer 1977 as *Helminthoidea*). The uppermost siltstones contain both *Scolicia*-like trails and vertical to oblique *Skolithos*-like tunnel systems. The systematics and environmental significance of this ichnofauna will be described in detail in a subsequent paper by Mørk, but the upwards replacement of pascichnid and fodinichnid feeding traces by protective domichnid burrows should be noted; this reflects increasing energy levels accompanying the deposition of this coarsening upwards sequence.

Tschermakfjellet Formation

Although beds assignable to this unit can be identified throughout Sørkapplandet, its formational status is somewhat dubious in this area. The unit is 27 to 31 m thick in the Treskelen area, and it thins southwards (Austjøkeltinden 18 m, Kistefjellet 12 m). Micaceous silty shales contrast with the underlying shale component of the Botneheia Formation, and the lower boundary is clearly defined. The upper boundary is arbitrarily taken at the first prominent sandstones of the De Geerdalen Formation: these are usually thickly bedded; they only rarely have markedly erosive bases, although mudflakes are common within their lower parts. Occasionally however (e.g. in the Treskelen area) the junction is marked by the appearance of a 10 to 20 m thick sequence of thickly bedded sandstones with a clearly erosive base.

Birkenmajer (1977) interpreted this boundary as representing a hiatus, and suggested that «erosion . . . caused by uplift of the area and regression of the sea» was probably responsible for the great lateral variation in the thickness of his Tschermakfjellet Member north of Hornsund. We would rather suggest that the Tschermakfjellet Formation represents a prodelta shale environment. Here, as elsewhere in Svalbard, deltaic progradation is responsible for the coarsening upwards sequence into the sandstones of the De Geerdalen Formation. The erosively based sandstone unit seen in the Treskelen area represents the natural development of distributary channels in this environment and there is no evidence of any hiatus in the succession at this level. The variation in thickness of the Tschermakfjellet Formation north of Hornsund probably reflects the persistence of clay deposition in areas between different distributary systems: it should be noted that the combined thickness of the Tschermakfjellet and De Geerdalen Formations varies in a constant pattern relative to the submerged margins of the Hornsund-Sørkapp High.

De Geerdalen Formation

Sections were logged at Hyrnefjellet (88 m), SE Treskelen (?112 m), Smalegga (42 m), Austjøkeltinden (70 m) and Kistefjellet (30 m). The formation is here recognised in the sense proposed by Worsley and Heintz (1977) and Edwards et al. (1978), and includes only the two lower informal units noted by Birkenmajer (1977) in the Hyrnefjellet and Treskelen areas (the uppermost of Birkenmajer's units is here assigned to the Wilhelmøya Formation).

The base of the unit has already been discussed under the previous formation. The formation generally consists of thickly bedded feldspathic sandstones and silty shales. Great lateral variation is seen in the development of the unit, the most sandy facies being seen in the Treskelen area and at Austjøkeltinden. Sandstones here often have erosive bases and mudflake conglomerates are common; some of the units on Austjøkeltinden show small fining-upwards rhythms; this is not seen in the major units on Treskelen — these are characterised by thin beds with marine trace fossils on their tops. Other sections show a more shaly development with occasional beds of cross-bedded or ripple laminated fine to medium-grained sandstone. In all localities plant remains are relatively common, but no coals have been seen; marine trace fossils and bivalves are restricted to rare thin horizons. In general terms this suggests the development of a subaqueous delta platform, with distributary channels developed in the Treskelen area. Thin marine horizons may represent transgressive facies associated with abandonment of the channels. The lack of coals or root zones suggests subaqueous environments, in contrast to the development of the formation in many localities in eastern Svalbard.

We have as yet no new evidence for the age of the unit; palynological preparations of material collected by us has yielded only black unidentifiable organic debris (Bjærke pers. comm.) and bivalves collected are too poorly preserved to be identified with certainty.

Wilhelmøya Formation

Although thin, the unit can be distinguished throughout the study area, and we do not agree with Birkenmajer (1975: 36) that — «no deposits comparable with the Wilhelmøya Formation. . .» occur in SW Torell Land; in contrast to underlying formations a slight thickening is seen along the traverse from Hornsund to Kistefjellet (Treskelen area 21 m, Smalegga and Austjøkeltinden 28 m, Kistefjellet 37 m). The base is usually marked by thin conglomerates with both phosphate, chert and quartzite clasts (the basal conglomerate seen on Kistefjellet is much thicker and more pronounced than similar horizons elsewhere). The upper contact is taken at the junction between the Brentskardhaugen Bed and the overlying dark shales of the Janusfjellet Formation.

The formation is characterised by medium to thickly bedded quartzites; grains were originally well rounded and sorted but original textures are obscured by interlocking silica overgrowths producing a highly compact rock. Marine trace fossils (especially *Diplocraterion*, *Skolithos* and *Rhizocorallium*) are common, together with bivalves and fossil wood at some horizones. Several nodular and conglomeratic phosphate horizons are seen within the unit at Kistefjellet. The marked change in lithology and fossil content at the base of the unit indicates a transgressive event which drowned the deltaic environments suggested by rocks of the De Geerdalen Formation; the development of the formation in this area suggests high energy marginal marine environments.

The age of the unit in the Sørkapplandet area is not known. Thicker transgressive sequences described from eastern Svalbard (Worsley 1973; Worsley and Heintz 1977; Edwards et al. 1978) are Rhaetoliassic in age, and thin representatives in Isfjorden (Bjærke and Dypvik 1977) indicate both Rhaetian and Pliensbachian transgressions in that area.

The development in Sørkapplandet is lithologically most akin to the Liassic Tumlingodden Member of the Wilhelmøya Formation in its type area, but dating of the Sørkapplandet unit must await new palaeontological finds.

Information given by Rozycki (1959) suggests that the Wilhelmøya Formation is also found north of Hornsund. Rozycki noted a conglomerate at Passhatten 44 m below the dark shales of the Janusfjellet Formation, and called this the basal conglomerate of the Rhaetian. The situation in Bellsund is difficult to interpret from published descriptions and relevant outcrops will be examined in 1978.

Discussion

A comparison of the lithostratigraphical scheme proposed by Birkenmajer (1977) and that adopted in this work is shown in Fig. 4.

The Drevbreen Formation as proposed by Birkenmajer comprises the Passhatten, Somovbreen, and the Tschermakfjellet Members. The unit would thus correspond to our combined Botneheia and Tschermakfjellet Formations.

The recognition of a Drevbreen Formation hinges in our opinion upon two points: first that the Botneheia Formation's equivalent in Hornsund is characterised by a coarsening upwards sequence which is not seen in the type area of the formation, and second that the Tschermakfjellet Formation's equivalent in the Hornsund area ought to be included with underlying beds because of the regional hiatus suggested by Birkenmajer at the base of the De Geerdalen Formation. In the first case we should remember that Buchan et al. (1965) noted the existence of a «hard siltstone horizon» at the top of the Botneheia Formation, forming a «thick marker bed in the west-

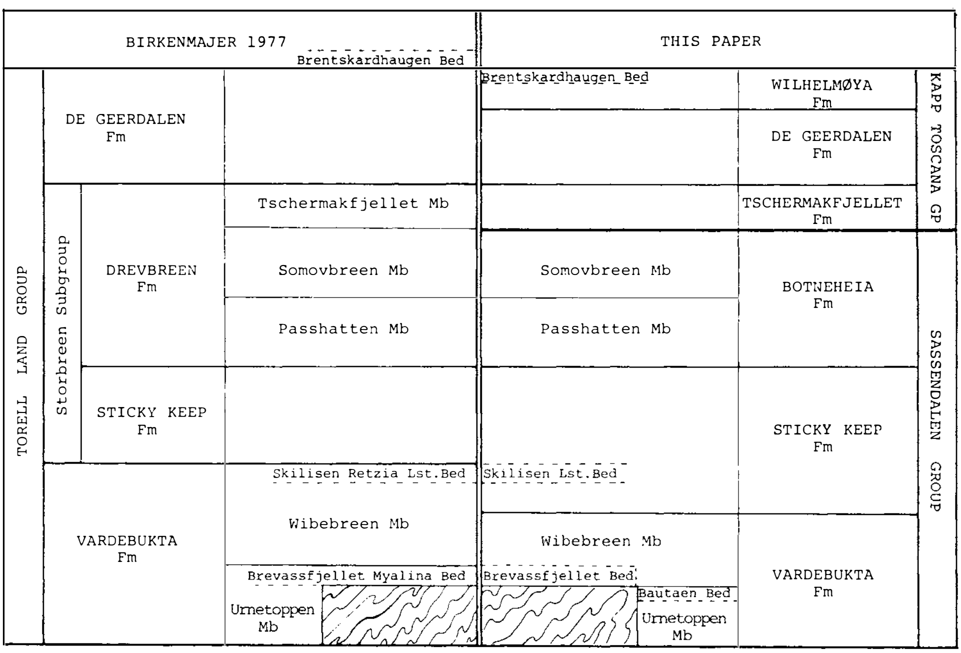


Fig. 4. *A comparison of the lithostratigraphical scheme for Hornsund presented by Birkenmajer (1977) and that adopted in this paper. Lateral variation in the development of the Vardebukta Formation between localities on and marginal to the Hornsund-Sørkapp High is shown schematically.*

ern outcrop belt.» This unit is approximately 30 m thick both at Festningen and in Bellsund. The greater thickness of the upper siltstones in Sørkapplandet certainly merits the introduction of the new Somovbreen Member, and the unit may be extended northwards to include Bellsund and Festningen. A new formational unit is, however, not justified, especially as in Hornsund and all other areas the characteristic dark phosphatic shales of the Botneheia Formation are well developed below the siltstones of the Somovbreen Member. We have already presented our interpretation of the «regional hiatus» proposed by Birkenmajer at the base of the De Geerdalen Formation; the close genetic relationship between the Tschermakfjellet and De Geerdalen Formations is a decisive factor which militates against acceptance of the Drevbreen Formation. The somewhat arbitrary status of the Tschermakfjellet Formation is a problem many places on Svalbard, but (as implied by Buchan et al. 1965: 24) problems arise because of the difficulty often experienced in distinguishing this unit from the De Geerdalen Formation, and not in defining a lower contact between these units and the Botneheia Formation.

A reassessment of the status of the Tschermakfjellet Formation is needed, but it is difficult to see how a grouping of this unit with the Botneheia Formation can help elucidate stratigraphical relationships in this part of the succession. Birkenmajer's designation of the Storbreen Subgroup also reflects earlier difficulties experienced in the identification of the Tschermakfjellet Member, the composition of his proposed subgroup conforming to that of the «Kongressfjellet Formation» originally used informally by Norsk Polarinstitutt in the preparation of the Adventdalen geological mapsheet. We cannot agree that the Storbreen Subgroup has «a practical application in the mapping of strongly tectonically disturbed areas» (Birkenmajer 1977: 10) and therefore suggest rejection of this unit. It should be noted that both the bottom and top of such a unit would represent horizons which are often difficult to map, while the most easily mappable horizons within the entire Triassic succession of the area would be included *within* this unit (i.e. base and top of the Botneheia Formation).

The Torell Land Group as envisaged by Birkenmajer would encompass the whole Triassic succession of the Hornsund area, thus corresponding to the combined Sassendalen and Kapp Toscana Groups of other areas. The latter division has been both useful and practical in distinguishing two sequences deposited in broadly different regimes (Figs. 1 and 5). We consider this situation also holds in Hornsund and Sørkapplandet, and that the designation of a new group implies greater differences in lithology between these and other areas than in fact exist. We would therefore advocate the rejection of the term «Torell Land Group».

Information which has accumulated in recent years permits better understanding of the depositional patterns seen in the Triassic succession of Svalbard. Compilations of thickness variations in the Sassendalen and Kapp Toscana Groups (Fig. 5) are based on literature reviews, on our own

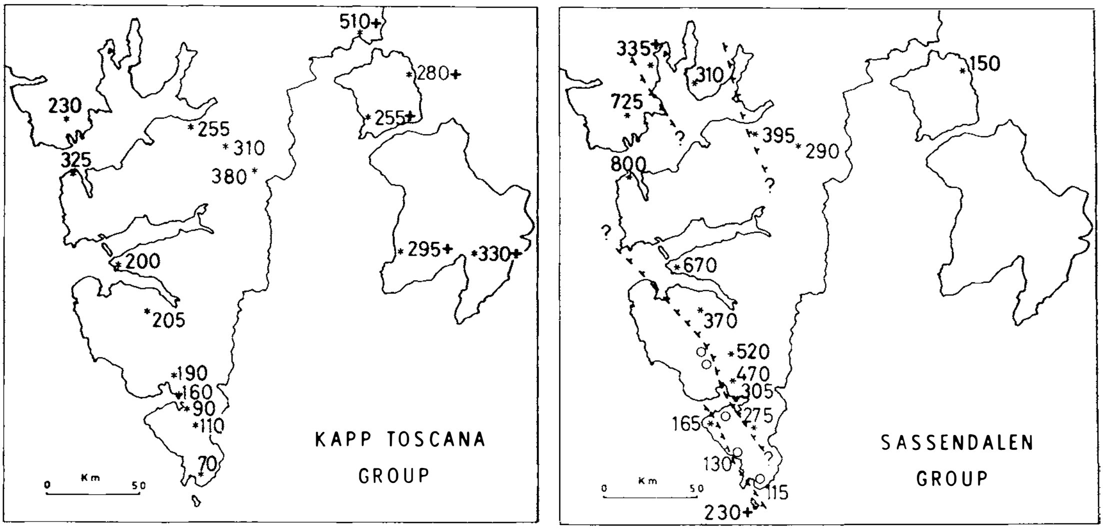


Fig. 5. *Known thicknesses of the Sassendalen and Kapp Toscana Groups in central and southern Spitsbergen. Localities marked by circles show known occurrences of Triassic basal conglomerates resting directly on the Hecla Hoek. Information from western Sørkapplandet (165 m & 130 m of Sassendalen Group) is supplied by E. Nysæther (pers. comm.). Other data are based on published sections and on our own work.*

work and on unpublished information from Nysæther (pers. comm.) The maps clearly show the continued existence of the Hornsund-Sørkapp High (here postulated as extending northwestwards through Wedel Jarlsberg Land) as a positive structural feature during deposition of the Sassendalen Group. Attenuated sequences are also seen on the Nordfjorden block in Dicksonland, and this structure may continue southwards in the subsurface of the main Tertiary basin of central Spitsbergen. Greatest thicknesses of the Sassendalen Group occur in the basin between the two blocks; the western part of this basin shows sequences with appreciable proportions of siltstones and fine sandstones, but these disappear eastwards, and thin sequences in eastern Svalbard are dominated by shales. Sedimentological studies now in progress should provide a more detailed analysis of the palaeogeography of the basin; these already confirm the western land area postulated by Frebold (1939): sandstones of the Siksaken Member (Vardebukta Formation) at Festningen, for example, constitute an offshore bar and lagoonal sequence, and Nysæther (pers. comm.) has identified deltaic coastal environments in the Lower Triassic of western Sørkapplandet.

The large-scale coarsening upwards rhythms seen in the Sticky Keep and Botneheia Formations of Sørkapplandet and Torell Land are thought to represent shoal sequences deposited in offshore environments. Fine grain size, sedimentary structures and trace fossils show no evidence of high energy or emergent conditions in the upper part of these rhythms (in contrast to the large-scale rhythms described by Edwards 1976 in the Rurikfjellet Member of Sørkapplandet).

The shoals evidently built up to wave base and then grew by lateral accretion, individual units extending over large areas of southern Spitsbergen. The relatively sharp tops of individual units may represent regional transgressive episodes — the base of the Botneheia Formation may represent such an event and this probably has important chronostratigraphical implications.

The Kapp Toscana Group shows a strikingly different depositional pattern, greatest thicknesses being seen in eastern Svalbard. Most workers have suggested an east to north-east source for the sandstones of the De Geerdalen Formation, and delta systems prograded westwards. In southern Spitsbergen the influence of the Sørkapp-Hornsund High is still apparent. A coherent synthesis of this group's development must, however, await comparative studies in Bellsund which are planned for 1978. The existence of units equivalent to the Wilhelmøya Formation of eastern Svalbard in localities both north and south of Hornsund should, however, be noted.

Acknowledgements

This work was made possible by extensive logistical support from Statoil, and we thank Jacob Bleie for inviting our group to participate in Statoil's expedition to Hornsund in 1977. Our work is a contribution to a cooperative research programme involving staff and students at the Paleontologisk Museum and Institutt for Geologi, University of Oslo. The programme and its sub-projects are financed from several sources and grants from NAVF (The Norwegian Research Council for Science and the Humanities, grant D.40.38-8) and NTNF (The Norwegian Council for Scientific and Industrial Research, grant B1810.6790) and support from Norsk Polarinstitutt are gratefully acknowledged.

Cheerful and enthusiastic field assistance given by Torleiv Agdestein and Terje Hellem in the inhospitable climate of Sørkapplandet was invaluable and the helicopter crews of A/S Lufttransport are congratulated for always managing to find the field party (however thick the fog). Ammonites were identified by Dr. J. Nagy and information on the Kistefjellet and western Sørkapplandet areas was given by Dr. M.B. Edwards, cand. real. A. Elverhøi, and Dr. E. Nysæther.

References

BIRKENMAJER, K., 1964: Devonian, Carboniferous and Permian formations of Hornsund, Vestspitsbergen. *Studia Geol. Polon.* 11: 47—123.

— 1972: Tertiary history of Spitsbergen and continental drift. *Acta Geol. Polon.* 22: 193—218.

— 1975: Jurassic and Lower Cretaceous sedimentary formations of SW Torell Land, Spitsbergen. *Studia Geol. Polon.* 44: 7—43.

— 1977: Triassic sedimentary formations of the Hornsund area, Spitsbergen. *Studia Geol. Polon.* 51: 7—74.

BIRKENMAJER, K. and J. TRAMMER, 1975: Lower Triassic conodonts from Hornsund, south Spitsbergen. *Acta Geol. Polon.* 25: 299—308.

BJÆRKE, T., 1977: Mesozoic palynology of Svalbard II. Palynomorphs from the Mesozoic sequence of Kong Karls Land. *Norsk Polarinst. Årbok* 1976: 83—119.

BJÆRKE, T. and H. DYPVIK, 1977: Sedimentological and palynological studies of Upper Triassic — Lower Jurassic sediments in Sassenfjorden, Spitsbergen. *Norsk Polarinst. Årbok* 1976: 131—150.

BJÆRKE, T. and S. B. MANUM, 1977: Mesozoic palynology of Svalbard I. The Rhaetian of Hopen, with a preliminary report on the Rhaetian and Jurassic of Kong Karls Land. *Norsk Polarinst. Skrifter* nr. 165.

BUCHAN, S. H., A. CHALLINOR, W. B. HARLAND and J. R. PARKER, 1965: The Triassic Stratigraphy of Svalbard. *Norsk Polarinst. Skrifter* nr. 135.

CUTBILL, J. L. and A. CHALLINOR, 1965: Revision of the Stratigraphical Scheme for the Carboniferous and Permian Rocks of Spitsbergen and Bjørnøya. *Geol. Mag.* 102: 418—439.

DAGYS, A. S., 1974: *Triasovije brahkiopody* (morfologija, sistema, fylogenija, stratigraficekoe, znacenie i biogeografija). 386 pp, Nauka, Novosibirsk.

EDWARDS, M. B., 1976: Depositional environments in Lower Cretaceous regressive sediments, Kikutodden, Sørkapp Land, Svalbard. *Norsk Polarinst. Årbok* 1974: 35—50.

EDWARDS, M. B., T. BJÆRKE, J. NAGY, T. S. WINSNES and D. WORSLEY, 1978: The Mesozoic stratigraphy of eastern Svalbard, a discussion. *Geol. Mag.* (in press).

FLOOD, B., J. NAGY and T. S. WINSNES, 1971a: The Triassic succession of Barentsøya, Edgeøya and Hopen (Svalbard). *Norsk Polarinst. Medd.* Nr. 100.

FLOOD, B., J. NAGY and T. S. WINSNES, 1971b: Geological Map of Svalbard 1 : 500.000. Sheet 1G, Spitsbergen Southern Part. *Norsk Polarinst. Skrifter* Nr. 154A.

FREBOLD, H., 1930: Verbreitung und Ausbilding des Mesozoikums in Spitzbergen. *Skr. Svalb. og Ishavet.* Nr. 31.

— 1939: Das Festungsprofil auf Spitzbergen V: Stratigraphie und Invertebraten — fauna der älteren Eotrias. *Skr. Svalb. og Ishavet* Nr. 77.

HARLAND, W. B., J. L. CUTBILL, P. F. FRIEND, D. J. GOBBETT, D. W. HOLLIDAY, P. I. MATON, J. R. PARKER, and R. H. WALLIS, 1974: The Billefjorden Fault Zone, Spitsbergen. *Norsk Polarinst. Skrifter* nr. 161.

HELLEM, T. and D. WORSLEY, 1978: An outcrop of the Kapp Starostin Formation at Austjøkeltinden, Sørkapplandet. *Norsk Polarinst. Årbok* 1977: 340—342.

KORČINSKAJA, M. V., 1972: Biostratigraphy of Triassic deposits of Svalbard. *Bull. Canadian Petrol Geology* 20: 742—749.

LUNDGREN, B., 1887: Anmärkningar om Permfossil från Spetsbergen. *Bih. Svensk. Vetensk.Akad. Aandl.* 13: 1—26.

ROZYCKI, S. Z., 1959: Geology of the north-western part of Torell Land, Vestspitsbergen. *Studia Geol. Polon* 2: 1—98.

SMITH, D. G., W. B. HARLAND, N. F. HUGHES, and C. A. G. PICKTON, 1976: The geology of Kong Karls Land, Svalbard. *Geol. Mag.* 113: 193—232.

SOKOLOV, V. N. and T. M. PCELINA, 1967: O niznem i srednem triase Zemli Serkap o Zapadnom Spicbergene. *Doklady Akademii nauk SSSR* 176 (6): 1374—1377.

TOZER, E. T. and J. R. PARKER, 1968: Notes on the Triassic biostratigraphy of Svalbard. *Geol. Mag.* 105: 526—542.

WORSLEY, D., 1973: The Wilhelmøya Formation — a new lithostratigraphical unit from the Mesozoic of eastern Svalbard. *Norsk Polarinst. Årbok* 1971: 7—16.

WORSLEY, D. and N. HEINTZ, 1977: The stratigraphical significance of a marine vertebrate fauna of Rhaetian age, Kong Karls Land. *Norsk Polarinst. Årbok* 1976: 69—81.

Observations on the stratigraphy and structure of the inner Hornsund area

By ATLE MØRK[1]

Abstract

A reinterpretation of the stratigraphy and structural setting of Mesozoic strata in the inner part of Hornsund is presented. Exposures on Strykejernet and Hornholmen, previously thought to be of Triassic and Jurassic age, are assigned to the Cretaceous. On Strykejernet, the Rurikfjellet Member consists of four coarsening upwards sequences. The Festningen Member is represented by a 40 m thick quartzitic sandstone in several fining upwards sequences. The Glitrefjellet Member, about 50 m thick, has coal, root zones and marine trace fossils indicating deposition in marginal marine to deltaic environments.

Exposures of the Kapp Toscana Group on the southeast coast of Treskelen, and overturned Triassic beds on Selodden and Condevintoppen suggest a new interpretation of the area's structure: large overturned fold terminates in a thrusted contact with rocks of the Adventdalen Group in eastern slope of Hyrnefjellet.

Introduction

A field party from the University of Oslo participated in the 1977 expedition to Hornsund organized by STATOIL. The party's main objective was the study of Permian and Triassic stratigraphy in the Hornsund and Sørkapplandet areas. Investigations of several exposures in inner Hornsund revealed that strata previously thought to be of Triassic age should be assigned to the Janusfjellet and Helvetiafjellet Formations. Rapid retreat of the glaciers in this area in recent years has produced important new exposures which facilitate a better structural interpretation of this sector of the Tertiary fold belt in the Hornsund area.

Triassic and Jurassic exposures in the Treskelen, Hyrnefjellet and Condevintoppen areas

Mapping in most of the Hyrnefjellet and Treskelen areas gave similar results to those of Birkenmajer (1964, 1977). However exposures through different parts of the Kapp Toscana Group and Agardhfjellet Member were

[1] Paleontologisk Museum, Sarsgt. 1, Oslo 5.

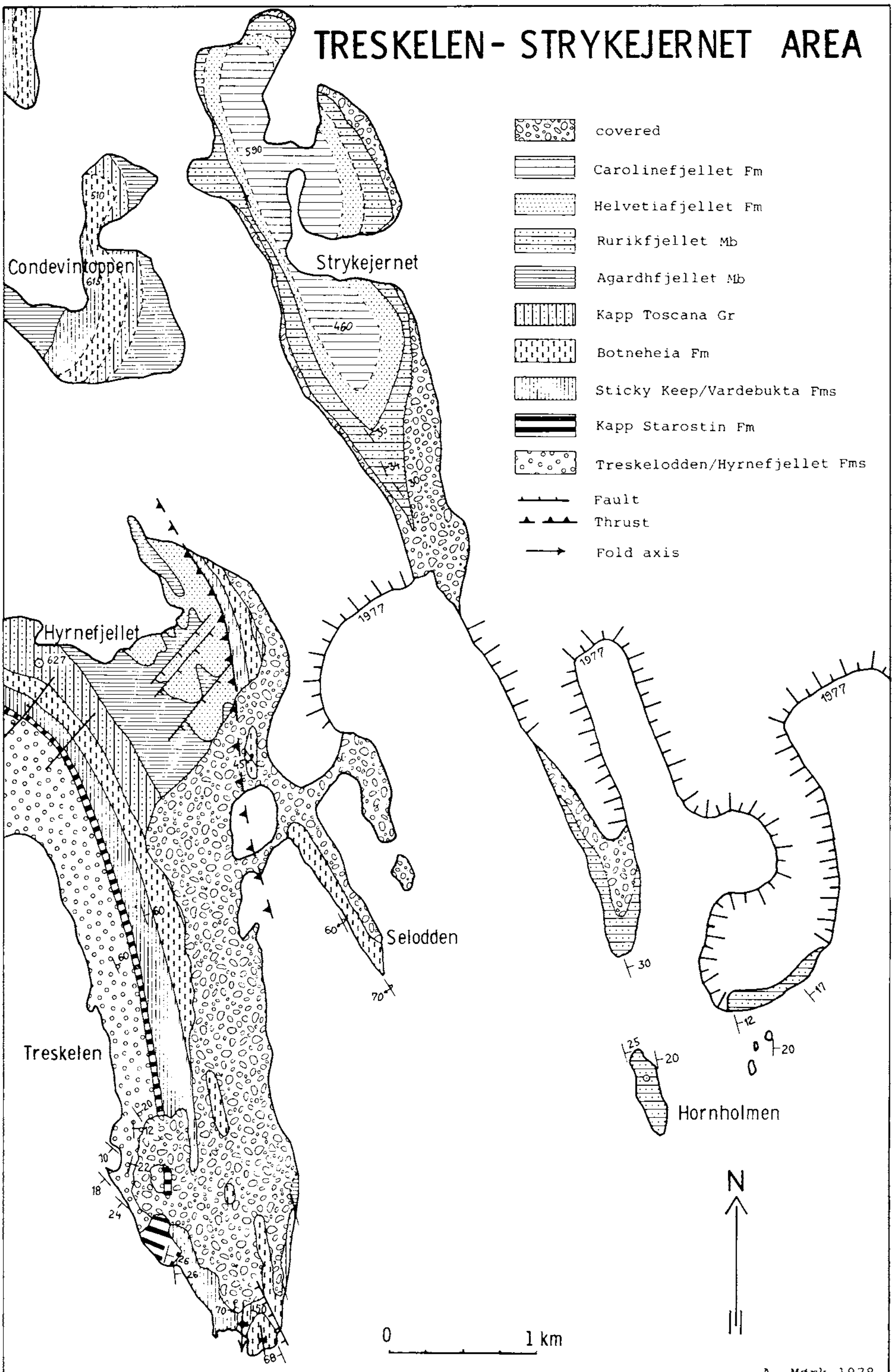


Fig. 1. *Geological map. Details on Hyrnefjellet and western part of Treskelen are taken from Birkenmajer (1964, 1977).*

found on the southeastern coast of Treskelen (exposures which were assigned to the Sticky Keep Formation by Birkenmajer 1977).

The Brentskardhaugen Bed and overlying dark shales of the Janusfjellet Formation could be seen here at extreme low tide, the shale apparently dipping steeply to the east.

Selodden, also assigned to the Sticky Keep Formation by Birkenmajer (1977) comprises overturned beds of the Botneheia Formation.

Inverted Triassic beds, E-Hyrnefjellet — Condevintoppen

As indicated by Birkenmajer (1964, 1975, 1977) Lower Triassic beds are «underlain» by Middle Triassic beds on the eastern slopes of Hyrnefjellet (below the thrust zone). Trace fossils on Selodden also show that beds assigned to the Middle Triassic Botneheia Formation occur in an inverted position.

Condevintoppen, north of Hyrnefjellet, was not studied on the ground, but observations from nearby nunataks were complemented by helicopter reconnaisance flights. In contrast to Birkenmajer (1975: Fig 12) I believe that Triassic exposures here are also overturned (see Fig. 5). Lowermost exposures on the northeastern foot of the mountain show black shales of the Janusfjellet Formation. These are overlain higher on the mountain slope by a cliff forming unit representing sandstones of the Kapp Toscana Group. The slope upwards shows a perfect inverted sequence which can be correlated with Triassic sections from Treskelen by Birkenmajer (1977) and Worsley & Mørk (1978).

Thus the thrust indicated on the eastern slope of Hyrnefjellet (Fig. 6) evidently continues southwards between Treskelen and Selodden, and northwards through the western part of Condevintoppen.

Adventdalen group

Exposures on Strykejernet, earlier mapped as Triassic and Lower Jurassic, form a continuous section from the Rurikfjellet Member to the Carolinefjellet Formation (Fig. 2). Exposures of the Rurikfjellet Member are also seen on Hornholmen, an islet covered by ice until recently, and on newly uncovered exposures immediately north of Hornholmen; these show an excellent section (Fig. 3) through the lower rhythm exposed on Strykejernet.

Rurikfjellet Member

About 115 m of this member is exposed on Strykejernet; the unit consists of four coarsening upward sequences; the lowermost sequence is well exposed at Hornholmen and was therefore logged in detail (Fig. 3). This detailed section shows several smaller rhythms within the lowermost major coarsening upwards sequence. The lower parts show a striking bimodal lithology with medium size quartz grains floating in a shale matrix; spherical concretions are common. Bioturbation is common throughout the section except in the sandstone with mud flake conglomerate seen between 60 and 65 m. Plant remains

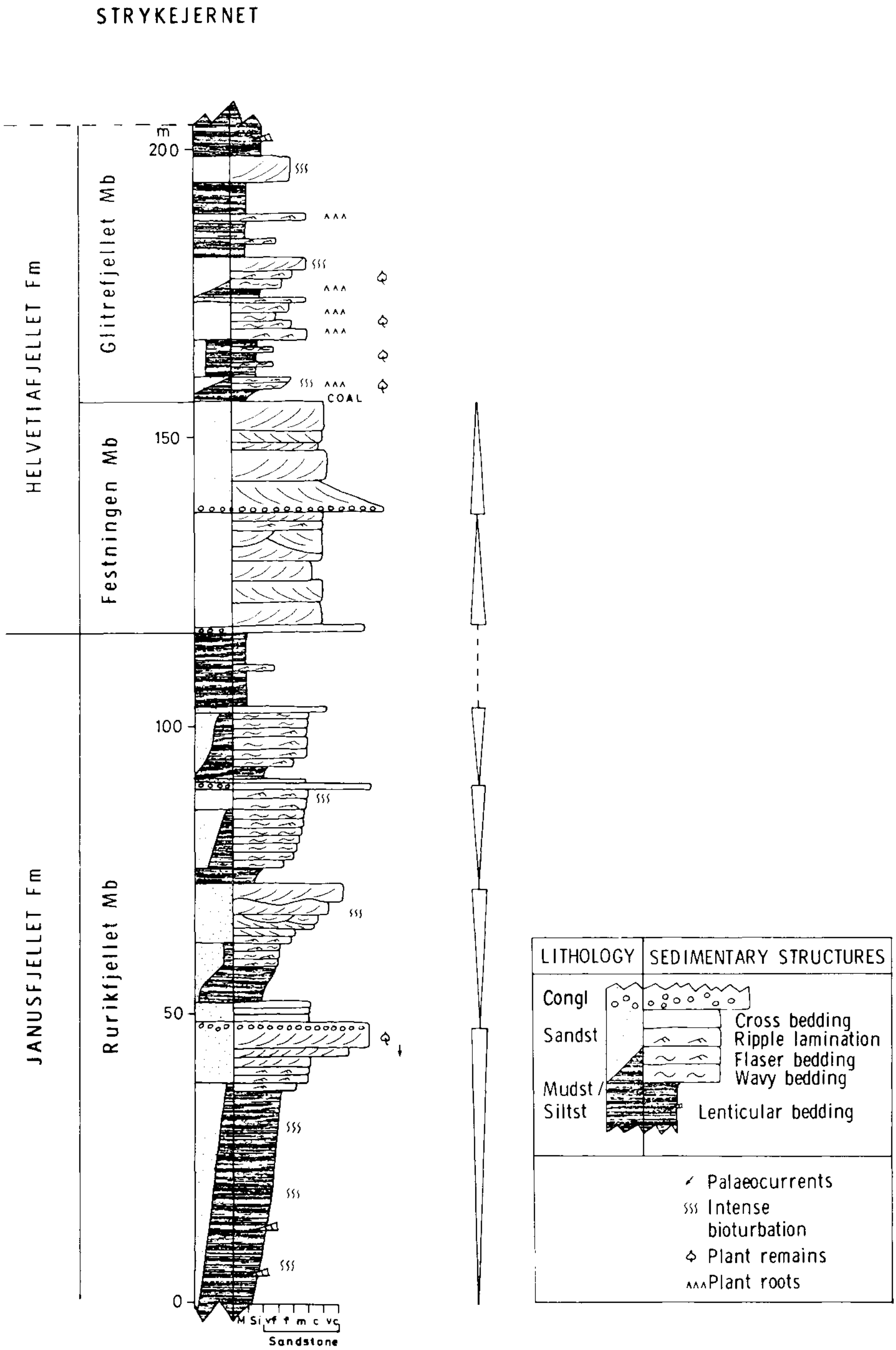


Fig. 2. *Simplified lithological and sedimentological section from the southern part of Strykejernet.*

are also common throughout the section and poorly preserved ammonites and belemnites are found in the upper part.

The three other coarsening upward sequences (on a scale of 10 to 20 metres) show wavy and flaser bedding in their lower parts, passing up into cross bedded sandstones.

The sandstones are orthoquartizitic and are mainly cemented by quartz overgrowths, although some calcite occurs as late pore infilling.

At Kikutodden (Sørkapplandet) Edwards (1976) described similar coarsening upward sequences in the Rurikfjellet Member. His lower sequence, coarsening upwards from mudstone to sandstone, was interpreted as representing a transition from offshore to nearshore environments, while his sandstones in the upper part of the sequence represent shallow marine coastal environments.

The highly bioturbated mudstones were probably deposited in a low energy offshore environment. Bioturbation has obliterated most primary sedimentary structures and lenticular bedding is only seen occasionally. These pass up into well-sorted, cross-bedded sandstones which may represent offshore sands possibly offshore bars; the non-bioturbated sandstone with mud flakes seen at Hornholmen is thought to represent such a sand body.

Helvetiafjellet Formation

Exposures on Strykejernet clearly show a division between the lower quartzitic Festningen Member, and the upper interbedded sandstones and shales of the Glitrefjellet Member. This formation was investigated in more detail by J. Gjelberg and G. Haarr (University of Bergen), as a part of Haarr's field work for his Cand. real thesis.

The Festningen Member is about 40 m thick and consists of cross bedded units, starting with conglomerate and fining upwards. Cross bedding indicates transport towards the southeast. The sandstones are quartzitic with some clastic chert grains; cementation by quartz overgrowth and pressure solution is seen. This competent sand unit forms a cliff around the whole of Strykejernet and its thickness seems to be fairly constant. It displays a gently synclinal structure with a vertical northwestern limb.

The Glitrefjellet Member is about 50 m thick, but the transition to the overlying Carolinefjellet Formation is mostly covered by scree. This member with interbedded sandstones and shales contains some coal in the lower part and dense root zones are common throughout the whole member. The shale contains flaser and wavy bedded sandstones. Some beds show marine trace fossils. The sandstone contains some feldspar and mica, and are mostly cemented by quartz overgrowth.

Orvin (1940) noted the presence of the Festningen Sandstone Member throughout Spitsbergen. Recent studies by Birkenmajer (1975), Edwards (1976), Smith and Pickton (1976), and Steel (1977), however, show great variation in thickness and facies even over short distances.

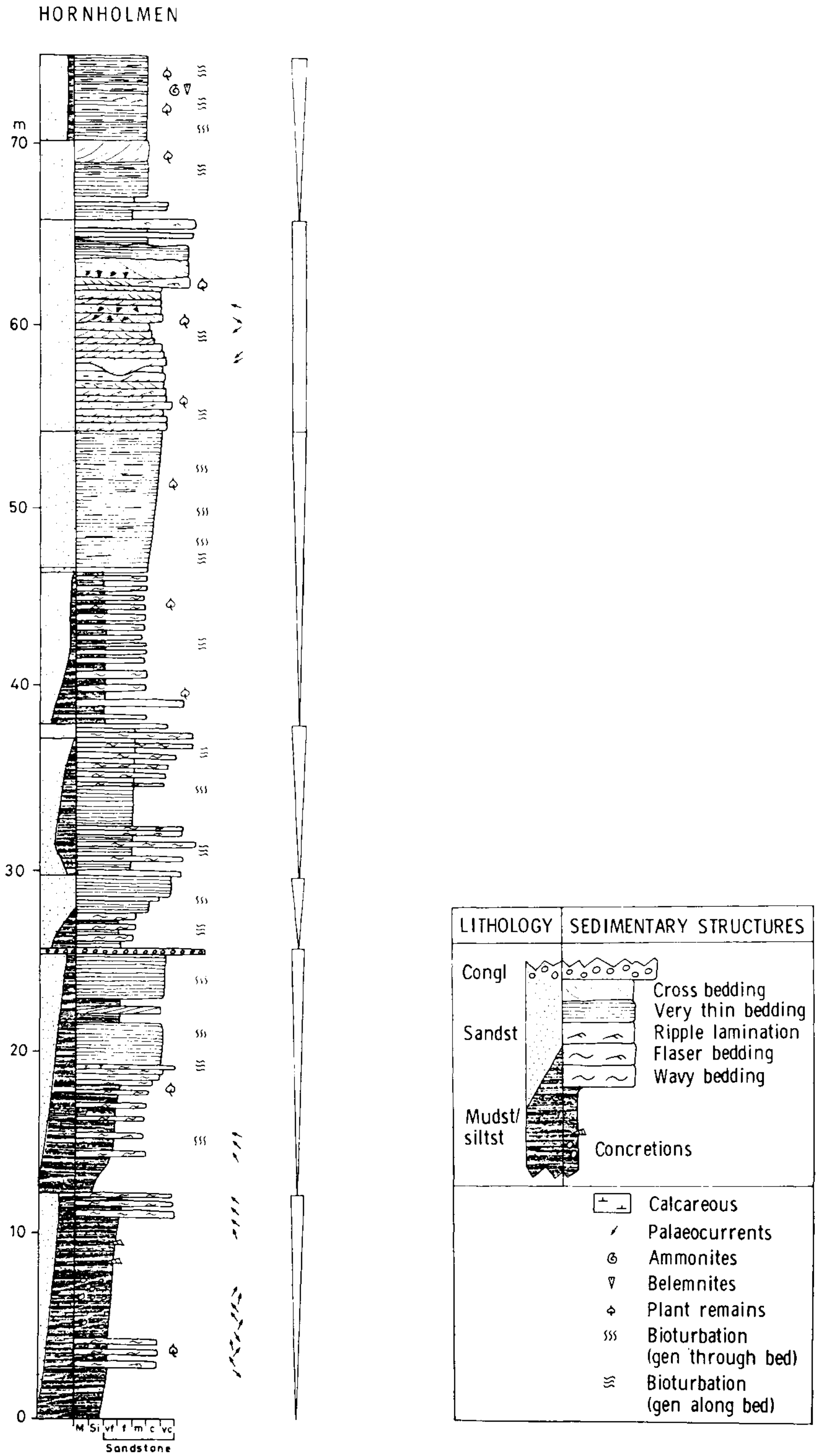


Fig. 3. *Sedimentological section across the northern part of Hornholmen.*

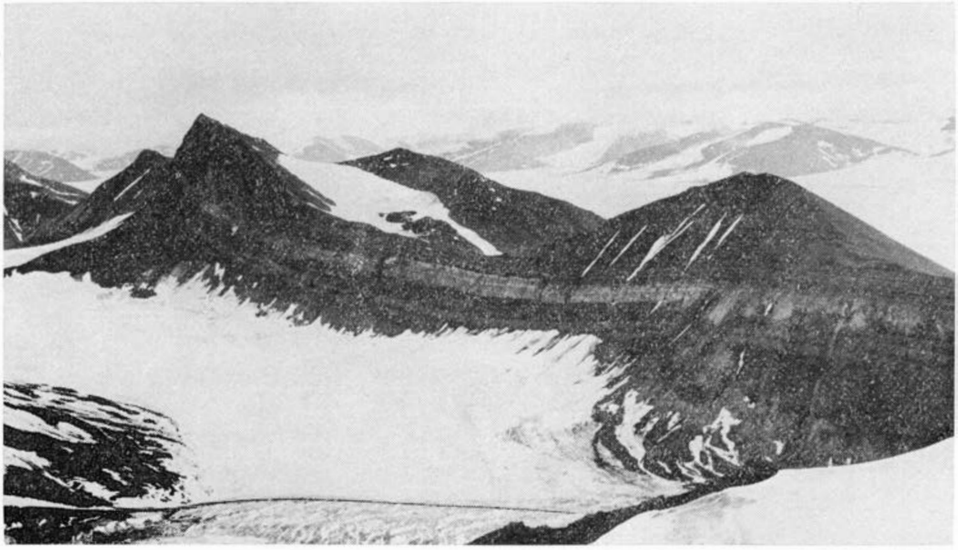


Fig. 4. *Western part of Strykejernet. The light coloured rock is the Festningen Sandstone Mb., overlain by Glitrefjellet Mb. The upper shaly part of the mountain is Carolinefjellet Fm. The Festningen Mb turns vertical at left side.*

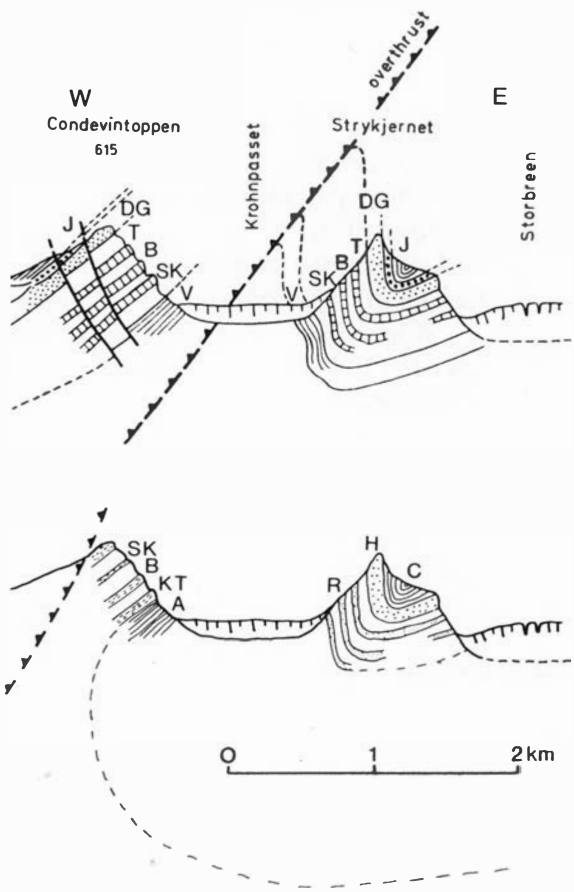


Fig. 5. *Cross-section through Condevintoppen and Strykejernet.*
Fig. 5 a: *after Birkenmajer (1975: Fig. 12), Fig. 5 b: the new interpretation of the same cross-section. V = Vardebukta Fm., SK = Sticky Keep Fm., B = Botneheia Fm., T = Tschermakfjellet Fm., DG = De Geerdalen Fm., J = Janusfjellet Fm. with Brentskardhaugen Bed at base, A = Agardhfjellet Mb., R = Rurikfjellet Mb., H = Helvetiafjellet Fm. and C = Condevintoppen Fm.*

Fig. 6. *Eastern slope of Hyrnefjellet. Pale sandstones from the Botneheia and Sticky Keep Fms. are overlain with thrust contact by Cretaceous sandstones.*

In the inner Isfjorden area, at Wimanfjellet and Carolinefjellet, an approximately 35 m thick coal bearing sandstone unit is interpreted as representing distributary channel sandstones, with interdistributary muds, siltstones and coals (Steel 1977).

On Strykejernet, the 40 m thick Festningen Member contains almost no fine grained material. The sandstone seems more similar to the alluvial channel system on Kikutodden described by Edwards (1976) rather than the deltaic coasts logged in Isfjorden (Steel 1977).

In the Glitrefjellet Member the associations of plant root zones, abundant plant remains, coals and marine trace fossils, indicate that these sediments were deposited in marginal marine, possibly deltaic costal environments. Edwards, on Kikutodden, did not report any marine influence in this member, but in the Isfjorden area Steel argued that the whole Helvetiafjellet had been deposited in a deltaic coast environment.

Carolinefjellet Formation

This formation is mostly covered by scree on the upper slopes of Strykejernet. It consists of a grey, more or less sandy shale with some sandstones in the lower part. In the upper part a couple of metres thick sandstone unit contains indeterminable bivalves. On the top of Strykejernet dark shale with some clay ironstone nodules are suggestive of the Innkjegla Member of Nagy (1970).

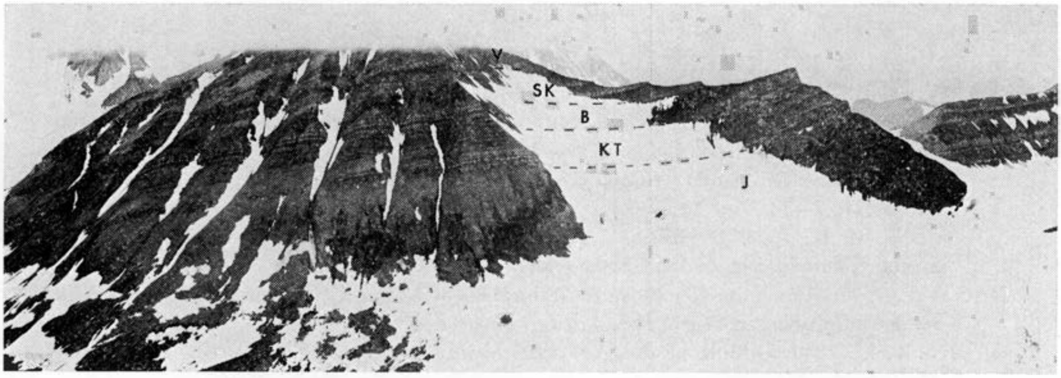


Fig. 7. *Condevintoppen and SW Firlingane (at right) photographed from Strykejernet. The Janusfjellet Fm (J) is overlain by Kapp Toscana Gp (KT), Botneheia Fm (B) and Sticky Keep Fm (SK). The Vardebukta Fm outcrops in the fog on the top of the mountain. The whole Triassic section is inverted as in lower part of Hyrnefjellet (Fig. 6).*

Structural pattern

Birkenmajer (1975: Fig. 12) presented an interpretative cross-section through Condevintoppen and Strykejernet. The new stratigraphical information presented here makes possible a better documentation of the Tertiary thrust contact in his area where both mountains comprise parts of the same fold (Fig. 5b).

Strykejernet comprises a NNW-SSE synclinal structure, with the western limb showing steep to vertical dips on the northwestern slopes of the mountain. Vertical beds of the Janusfjellet Formation have probably been eroded by the glaciers between Hyrnefjellet and Condevintoppen which comprise inverted beds underlying a major thrust.

Acknowledgements

This contribution represents a subproject of the University of Oslo programme: Paleontological and sedimentological investigations on Svalbard. The subproject is financed by the Norwegian Council for Scientific and Industrial Research (NTNF). The field investigations were possible by logistical support from Statoil. Collaboration in the field with T. Agdestein, J. Gjelberg, G. Haarr, T. Hellem and D. Worsley is gratefully acknowledged. Technical assistance from the photography and design staff and from Liza Kravik at Paleontologisk Museum, and help in preparing the manuscript from Dr. D. Worsley were invaluable.

References

BIRKENMAJER, K., 1964: Devonian, Carboniferous and Permian formations of Hornsund, Vestspitsbergen. *Studia Geol. Polon.* 11: 47—123.

— 1975: Jurassic and Lower Cretaceous sedimentary formations of SW Torell Land, Spitsbergen. *Studia Geol. Polon.* 44: 7—43.

— 1977: Triassic sedimentary formations of the Hornsund area, Spitsbergen. *Studia Geol. Polon.* 51: 7—74.

EDWARDS, M. B., 1976: Depositional environments in Lower Cretaceous regressive sediments, Kikutodden, Sørkapp Land, Svalbard. *Norsk Polarinstitutt Årbok* 1974: 35—50.

NAGY, J., 1970: Ammonite faunas and stratigraphy of Lower Cretaceous (Albian) rocks in southern Spitsbergen. *Norsk Polarinstitutt Skrifter* Nr. 152.

ORVIN, A. K., 1940: Outline of the geological history of Spitzbergen. *Norsk Polarinstitutt Skrifter* Nr. 78.

SMITH, D. G. & C. A. G. PICKTON, 1976: The Helvetiafjellet Formation (Cretaceous) of North East Nordenskiöld Land, Spitsbergen. In: Some coal-bearing strata in Svalbard. *Norsk Polarinstitutt Skrifter* Nr. 164.

STEEL, R. J., 1977: Observations on some Cretaceous and Tertiary sandstone bodies in Nordenskiöld Land, Svalbard. *Norsk Polarinstitutt Årbok* 1976: 43—68.

WORSLEY, D. & A. MØRK, 1978: The Triassic stratigraphy of southern Spitsbergen. *Norsk Polarinstitutt Årbok 1977: 43—60 (this volume).*

Facies analysis of the coal-bearing Vesalstranda Member (Upper Devonian) of Bjørnøya

By JOHN GJELBERG[1]

Abstract

One of the oldest known coal-bearing sequences, Vesalstranda Member (Upper Devonian) on Bjørnøya (Svalbard), has been re-examined and interpreted. Two main groups of facies are identified. One, a floodplain association, has sandstones, siltstones, and mudstones organized as fluvial channel, levee/channel fill and floodbasin deposits, often characterized by upwards fining sequences. The other, a probable lacustrine-deltaic association, has crevasse-channel and mouth bar sediments organized into upwards coarsening sequences indicative of delta lobe progradation into lakes or bays. A thinly developed, basal conglomerate may represent braided streams or (less likely) shoreline deposits.

An overall time trend of sedimentation from deltaic up to fluvial suggests a general progradational, basin-filling episode, which probably culminated in the coarse-grained, overlying Kapp Levin Member (low-sinuosity fluvial). Palaeocurrents indicate the basin-filling palaeoslope towards the north and northwest.

Introduction

Fig. 1 shows a generalised vertical log from the Upper Palaeozoic coal bearing succession of Bjørnøya, with an outline interpretation of depositional environments. This study deals with the lowermost member of Røedvika Formation, Vesalstranda Member, which contains the Misery coal series of Horn and Orvin (1928).

The Røedvika Formation of Bjørnøya, of probable Upper Devonian/ Lower Carboniferous age (Fig. 1), is well known because of its coal reserves. Its best and most accessible outcrop lies along the eastern and north eastern coast of the island. The Vesalstranda Member (Worsley and Edwards 1976) was studied during the summer of 1975 as a part of a more comprehensive sedimentological investigation of the supposed non-marine portion of the Lower Palaeozoic succession of Bjørnøya.

Although the Vesalstranda Member has been previously examined in detail by Horn and Orvin (1928), there has been only one earlier attempt at an interpretation of its stratification sequence, by Worsley and Edwards

[1] Geological Institute, University of Bergen, Norway.

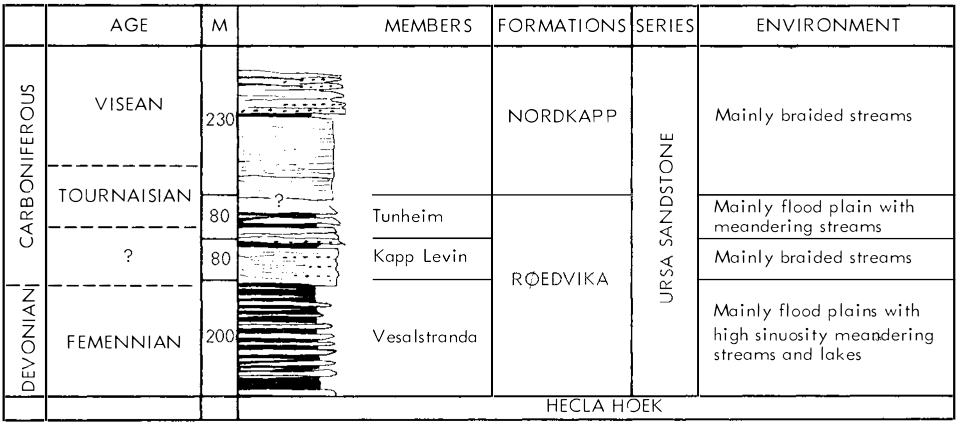


Fig. 1. *Generalized vertical log of the lower Palaeozoic coalbearing succession of Bjørnøya (Modified after Worsley and Edwards 1976).*

(1976). They have suggested, without showing measured logs, that this member consists of fining-upward cyclothems and have interpreted these in terms of alluvium deposited by meandering fluvial systems (Worsley and Edwards 1976, p.22). The present study shows that coarsening upward sequences also occur, and that lacustrine sub-environments were important.

Röedvika Formation general

Røedvika Formation, the lower coal and shale unit of the Ursa Sandstone of earlier investigators (Horn and Orvin 1928), was renamed by Cutbill and Challinor (1965). Because it is coalbearing it is an important portion of the non-marine Lower Palaeozoic succession of Bjørnøya, and this is obviously why these sediments have been examined closely by earlier investigators.

Along the east coast of Bjørnøya, the original bedding of the formation dips uniformly at 6—7 degrees towards the northeast and unconformably overlies the Hecla Hoek basement of Late Precambrium-Ordovcian age. Krasil'ščikov and Livšic (1974) suggest that the boundary between these two units is a thrust plane. The exposure along the boundary, however, is poor and brecciation or cleavage has not been seen by the writer. However, on the plateau south-west of Miseryfjellet and north of Ellasjøen, a very distinct basal conglomerate is exposed (Figs. 3, 5). This conglomerate is completely absent in Røedvika on the eastern slope of Miseryfjellet, and, as seen from Fig. 2, the bedding of Røedvika Formation makes an angle with the boundary plane of Hecla Hoek. This relationship may have resulted either from normal depositional on-lap or from subsequent faulting. It is suggested that the absence of basal conglomerate in Røedvika (despite its presence elsewhere) favours the latter explanation. Fig. 3,

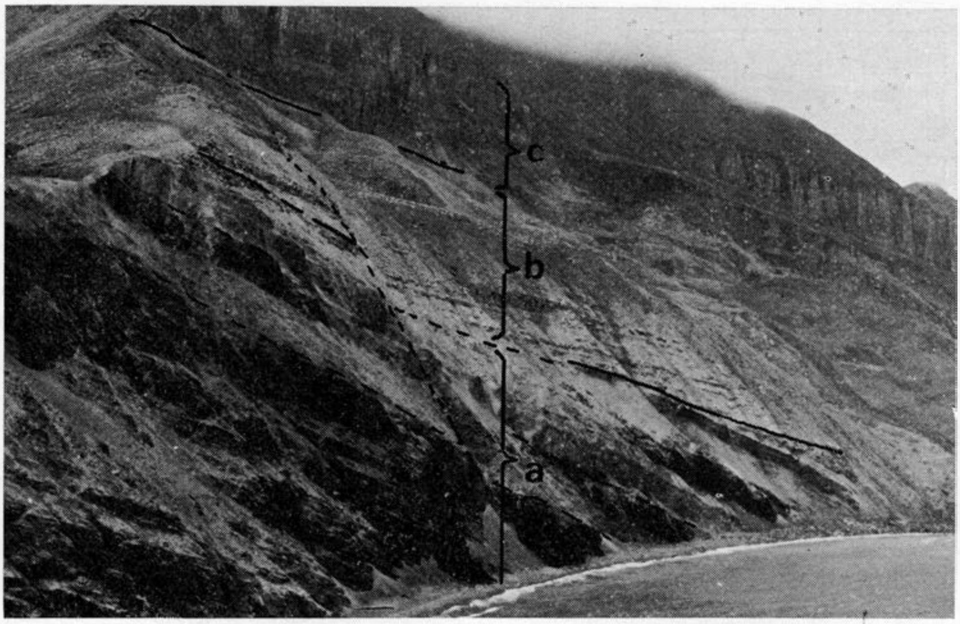


Fig. 2. *Location of Vesalstranda Member in Røedvika, eastern coast of Bjørnøya. a) Hecla Hoek. Slate-quartzite Formation (? Lower Ordovician); b) Røedvika Formation, Vesalstranda Member (Upper Devonian); c) Miseryfjellet Formation (? Upper Permian). Note how the bedding of Vesalstranda Member makes an angle with the Hecla Hoek boundary.*

showing the area just south of Miseryfjellet, illustrates why the basal conglomerates occur in this area but not along the boundary between Hecla Hoek and Vesalstranda Member on the east side of Miseryfjellet. It should be noted, however, that the boundary between Hecla Hoek and Vesalstranda Member on the east side of Miseryfjellet is more likely to represent a low angle normal fault than a thrust.

The boundary of the Røedvika Fm. with the overlying Norkapp Fm. (Culm of Horn and Orvin 1928) is nowhere exposed although there is a great contrast in lithology between the two formations.

The thickness of the formation varies from about 360 m on the eastern coast to about 120 m on the south western coast over a distance of about 10 km and it is subdivided into three members on a lithostratigraphic basis, with the type section along the east coast (Worsley and Edwards 1976). The three members are the Vesalstranda Member (oldest), described and interpreted here, Kapp Levin Member, and Tunheim Member (Fig. 1).

The age of Røedvika Fm. has been traditionally accepted as Upper Devonian. This was mainly based on plant fossils (Nathorst 1894, 1900, 1902) but also on fossil fish-remains (Woodward 1900). However, Cutbill and Challinor (1965) call this age into question and suggest a Lower Carboniferous (Tournaisian-Viséan) age. Kaiser (1970, 1971) on the basis

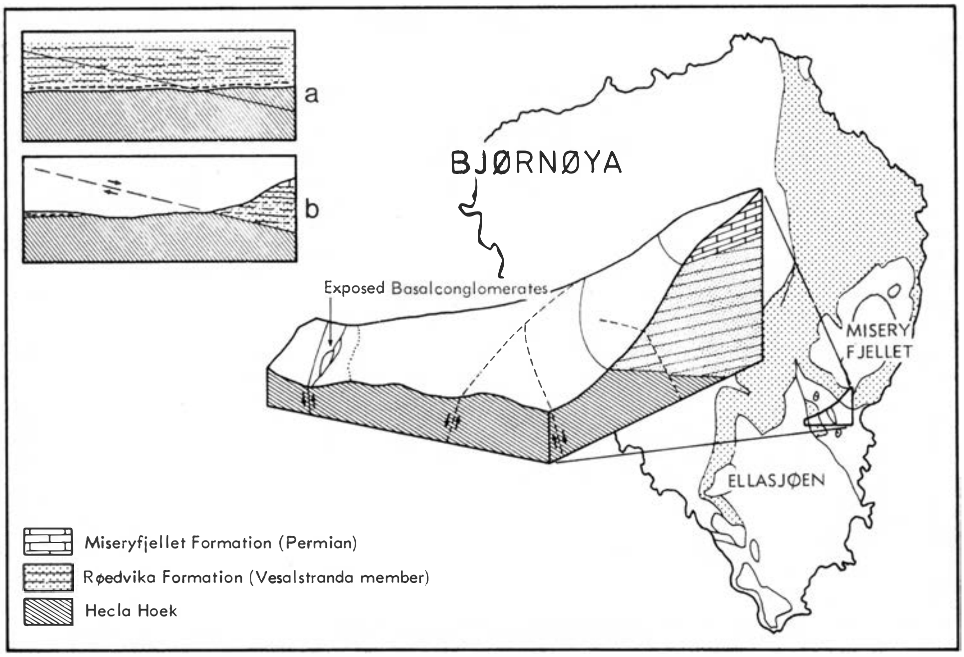


Fig. 3. *Block diagram showing the occurrence of the basal conglomerates just south-west of Miseryfjellet compared with the boundary between Vesalstranda Member and Hecla Hoek as it appears on the east side of Miseryfjellet. The diagrams in the upper left corner give, in outline, a suggested interpretation of the relationship.*

of palynological studies, suggests that the formation spans the Devonian/ Carboniferous boundary, ranging from Famennian to Lower Tournaisian.

The lithology of the Vesalstranda member consists mainly of grey and purple sandstones with subsidiary siltstones, mudstones and only a few thin beds of conglomerate. Beds of coal and black coaly shales with abundant plant fossils occur often in the fine-grained parts of the member (Fig. 4).

Facies analysis

Because of limited exposure, the facies analysis relies heavily on deductions made from detailed vertical lithological logging. The main parameters measured systematically were grain size, bed or set thickness, sedimentary structures, and palaeoccurrent directions. This approach was used in the belief that those environments and subenvironments which are laterally associated with each other geographically are likely to become associated in vertical sequence (see Walther 1894). Six lithofacies associations are distinguished.

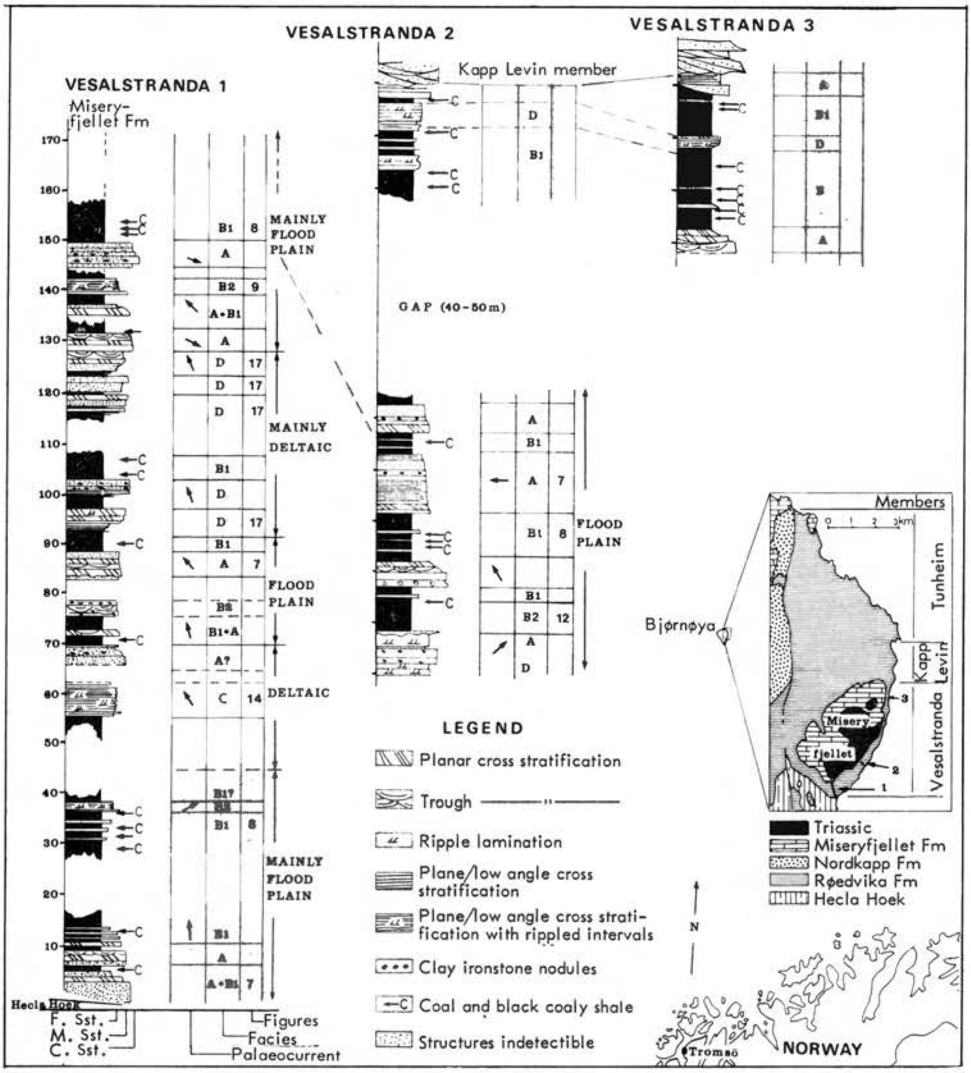


Fig. 4. *Generalized stratigraphic logs illustrating Vesalstranda Member (Røedvika Formation, Upper Devonian). Location map for the three profiles is shown to the right.*

Basalconglomerate

The basal beds of the Vesalstranda Member consist of conglomerates of various types. The basal conglomerate is exposed in two different areas, one just north-east of Ellasjøen, the other south-west of Miseryfjellet. At the latter, the river Ørvella cuts through the conglomerates in a few places. The exposures have a very short lateral extension because of debris cover. The stratigraphical contact between the basal conglomerate and the underlying Hecla Hoek is not exposed, but Hecla Hoek outcrops only a few meters beneath the conglomerate at each location.

Description

The basal conglomerate varies both texturally and structurally from the area north-east of Ellasjøen to the area south-west of Miseryfjellet.

At Ellasjøen the basal conglomerate consists mainly of pebbly sandstone, very low angle cross bedded in the lower part with some conglomeratic foresets, and thin, well segregated, nearly horizontal conglomerate strata, composed of well rounded small quartzite pebbles (Fig. 5).

South-west of Miseryfjellet, however, the conglomerate is much coarser and maximum particle size of more than 8 cm is quite common. The matrix content varies considerably from pebbly sandstone to sand supported framework conglomerate, and the sandstone/conglomerate ratio is much smaller than in the area north of Ellasjøen. The pebble composition of the conglomerate is, however, much the same and consists almost exclusively of well rounded quartzitic pebbles. The most common sedimentary structures are low-angle trough cross bedding with many curved erosional surfaces. Planar low angle cross-stratification occurs in some of the sandstones interbedded in the conglomerate. Very large scale low angle cross-stratification occurs in the upper part of one of the conglomerate outcrops south-west of Miseryfjellet (Figs. 5, 6). These large-scale foresets dip towards the east, while the palaeocurrent in the interbedded sandstone strata shows a northerly transport direction. Figure 6 shows typical bedding configuration of the basal conglomerates south-west of Miseryfjellet.

No plant fossils were recorded. Fossil fish scales have earlier been found in some loose blocks of the conglomerate (south-west of Miseryfjellet), determined by A. Smith Woodward (1900) as belonging to the genus Holoptychius.

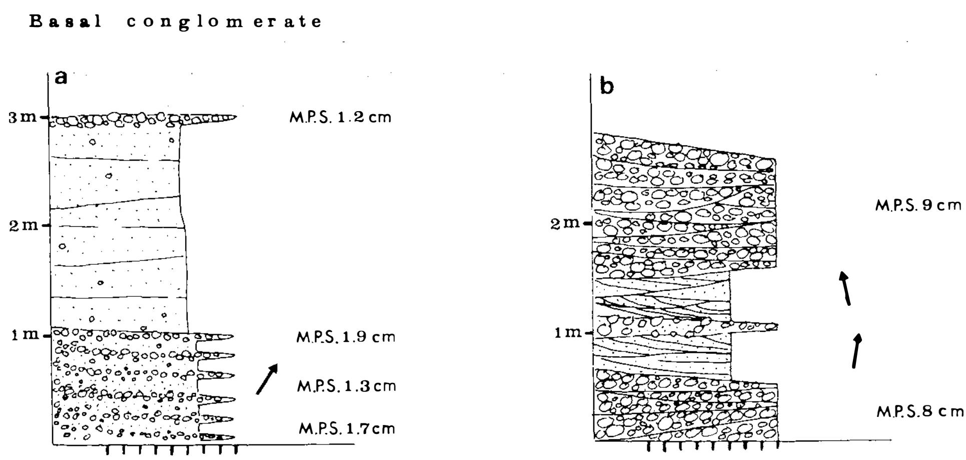


Fig. 5. *Two stratigraphical logs, measured through the basalconglomerate, a) North-east of Ellasjøen; b) South-west of Miseryfjellet. MPS = maximum particle size.*

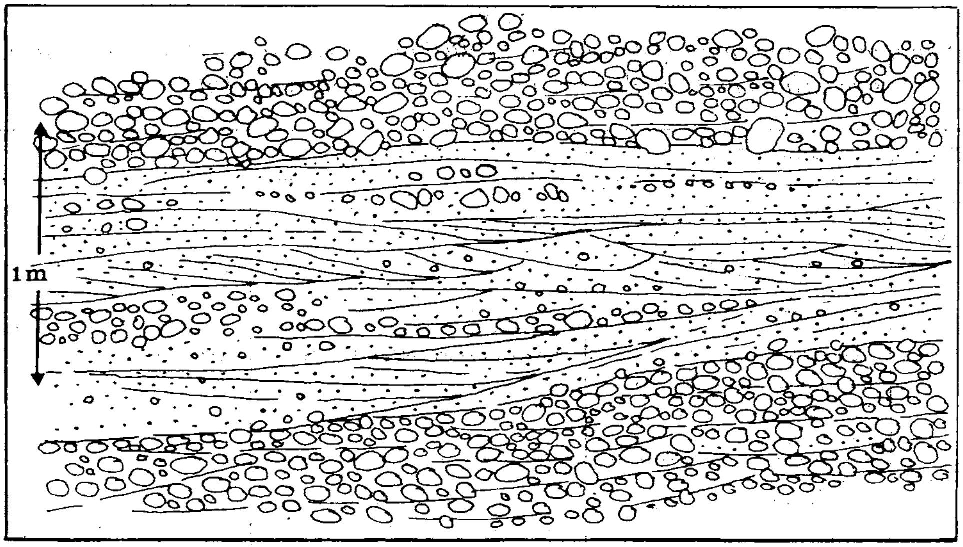


Fig. 6. *Some typical bedding configuration of the basal conglomerate south-west of Miseryfjellet (Field sketch).*

Interpretation

Horn and Orvin (1928) proposed that the coarse conglomerate south-west of Miseryfjellet represents a river bed or littoral conditions.

Steel et al. (1975) give a summary of some criteria which are used to distinguish mudflow, streamflood and braided stream conglomerate (Table 1). According to this table and the textural and structural nature of the basal conglomerate south-west of Miseryfjellet, a fluviatile interpretation is the most likely of the three types. Deposits of modern, braided, low-sinuosity stream channels show many similarities. Cross bedded, multistorey sand and conglomerate bodies, broken by frequent curved, erosional surfaces are especially characteristic of braided channel complexes (eg. Douglas 1962; Williams and Rust 1969; Smith 1970, 1971; McGowarn and Garner 1970).

The littoral hypothesis, also proposed as a possible sedimentary environment (Horn and Orvin 1928), is unlikely for the conglomerates south-west of Miseryfjellet, because of a lack of features suggestive of wave activity. However, in the exposures north of Ellasjøen there are some features which can indicate a littoral influence: 1) The very low angle cross-stratification occurring in these exposures is a very common sedimentary structure in a beach environent, e.g. Thompson (1937); Clifton (1969, 1973). 2) The much smaller, well rounded quartzitic pebbles can indicate a wave-reworking of a coarser fluviatile conglomerate. 3) In contrast to the conglomerate south-west of Miseryfjellet, the bedding lenticularity is much lower, and a better pebble segregation occurs throughout most of

Table 1.
Summary of the main criteria used to distinguish conglomerates of mudflow, streamflow and braided stream (from Steel and A.C. Wilson 1975).

CRITERIA	MUDFLOW DEPOSITS	STREAMFLOOD DEPOSITS	BRAIDED STREAM DEPOSITS
SEDIMENT-ATION UNIT	Conglomerate bed alone, or sometimes with an overlying thin sandstone and/or conglomerate bed.	Conglomerate bed usually overlain by sandstone beds.	Conglomerates pass vertically or laterally into sandstones. Thin impersistent siltstones sometimes present.
SORTING	Conglomerates very poorly sorted; usually with a muddy or silty matrix; sometimes pebble/cobble frameworks, particularly towards the top of units.	Conglomerates usually poorly sorted, but normally with pebble and cobble frameworks.	Conglomerates usually fine-grained and well sorted.
STRUCTURES	Rare. Low-angle planar cross-stratification in the sandstones.	Conglomerates often planar cross-stratified, sometimes on a very large-scale (set thickness > 1.5m). Sandstones cross-stratified or flat-bedded.	Abundance of trough cross-stratification in sandstones and conglomerates. Sandstones are also flat-bedded.
CLASTS	Extraformational clasts.	Extraformational clasts.	Intraformational clasts are common.
BASAL EROSION	Only rare signs of basal erosion.	Marked basal erosion.	Abundance of concave-up erosion surfaces.
GEOMETRY OF UNITS	Usually sheet-like.	Laterally impersistent along depositional strike; often filling large channels.	Always laterally impersistent, usually filling smaller channels than the streamflood deposits.

the exposures. This is also a common feature for wave-reworked sediments contra fluvial sediments (Clifton 1973). The three factors mentioned above all favour a wave-dominated, littoral environment, but they do not present definite evidence, since such features can result from fluvial processes.

Facies Association A

This facies association, typically sharply based and often erosional, consists of a vertical sequence in which thin discontinuous sandy conglomerate beds are overlain by medium to coarse grained, planar and trough cross-stratified (with subsidiary upper plane beds), relatively well-sorted grey sandstones. The latter continuously grade up to more poorly sorted, fine to very fine grained sandstones with small-scale, cross-stratification, ripple lamination and lower phase, plane parallel lamination (Fig. 7).

The basal conglomerates vary from a few centimetres to about 0.5 m in thickness. Although they contain some quartz pebbles they are largely intraformational, with mudflake clasts and clay ironstone concretions. Set

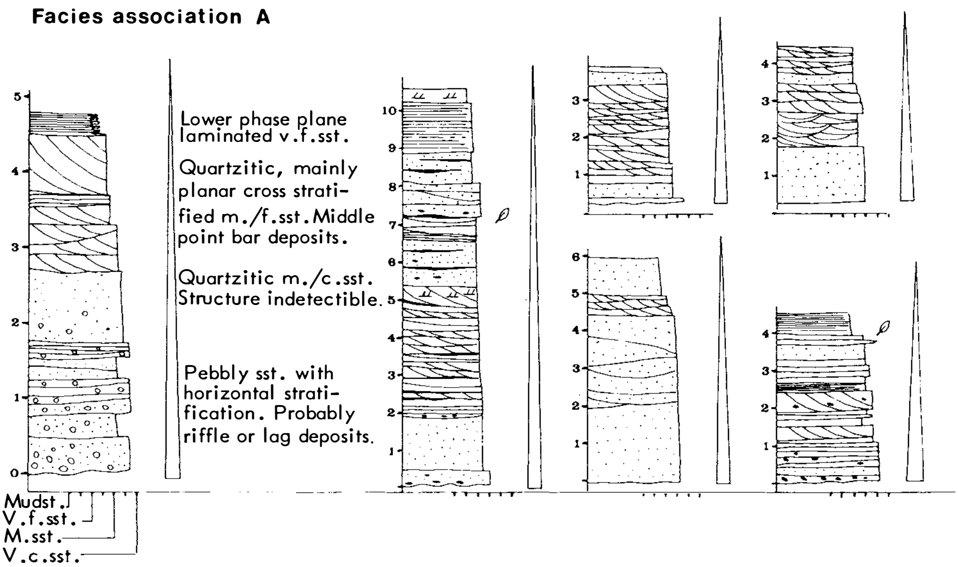


Fig. 7. *Stratigraphic logs illustrating Facies association A (interpreted as point bar deposits of high sinuosity meandering streams).*

thickness in the medium/coarse sandstones reaches 1.5 m while in the fine laminated sandstones this averages 0.3 — 0.5 m. Facies association A sequence is typically about 5 m thick (Fig. 7). Fig. 7 (a—f) shows the considerable range of variation in sequence thickness, stratification sequence, and grain size sequence encountered within Facies association A.

The sandstones consist mainly of monocrystalline quartz and rock fragments composed of quartzite. There is usually a siliceous and ferric cement in the lower and middle parts of the sequence. Small spots of ferric minerals, probably derived by oxidation of siderite occur as small concretions in the sandstones. Siderite is somewhat more common in the upper part. Traces of rutile, mica and probably pyrites are present.

No fauna or trace fossils were observed in this association, although a few plant remains were found in the upper parts of some Facies association A sequences (Fig. 7).

Facies association A usually erosively overlies Facies association B1 (interpreted below as flood basin deposits), and either grades up or is abruptly overlain by Facies association B2 (levee deposits).

Interpretation

Most of the sedimentological features, and the grain size/stratification sequences described above are consistent with descriptions of the internal features of recent point bar deposits of meandering channels (Allen 1963; McGowen and Garner 1970; Fisk 1944, 1947; Folk and Ward 1957; Frazier and Osanik 1961).

However, large scale transverse cross-stratification or epsilon cross stratification (Allen 1963), an important feature of some point bars, has not been observed in any of the deposits of this facies association. This may be due to (a) the insufficient lateral extent of exposures on Bjørnøya, (b) the difficulty of identifying this type of cross-stratification because of its extremely low angle on bars of any size (Allen 1970), or (c) its poor development here, as is often the case in many recent point bars (Reineck and Singh 1973: p. 273).

The most common sedimentary structures in the lower part of Facies association A, trough and planar cross-stratification, probably originated from deposition by migrating, subaqueous sand-dune bedforms at moderate flow power (Allen 1968; Leeder 1974). In the curves of meandering rivers there are both downstream and weaker sideways velocity components. In general, the lateral velocity component is about 10—20% of the downstream component (Allen 1965a) and carries sediment from the channel deeps to a relatively high position on the point bar. The finer grained sediments are carried higher up on the bar than the coarse. In this way the characteristic fining-upwards sequence and the stratification sequence are constructed. Small variations in grain size within the sequence are probably due to varying discharge (Allen 1965a).

Thick sets of extra-formational conglomerate, or pebbly sandstone, occur only at one location in the investigated area (Figs. 4, 7a). Here the conglomerate sets together with a few associated sets of medium sandstone, make up a 1.7 m thick sequence which is probably too thick to be a single lag deposit. This coarse sequence may represent multistorey lagging due to rapid shifting in the position of the meandering channel or, more likely, because there are no significant erosional surfaces between successive units, some kind of riffle deposit (see Bluck 1971).

Smaller variations in grain size between coarse and finer sediments are due to variation in discharge (Allen 1965a). McGowen and Garner (1970) distinguish between two types of point bar deposits, namely a coarse grained type and a fine grained type. From preliminary investigations here, it is most reasonable to assume that Facies association A is mainly of the finegrained point bar type.

The typical thickness of a Facies association A sequence is about 5 m. One of the sequences, however, reaches a thickness of 10 m (Figs. 6, 7), and it is of interest that this particular sequence is one of the most finegrained and contains more interbedded silt than the other Facies A sequences in the member. It is suggested that this is a predictable relationship between grain-size and thickness in a point bar unit because the former is known to decrease as river channel slope decreases (Shumm and Khan 1972). Slope decrease also often implies greater depth/width ratio of channels (Leopold and Wolman 1957), and therefore greater depth of scour (point bar thickness).

Because the thickness of a point bar deposit is approximately equal to

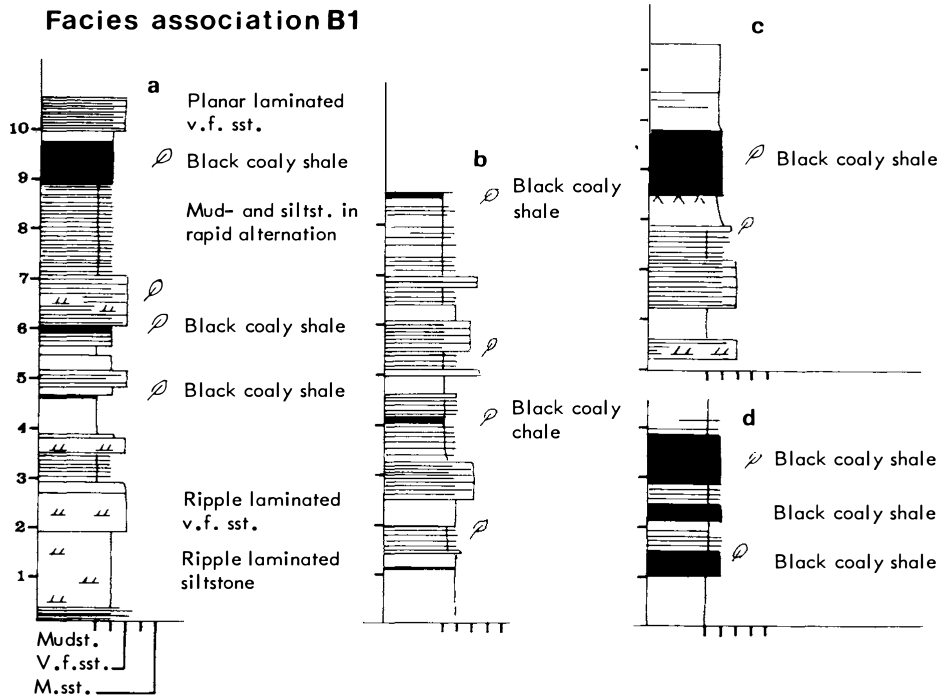


Fig. 8. *Stratigraphic logs illustrating Facies association B1 (interpreted as flood basin deposits).*

the channel depth or the depth of scour, identification of an ancient point bar sequence gives an impression of the depth of the river channel (e.g. Leeder 1973). Facies A sequences vary from a few metres to about 10 m. For comparison, the point bar deposits of the Mississippi river can reach a thickness of 20—50 m (Fisk 1944, 1947) and the Niger River 10—15 m (Allen 1965b).

Facies Association B1

This association consists of grey/reddish-grey, thinly laminated mudstones and siltstones with thin sharply based fine/very fine sandstones and closely associated coaly shales (Fig. 8). Sequences of this type usually overlie the channel sandstones of Facies association A (Fig. 4). Together with the upper beds of Facies association A, the sequences often constitute a slight fining-upward.

The most common sedimentary structures of this association are plane stratification of lower phase and ripple lamination (Fig. 8). The sandstone beds are very often interstratified with thin, silt and mudstone strata.

The black shales which associate with the finest sediments reach a maximum thickness of 1 m, while the sharp-based sandstones average 0.3—0.4 m.

Abundant plant fossils are found in the beds of this facies association, and especially in the shales. No fossil fauna or bioturbation were observed. A few thin horizons with clay ironstone nodules are developed.

The total thickness of the association ranges from 1 m to more than 10 m (Fig. 8).

Interpretation

The grain size and structural characteristics of these deposits indicate an environment dominated by sedimentation from suspension while their close association with underlying fluviatile point bar deposits (Facies association A) suggests deposition in a floodbasin.

The repetition of mudstones and siltstones indicates successive pulses of deposition from suspension during episodes of channel flooding, after the coarser sediments have been deposited on levees and crevasse splays. The sharp-based, very fine sandstones probably represent the product of more severe flooding, with active bed-form migration following brief scouring of the flood-basin surface (e.g. Leeder 1974). The considerable thickness of some units of this association, more than 10 m, is likely to have resulted from the stream channels being more or less fixed in position so that relatively long periods were available for fines to be deposited in one area. Stream channels are likely to have been sinuous since floodbasin deposits of this thickness are rarely developed adjacent to braided streams where a rapid rate of lateral migration inhibits the development of thick floodbasin deposits (Reineck and Singh 1973). Alternatively a complete abandonment or evolution of an earlier river channel system may have aided the development of a semi-permanent floodbasin site.

In a humid climate, flood basins usually are low, wet and thickly vegetated, commonly developing as backswamps (Reineck and Singh 1973). In coastal plain areas where major rivers join, swampy floodbasins may be particularly large. This thick vegetation results in incorporation of much organic matter which may accumulate as peat layers, associated with silty clayey sediments (Reineck and Singh 1973: p. 251).

It is likely that Facies B1 has formed under conditions of high water table, with reducing conditions, preventing the oxidation of coal-forming vegetation, and forming ferrous compounds like siderite. On the basis of the present data it is not possible to be certain whether sediments of association B1 were deposited on a coastal plain or on an interior floodplain, but the latter is most likely because no associated sediments of marine or marginal marine origin have been recorded.

Facies Association B2

This Facies association is represented at only three locations with distinct sequences (Fig. 4). They resemble on a thicker scale, the coarser grained portion of Facies association B1, and are always vertically associated with B1. Characteristic of the association is a rhythmic alternation between thin, evenly bedded, grey (and purple), fine to very fine sandstone units and thin, finely laminated grey siltstone strata (Figs. 9, 10). The sandstone strata are mainly plane-parallel laminated, and ripple laminated, although some rare sets of very low-angle cross-bedding have been recorded. A few erosional surfaces with scour and fill structures occur at the base of some of the sandstone units. The siltstone strata are mainly plane-parallel laminated, and ripple laminated (Figs. 10, 11). Raindrop imprints are present on a few bedding planes, but instead of well-developed imprints the surfaces are covered by irregular depressions with small, distorted, impact craters.

Generally the sandstone units (a few cm to a few dm thick) are overlain by thinner siltstone sets (from less than a cm to a few cm thick) in such a fashion that they form minor fining-upwards seuqences.

The type profile of this Facies (Fig. 9) has a maximum thickness of about 3 m, but this thins out towards the north-east. The sandstones differ from those of Facies association A in containing a much greater percentage of matrix. The matrix usually consists of mica minerals and ferric cement, probably derived from oxidation of siderite.

Plant fossils are not common, but were recorded in a red silty bed in the upper part of one seuqence (Fig. 9). Fauna is entirely absent.

Interpretation

Most of the features described in Facies association B2 are consistent with the internal features of recent natural levee deposits.

Natural levees are wedge-shaped ridges of sediment bordering stream channels with their maximum elevation at or near the channel edge. They are formed when flood waters overtop the channel banks (Reineck and Singh 1973: p. 244).

Rapid vertical interbedding of relatively coarse with relatively fine sediments (silt, clay) has been widely recorded as the most characteristic feature of natural levee deposits (Fisk 1944, 1947, 1961; Shantzer 1951; Lorents and Thronson 1955; Shepard 1956; Lattman 1960; B. Anderson 1961; Allen 1964, 1965b). The minor fining-upward sequences in Facies association B2 are most likely to have resulted from waning flow during a single flood event, where the sandstone base represents the most severe

Facies association B2

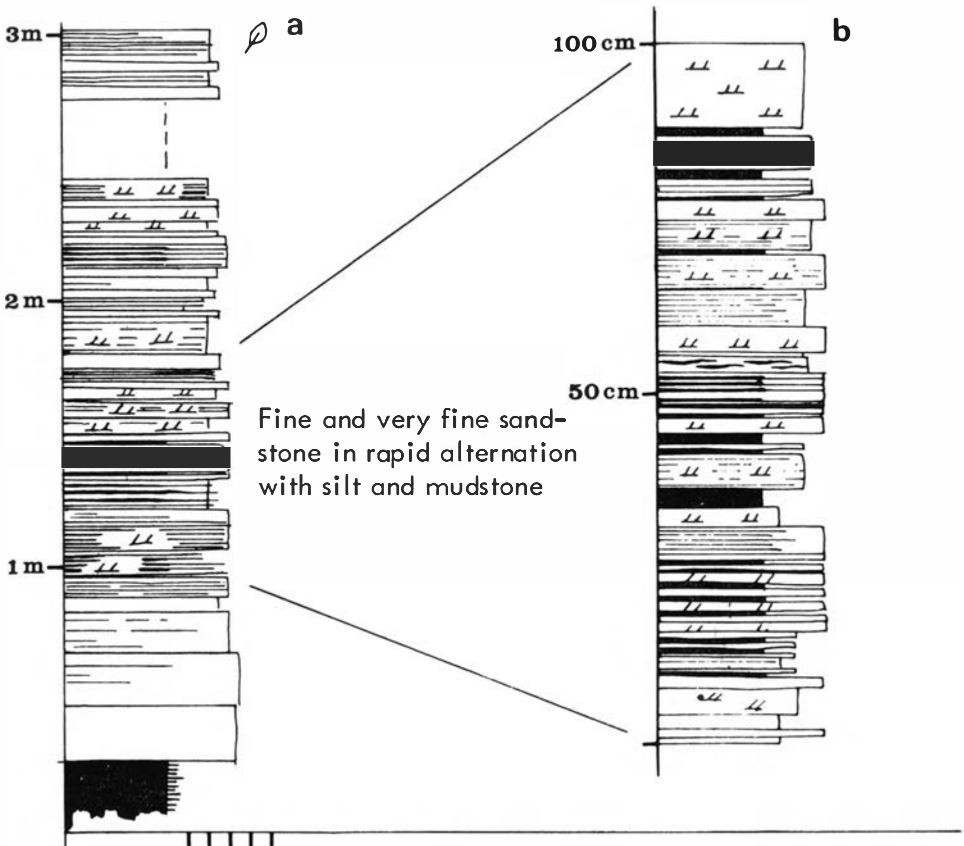


Fig. 9. *Detailed stratigraphic log illustrating Facies association B2 (see also Figs. 10 and 11).*

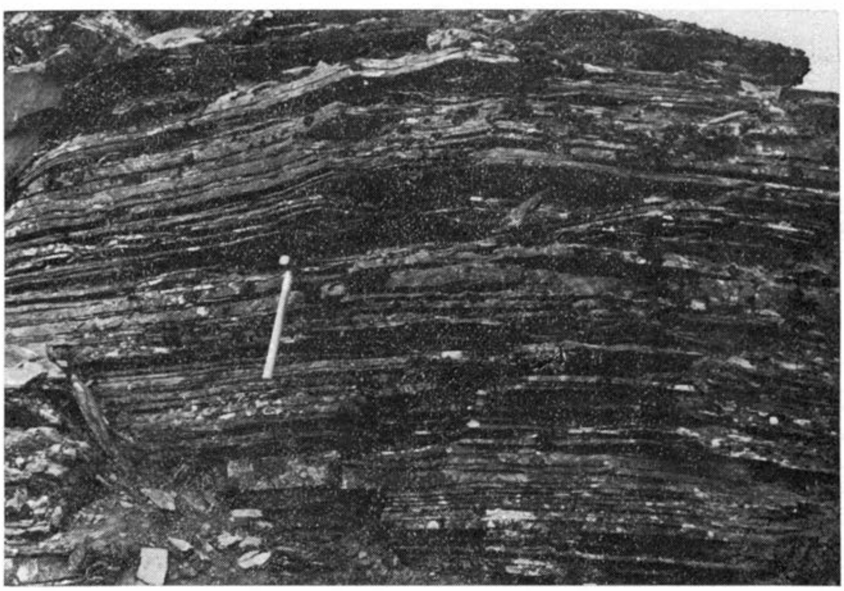


Fig. 10. *Rhythmic change between thin units of ripple laminated fine to very fine sandstone, and thin, finely laminated grey siltstone strata of Facies association B2 (interpreted as natural levee deposits).*

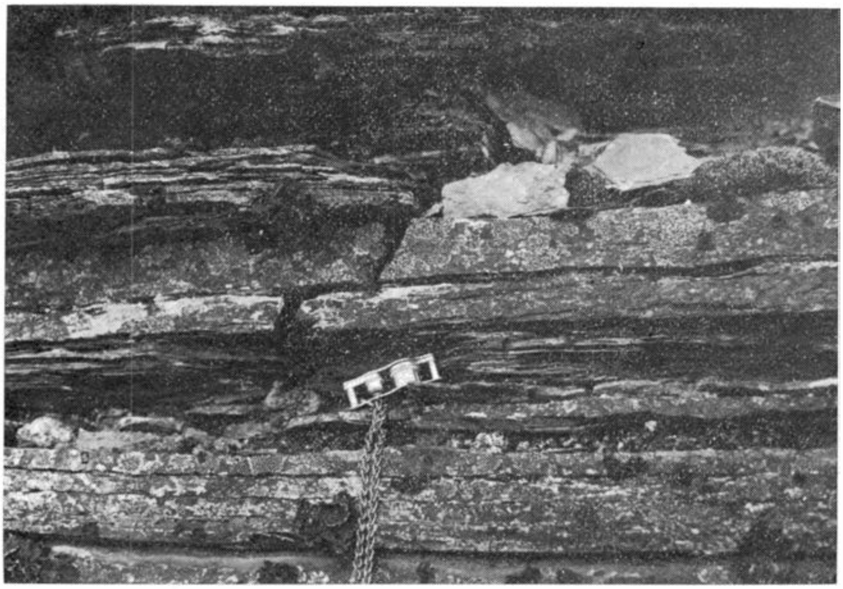


Fig. 11. *Part of Facies association B2. Note the finely laminated siltstone overlying massive and ripple laminated sandstone units, making a minor fining-upward sequence.*

part of the flood and the silty sediments are deposited mainly from suspension during falling stage. The scale of the interbedding varies, probably depending on the size of the levee and the grades of sediments made available by the stream, and is expressive of the repeated submergence and intermittent construction of levees during floods (Allen 1965a). According to Reineck and Singh (1973), natural levee deposits should be made up of somewhat finer sediments than their corresponding point bars. This is the case in the Vesalstranda member (compare Facies B2 and A in Fig. 4).

The sedimentary structures of B2 are similar to the internal structures of known levee deposits. Allen (1964, 1965b) recorded small-scale cross-stratification and even lamination in Niger delta levees. The occurrence of raindrop imprint indicates an intermittent emergence of sediment surface, which is a common phenomenon in natural levee, as it represents the most elevated part of the flood plain.

Another possible interpretation of Facies B2 is channel-fill sediments. The relatively high proportion of sandstones to siltstones and mudstones suggests that channel-fill of the chute cut-off type (described by Allen 1965a; Fisk 1944, 1947) would be the most likely possibility because bed load sediments make relatively important contributions to such channel-fills (Fig. 13). The neck cut-off type of fill usually consists of much finer grained deposits and is a less likely interpretation, unless the sediments were deposited very close to the end of the abandoned channel. Lack of evidence as to geometry of this Facies association precludes a definite conclusion as to which of the various hypotheses is correct.

Facies Association B3

This association has been observed only at one single location. It is dominated by an erosively based medium/coarse, grey quartzitic sandstone, about 50 cm thick, and an overlying seuqence of rapidly alternating finely laminated silty mudstone and very fine silty sandstone (Fig. 12). The very thin (cm) laminae in this seuqence are extremely regular, mainly plane parallel with only a few rippled intervals.

The upper limit of this association is placed above the thin, coaly shales (Fig. 12), the upper part of which consists of laminated mud and silt and a rare sandy bed. As a whole the Facies association shows a slight fining-upwards tendency (Fig. 12), over a total thickness of the order of 5 m.

Just above the basal bed, a thin, black siltstone/mudstone bed (15 cm thick) with some sulphuric (probably marcasite) nodules occurs. Abundant plant fossils were recorded only in the upper part of the sequence. Fossil fauna or trace fossils do not occur.

Facies association B3 has many features in common with the floodbasin deposits of association B1, but contrasts with the latter in having a basal coarse sandstone unit (which is very similar to the basal beds of Facies A) and in the extremely regular nature of the plane parallel lamination in the mudstone/siltstone part of the sequence.

Interpretation

This association probably represents the infill of a channel abandoned due cut-off or avulsion processes. Cut-off processes are associated with meandering streams, and occur whenever a stream can shorten its course and thus increase its slope (Reineck and Singh 1973: p. 248).

The sediments of Facies association B3 (excluding the basal beds) probably represent a depositional environment of very low energy because of their fine grain size and the sedimentary structures (plane lamination of lower phase and ripple lamination). The rapid alternation of sandy silt and silty sand probably resulted from variation in stream discharge during overbank flooding while the finest sediments are likely to have been deposited from suspension after flood periods. Sedimentary sequences of similar grain size distribution and sedimentary structures have been recorded from floodplains in areas of channel-fill, as for example from the Brazos River (Bernard et al. 1962; Bernard and Major 1963). In such sequences there is little contribution from bed-load processes (Reineck and Singh 1973) as was evidently the case in Facies association C with the exception of the basal sandstone bed. The latter bed, on account of its similarity to the basal beds of Facies association A, is likely to represent some kind of channel floor sediment, deposited before the abandonment of the channel. This is apparently a significant feature of many channel fill sequences (Selley 1970). As an alternative explanation, it may represent a discrete crevasse splay deposit.

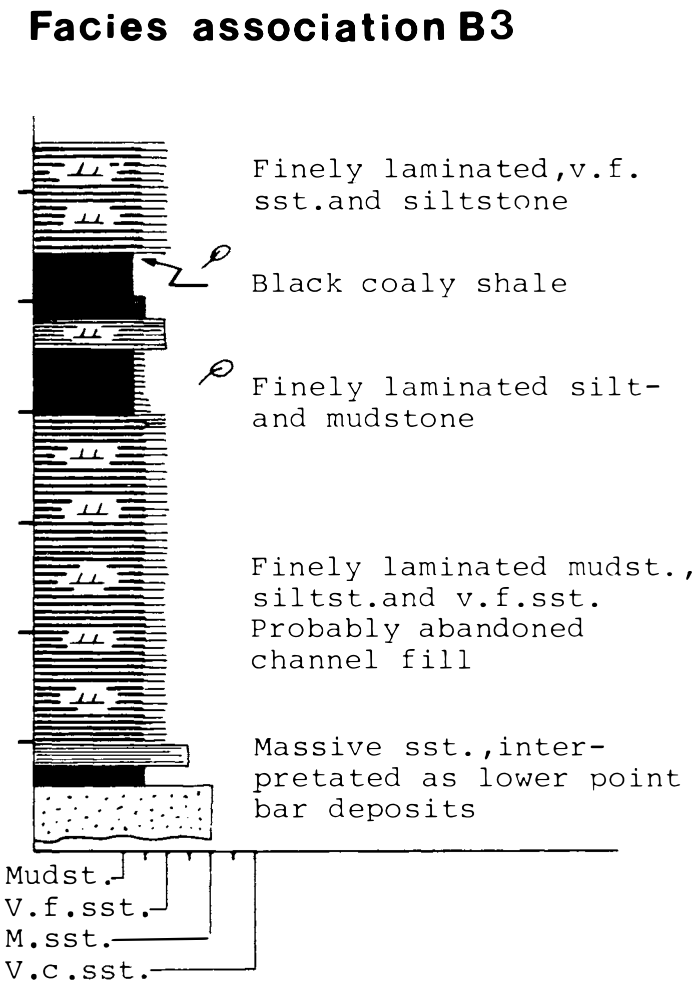


Fig. 12. *Stratigraphic log illustrating Facies association B3 (interpreted as neck cut-off channel-fill sediments).*

The sulphide nodules, located in the lower part of the association, indicate a reducing environment with probable derivation of sulphur from the decomposition of organic matter (Pettijohn 1975). Such reducing conditions are typical of the stagnant water conditions in abandoned channels.

The occurrence of coal and in situ plant fossils in the upper part of the association indicates a subaerial, vegetated environment, probably a consequence of the gradual filling of the channel.

As noted above (Fig. 13), two types of cut-off in meandering streams are known (chute cut-off and neck cut-off). Because the geometry of Facies association B3 is unknown, it is not possible to be certain of which kind of cut-off is represented, but the high portion of fine sediment is consistent with a neck cut-off.

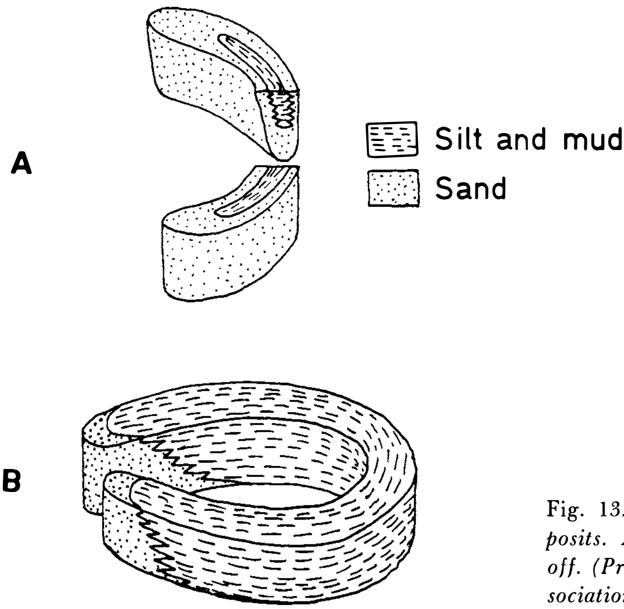


Fig. 13. *Two types of channel-fill deposits. A) Chute cut-off. B) Neck cut-off. (Probably represented in Facies association B3) (After Allen 1965).*

Facies Association C

This Facies association is present at only one location and forms part of a large-scale (Facies C-A) coarsening-upwards sequence. It consists of grey and purple, fine/very fine sandstones, finely laminated, plane-parallel and low angle cross stratified, with some ripple intervals. Some small-scale planar cross stratification and trough cross stratification, are also present in some isolated parts of the sequence (Figs. 14—16). Parting lineation is common on some of the bedding-planes.

The degree of sorting in the sandstones is mainly good/moderate, but some matrix is present. The clastic grains consist mainly of quartz (both monocrystalline and polycrystalline), and ferric minerals. Mica is present, causing the very regular and distinct fissility (Figs. 15, 16). The ferric minerals (also present in cement) are mainly derived from oxidized siderite, as some of the minerals still have a core of unaltered siderite.

The thickness of this Facies association is more than 6 m, and within this interval there is no significant fining or coarsening-upward tendency (Fig. 14). The top of the unit seems, however, to contain more silt- and mudstone than the sediments below. The exposure of the upper part of the association, however, is insufficient as a 3 metre thick interval is covered by scree.

No fauna has been recorded, although a few trace fossils (planolites) were seen on one bedding plane. Plant fragments are present in a few laminae, but are not common.

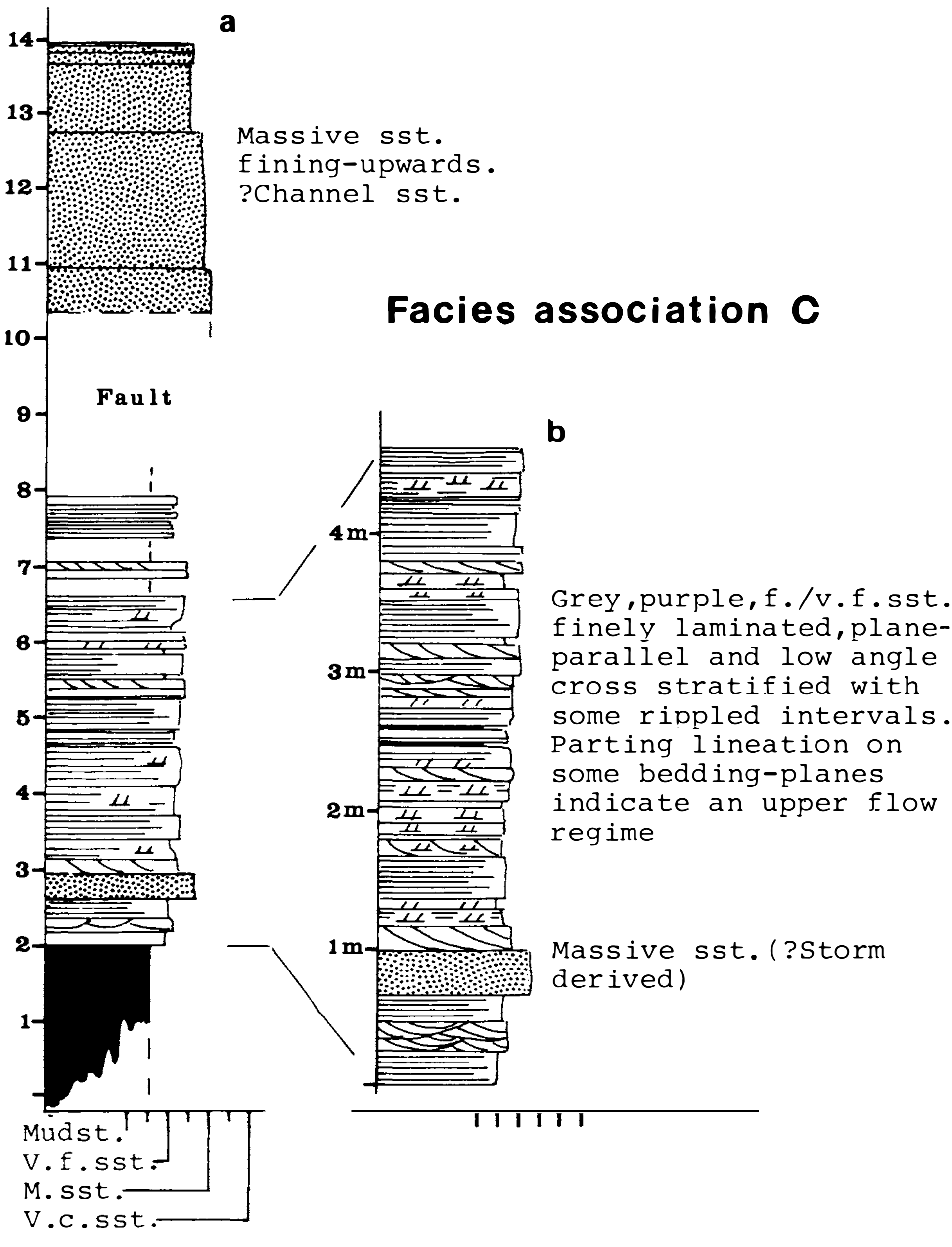


Fig. 14. *Detailed stratigraphic log illustrating Facies association C (See also Figs. 15 and 16).*

As seen from Fig. 14, this Facies association probably occupies the middle part of a larger (20 m thick) coarsening-upward sequence. The upper, coarse-grained part of this succession has been interpreted as a point bar deposit (Facies association A), while the gap below Facies C is likely to be largely grey mudstone/siltstone.

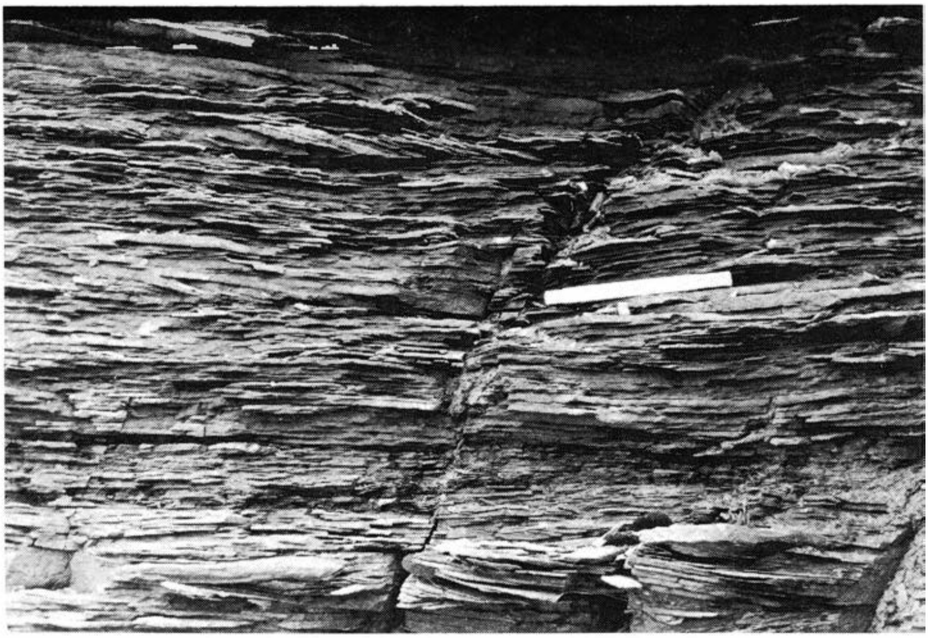


Fig. 15. *Typical bedding configuration of Facies association C. Plane parallel and very low angle cross-stratification occur as the most common sedimentary structure.*

Interpretation

The coarsening-upward sequence described above probably represents some kind of prograding delta lobe. The poorly exposed basal unit probably represents distal bars and prodelta silt and mud, while Facies C, as argued below most likely represents more proximal sediments such as distributary mouth bar deposit. The thick sandstone which constitutes the uppermost part of the coarsening-upwards sequence (Fig. 14) probably represents distributary channel sand.

The sediments of Facies C are deposited in a relatively high energy environment as seen from the abundance of plane parallel lamination, low angle cross-stratification and parting lineation, which, according to Jopling (1967), indicates upper flow regime conditons. Because the cross lamination of association C is unidirectional, a stream-dominated depositional environment is most probable.

The thin laminae (causing the fissility) are probably a result of rapid changes in stream discharge.

The finer sediments that probably immediately overlie Facies association C (Fig. 14), are thought to have been deposited during periods of distributary channel abandonment, while the 30 cm thick medium/fine, massive sandstone in the lower part of the association (Fig. 14) is possibly storm-generated.

Because no sign of typical marine or shallow marine influence has been

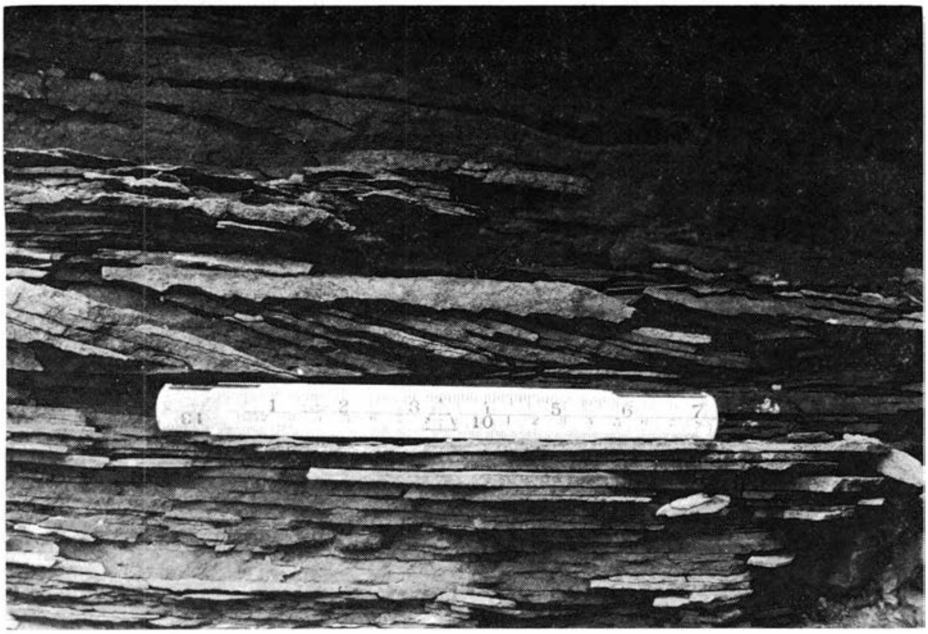


Fig. 16. *Part of Facies association C, middle part. Showing plane parallel stratification and planar cross-stratification (probably caused by migrating dunes).*

recorded from these or associated sediments, it is likely that the coarsening-upwards sequence shown in Fig. 14 represents a delta lobe prograding into a standing water body or lake environment. This suggestion is supported by the fact that:

a) Associated sediments are typical continental (fluvial).
b) The frequent occurrence of siderite indicates stagnant water conditions. It has not been possible, however, to present definite evidence that the siderite occurring in this association is of syndepositional origin.
c) It is likely that the sediments of Facies association C were deposited into a permanent water body as no signs of subaerial exposures such as raindrop imprints, dessication cracks, or in situ plant fossils have been recorded.

A distributary mouth bar is a sandy shoal formed near the mouth of a distributary channel. Formation of the shoal is directly a result of decreasing current velocity and carrying capacity as it leaves the channel (Reineck and Singh 1973: p. 269).

Facies Association D

The sediments of this association are organised into coarsening-upward sequences from 3 to 7 m thick (Fig. 17). Individual units begin with grey

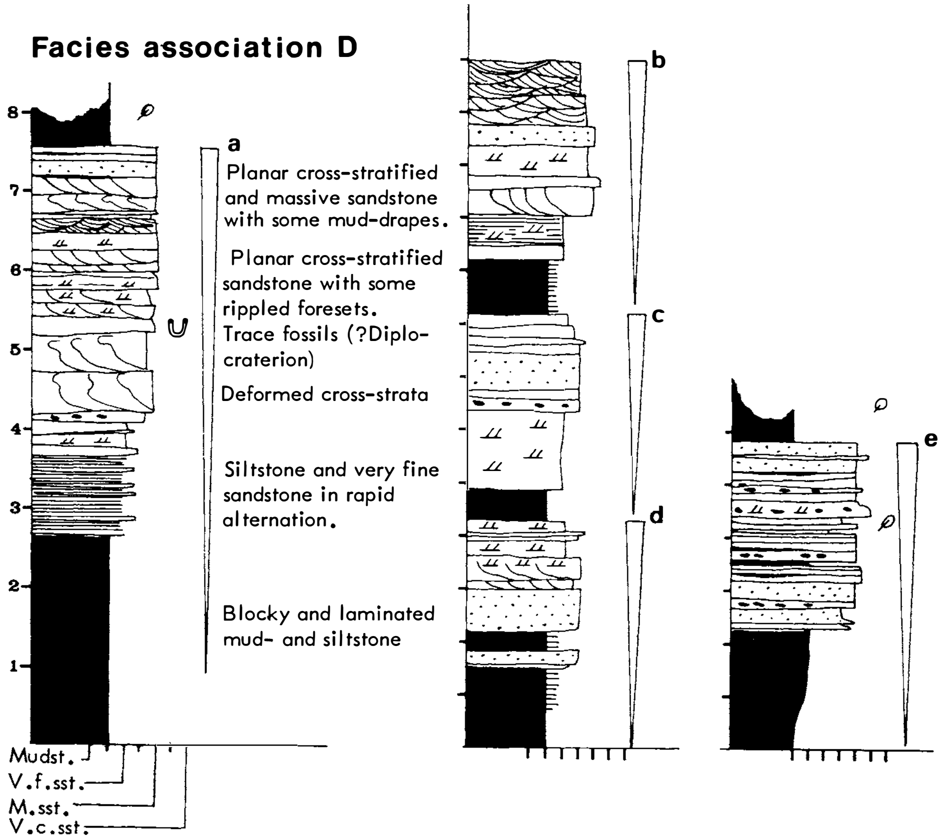


Fig. 17. *Stratigraphic logs illustrating Facies association D (interpreted as delta lobe deposits).*

mudstones and siltstones which are often finely laminated. Above these basal beds occur very fine sandstones which are ripple laminated, evenly laminated and, in contrast to the fine-grained sandstones of Facies association C, contain thin siltstone strata. The middle and upper part of this Facies association consists mainly of grey, fine/medium sandstones which are planar cross-laminated, ripple laminated, and trough cross-laminated (Fig. 17). Some of the cross-laminated sandstones have suffered soft sediment deformation and as a consequence internal structures were often difficult to distinguish. Thin, grey, ripple-bedded siltstone strata are often interbedded in the sandstone units. Clay ironstone nodules are quite common.

The lithology and structure of the sandstones are often similar to those in the sandstones of Facies association A. The grain-size sorting is moderate, and the grains are mainly composed of monocrystalline quartz and rock fragments of quartzite. Ferruginous cement is common.

Plant fossils are not common in this Facies association, but mudstones and siltstones containing thin beds of coaly shales with some plant remnants abruptly overlie a few of the sequences.

Interpretation

The coarsening-upwards character of these sequences probably records a gradual increase in sediment transporting power with time, resulting in the building up of a sedimentary pile, up to or near to the water surface, as seen from the occurrences of coaly shale just above some of the sequence. The three most obvious possibilities for the building of these sequences are:

1) The coasening-upwards is a result of transgression by a barrier or barrier washover sand body over a landwards lagoonal area (eg. Davies et al. 1971).
2) The coarsening-upwards is a result of the outgrowth of a delta lobe into a marine environment (e.g. Fisk 1955; Scruton 1960; Gould 1970; Oomkens 1970).
3) The upwards-coarsening is the result of outgrowth of delta distributaries into a marginal water body such as lagoon, bay or lake (Oomkens 1970; Elliot 1974).

Facies association D has no deposits with sedimentary structures suggestive of a barrier or offshore origin. There is no significant low angle beach laminae, no wave formed ripples, and the palaeocurrent measurements, based on planar cross lamination, are unidirectional.

Since no sign of marine or restricted marine influence were recorded from this sequence (such as marine- and shallow marine fossils or trace fossils) it is most probably that the sequences of this facies association are a result of outgrowth of delta lobes into a more or less standing water body or lake. Sand may have been generated into the lacustrine environment directly by the main distributary river channels, or by smaller scale crevasse channels lateral to the main distributary channels. It is hence possible that some of the sequences represent mouth bar environments of mainly the same origin as Facies association C. The scale, however, differs considerably, as the sequences of this Facies association are much smaller.

The occurrence of deformed cross-bedding, which is quite common in a few sequences of this Facies assosiation, indicates highly liquified sand beds, possibly as the result of earthquake shocks (Allen and Banks 1972).

Environment of Deposition

On the basis of their interpreted mode of origin and of their stratigraphic association, Facies associations A, B1, B2 and B3, can be grouped together into a single fluvial facies-model. The processes and conditions of deposition of these associations suggest a floodplain environment constructed largely from sedimentation in and adjacent to streams of high sinuosity. Coarse bed-load sediments were probably deposited in narrow linear bodies, elongated in the general direction of drainage (Allen 1965a). Cross-stratified sandstones organised in a fining-upwards manner dominate. Finer sediments laterally and vertically associated with the coarser sand bodies accumulated as levee, floodbasin, and channel-fill deposits. The bed-load sediments form linear bodies because the channel-fill and floodbasin deposits tend to restrict the extent to which the stream channels in each meander belt can wander laterally. As a consequence, avulsion was probably the dominant mode of sudden channel shifting (Allen 1965a) and relative thick floodbasin sequences were able to accumulate because of the relatively stable channel position.

Facies associations C and D represent the progradation of deltaic lobes into standing fresh water bodies. The deltaic facies alternate with fluviatile sediments as shown in Fig. 4.

Because of their close association with the deltaic sequences it is most likely that the fluviatile sediments accumulated in a floodplain area dominated by high sinuosity meandering streams and lakes.

An overall time trend of sedimentation, from lacustrine deltaic in the lower and middle part of the member, to fluvial dominated in the upper part (Fig. 4), suggests a general progradational, basin-filling episode, which probably culminated in the coarser-grained, overlying Kapp Levin Member.

Palaeocurrent analyses

Palaeocurrent patterns were analysed using planar cross stratification and, in a few instances, trough cross-stratification. The mean palaeocurrent directions for most of the Facies associations are given in Fig. 4. Despite a considerable variation, the distribution is concentrated between north and west-northwest. In Fig. 18, all palaeoccurent measurements (total 104) are collected in one diagram, based on 20 degree intervals. The azimuth of the resultant vector ($\bar{x}$) is calculated giving a mean palaeocurrent direction of 323°N. The magnitude of the resultant vector L is 46% (Fig. 18).

Because the directional features of sand bodies deposited by meandering streams yield an average vector parallel to sand body trend and stream flow (Allen 1965a) it is reasonable to assume that during the deposition of the Vesalstranda member (Upper Devonian) a source area south and southeast of Bjørnøya existed, with a low angle palaeoslope towards the north and west-northwest.

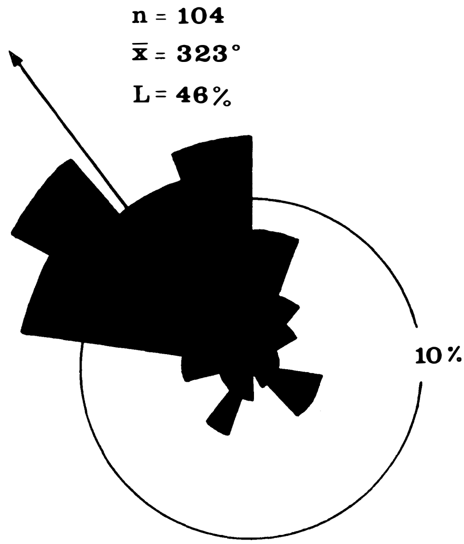


Fig. 18. *Total palaeocurrent distribution in Vesalstranda Member. All palaeocurrent directions measured in the member are plotted in the diagram, based on twenty degree intervals. n = Total number of measurements.* $\bar{x}$ = *The azimuth of the resultant vector. L = Magnitude of resultant vector in terms of per cent.*

Palaeoclimate

The palaeoclimate is likely to have been of a relatively moist character throughout the whole of the period discussed above, as the floodbasin sediments show no features indicative of dry periods. There are no signs of ground water fluctuation, no dessication cracks and no development of fossil calcrete (e.g. see Steel 1974) as there are, for example, in the Landnørdingsvika Formation (Lower Carboniferous) some 400 m higher in the succession. On the contrary, plant fragments are reduced to coal or coaly shale, and ferrous minerals (siderite) are common in most of the succession (reducing conditions).

Occurrence of coal with respect to sedimentary sequences

A simple Markov chain analysis has been made to obtain statistical data for the most common upwards transitions of various lithologies, with the purpose of finding out where coal occurs with respect to sedimentary sequences. The following lithologies have been analysed:

A = siltstone
B = shale (mudstone)
C = sandstone
D = coal
E = coal shale

Only transitions between different types of lithologies have been recorded. The upward transition probability matrix is shown in Table II, together with calculated values for prior depositional criterion, k, (Allen 1970).

Table 2.

Probability matrix showing upward transitions of the lithologies A, B, C, D, and E. A = siltstone, B = shale (mudstone), C = sandstone, D = coal, E = coaly shale.

	A	B	C	D	E
A		0,436	0,394	0,099	0,070
		k=1,01	k=0,80	k=0,82	k=0,94
B	0,358		0,358	0,278	0,111
	k=0,990		k=0,92	k=1,536	k=0,808
C	0,407	0,383		0,000	0,012
	k=1,25	k=1,087		k=0,00	k=0,338
D	0,308	0,346	0,154		0,192
	k=1,22	k=0,65	k=0,00		k=1,00
E	0,208	0,458	0,125	0,208	
	k=1,06	k=1,238	k=2,958	k=1,00	

$k = \frac{nij\ Ni}{nji\ Nj}$

k = prior deposition criterion
nij = number of upward transitions from state *i* to state *j*, *Ni* is the number of representatives of state *i*
nji = number of upward transitions from state *j* to state *i*, *Nj* is the number of representatives of state *j*

Figure 19 illustrates the most common upwards transition of the lithologies being analysed. A very complex pattern of transitions occurs because both fining and coarsening upwards sequences are present. Occurrence of coal and coaly shales with respect to sedimentary sequences seems mainly to be related to coarsening and fining upwards sequences as showed in Fig.

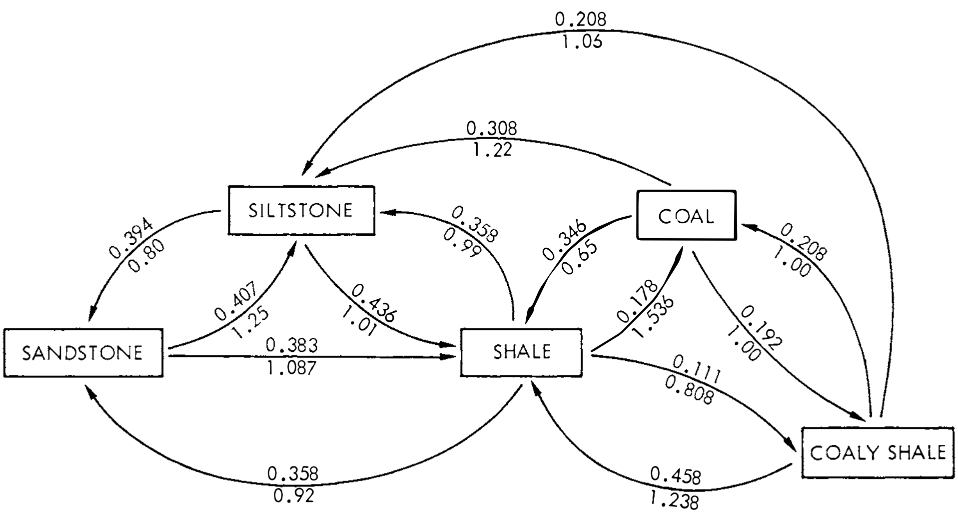


Fig. 19. *Diagram showing upward transition probabilities for the lithologies A, B, C, D, and E. For any transition the upper value represents the transition probability while the lower one shows the prior deposition criterion.*

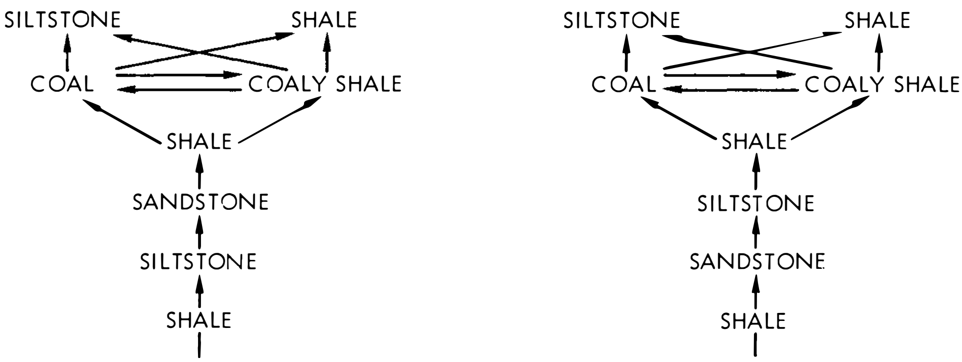


Fig. 20. *Most common types of coal-bearing sequences (generalized) occurring in Vesalstranda Member (Røedvika Formation), Bjørnøya.*

20. This relationship, observed from Markov chain analyses, corresponds fairly well with observations in the field, as coal and coaly shale very often are associated with lacustrine delta sequences and fining upwards channel sandstone sequences. The very generalized lithological sequences illustrated in Fig. 20 may hence be predictive with respect to coal occurrence.

Acknowledgements

This work is part of a cand. real. thesis submitted to the University of Bergen (1978). It is also part of the Svalbard Project (Geologisk Institutt, Universitetet i Bergen), finaced by Norges Teknisk-Naturvitenskaplige Forskningsråd, Norsk Polarinstitutt, and the University of Bergen. I thank Dr. Ronald J. Steel for suggesting and supervising the work, and Dr. Mark Edwards for discussion. Jordskjelvstasjonen (University of Bergen) provided transport to Bjørnøya in 1975.

References

ALLEN, J. R. L., 1963: The classification of cross-stratified units, with notes on their origin. *Sedimentology* 2: 93—114.

— 1964: Sedimentation in the modern delta of the River Niger, West Africa. In: L. M. J. U. Van Straten (ed.), *Deltaic and Shallow Marine Deposits*, Elsevier, Amsterdam: 26—34.

— 1965a: A review of the origin and characteristics of recent alluvial sediments. *Sedimentology* 5 (2): 89—91.

— 1965b: Late Quarternary Niger delta and adjacent areas: sedimentary environment and lithofacies. *Bull. Am. Assoc. Petrol. Geol.* 49: 547—600.

— 1968: *Current Ripples. Their relation to patterns of water and sediment motion.* 443 pp. Amsterdam North-Holland Publ. comp.

— 1970: Studies in fluviatile sedimentation: A comparison of fining-upwards cyclothems, with special reference to coarsemember composition and interpretation. *J. Sediment. Petrol.* 40: 298—323.

ALLEN, J. R. L. and N. L. BANKS 1972: An interpretation and analysis of recumbent-folded deformed cross-bedding. *Sedimentology* 19: 257—283.

ANDERSON, B., 1961: The Rufiji Basin, Tanganyika. 7. Soils of the Main Irrigable Areas. *Rept. Govt. Tanganyika, Prelim. Reconnissance Surv. Rufiji Basin.* 125 pp.

BERNARD, H. A., R. J. LeBLANC, and C. F. MAJOR, 1962: Recent and pleistocene geology of southeast Texas. Geol. Gulf Coast and central Texas and guidebook of excursion. *Houston Geol. Soc.:* 175—224.

BERNARD, H. A. and C. F. MAJOR, 1963: Recent meander belt deposits of the Brazoz River: An alluvial «sand» model. *Bull. Am. Assoc. Petrol. Geol.* 47: 350 (Abstract).

BLUCK, B. J., 1971: Sedimentation in the meandering River Endrick. *Scottish Journal of Geology* 7 (2): 93—138.

CLIFTON, H. E., 1969: Beach Lamina: Nature and origin. *Marine Geol.* 7: 553—559.

— 1973: Pebble segregation and bed lenticularity in waveworked versus alluvial gravel. *Sedimentology* 20: 173—187.

COLEMAN, J. M. and J. E. WEBB, 1964: Minor sedimentary structures in a prograding distributary. *Mar. Geol.* 1: 240—258.

CUTBILL, J. L. and A. CHALLINOR, 1965: Revision of the stratigraphical scheme for Carboniferous and Permian rocks of Spitsbergen and Bjørnøya. *Geol. Mag.* 102 (5): 418—439.

DAVIES, D.K., F. G. ETHRIDGE, and R. R. BERG, 1971: Recognition of barrier environments. *Bull. Am. Assoc. Petrol. Geol.* 55 (4): 550—565.

DOUGLAS, D. J., 1962: The structure of sedimentary deposits of braided rivers. *Sedimentology* 1: 167—190.

ELLIOTT, T., 1974: Interdistributary bay sequences and their genesis. *Sedimentology* 21: 611—622.

FISK, H. N., 1944: Geological investigation of the alluvial valley of the lower Mississippi River. *Mississippi River Commission Vicksburg, Miss.* 77 pp.

— 1947: Fine-grained alluvial deposits and their effects on Mississippi River activity. *Mississippi River Commission Vicksburg, Miss.* 82 pp.

— 1955: Sand facies of recent Mississippi delta deposits. *Proceedings of the Fourth World Petroleum Congress, Sec I/C* 3: 377—398.

— 1961: Bar-finger sands of the Mississippi delta. In: J. A. Petterson and J. C. Osmond (eds.), Geometry of sandstone bodies, Tulsa, Oklahoma. *Am. Assoc. Petrol. Geol.:* 29—52.

FOLK, R. L. and WARD, 1957: Brazo River bar: A study in the significance of grain size parameters. *J. Sediment. Petrol.* 27: 3—26.

FRAZIER, D. E. and A. OSANIK, 1961: Point-bar deposits, Old River Locksite, Louisiana. *Trans. Gulf Coastal Assoc. Geol. Soc.* 11: 121—137.

GOULD, H. R., 1970: The Mississippi delta complex. In: J. P. Morgan ed., Deltaic sedimentation modern and ancient. *Spec. Publ. Soc. Econ. Paleont. Miner., Tulsa* 15: 2—47.

HORN, G. and A. ORVIN, 1928: Geology of Bear Island. *Skr. Svalb. og Ishavet* Nr. 15. 152 pp.

JOPLING, A. V., 1967: Origin of laminae deposited by the movement of ripples along a streambed: A laboratory study. *J. Geol.* 75: 287—305.

KAISER, H., 1970: Die Oberdevon-Flora der Bäreninsel, 3. Mikroflora des höheren Oberdevons und des Unterkarbons. *Palaeontographica Abt. B* 129: 71—124.

— 1971: Die Oberdevon-Flora der Bäreninsel, 4. Mikroflora der Misery-Serie und der flözleeren Sandstein-Serie. *Palaeontographica Abt. B* 135: 127—164.

KRASIL'ŠČIKOV, A. A. and Ju. Ja: LIVŠIC 1974: Tectonika ostrova Medvežij (Tectonics of Bjørnøya). *Geotektonika* 1974 No. 4: 39—51.

LATTMAN, L. H., 1960: Cross-section of a flood plain in a moist region of moderate relief. *J Sediment Petrol.* 41: 651—670.

LEEDER, M. R., 1973: Fluviatile fining-upwards cycles and the magnitude of palaeochannels. *Geol. Mag.* 110 (3): 265—276.

— 1974: Lower Border Group (Tournaisian) fluvio-deltaic sedimentation and palaeogeography of the Northumberland Basin. *Proc. Yorks. geol. Soc.* 40: 120—180.

LEOPOLD, L. B. and M. G. WOLMAN, 1957: River floodplains — some observations on their formation. *U.S. Geol. Survey Prof. Paper* 282-C: 85—120.

LORENS, P. J. and R. C. THRONSON, 1955: Geology of the fine-grained alluvial deposits in Sacramento Valley and their relationship to seepage. In H. O. Banks (ed.), *Seepage Conditions in Sacramento Valley — Rept. Water Proj. Authority Calif.* A1—A26.

McGOWEN, J. H. and L. E. GARNER, 1970: Physiographic features and stratification types of coarse-grained point bars: Modern and ancient examples. *Sedimentology* 14: 77—111.

NATHORST, A. G., 1894: Zur paläozoischen Flora der arktischen Zone enthaltend die auf Spitzbergen, auf der Bären-Insel und auf Novaja Zemlja von den schwedischen Expeditionen entdeckten paläozoischen Pflanzen. Stockholm 1894: 53—77. — *Stockholm, Vet. — Ak. Handl.* 26 (4).

— 1900: Über die oberdevonische Flora (die «Ursaflora») der Bären-Insel. (Vorl.Mitt.). — *Upsala, Bull. Geol. Inst. No 8* (vol. 4 pt. 2), 1899, (pr. 1900): 152—156.

— 1902: Zur oberdevonischen Flora der Bären-Insel. *Stockholm, Vet. — Ak. Handl.* 36: (3).

OOMKENS, E., 1970: Depositional sequences and sand distribution in the postglacial Rhone Delta complex. In: J. P. Morgan (ed.). Delta sedimentation modern and ancient. *Spec. Publ. Soc. Econ. Paleont. Miner., Tulsa* 15: 198—212.

PETTIJOHN, F. J., 1975: *Sedimentary rocks.* Harper and Row, (Publishers) New York, Evenston, San Francisco and London. 628 pp.

REINECK, H. E. and I. B. SINGH, 1973: *Depositional Sedimentary Environments.* Springer-Verlag, Berlin. 439 pp.

SCRUTON, P. C., 1960: Delta building and the deltaic sequence. In: F. P. Shepard, F. B. Phleger, T. H. Van Andel (eds.), Recent sediments, northwest Gulf of Mexico. Tuls, Oklahoma. *Am. Assoc. Petr. Geol.:* 82—102.

SELLEY, R. C., 1970: *Ancient Sedimentary Environments.* Chapman and Hall, Ltd. London. 237 pp.

SHANTZER, E. V., 1951: Alluvium of river plains in a temperate zone and its significance for understanding the laws governing the structure and formation of alluvial suites. *Tr. Inst. Geol. Nauk, Akad. Nauk S.S.S.R., Geol. Ser.* 135: 1—271 (In Russian).

SHEPHARD, F.P., 1956: Marginal sediments of Mississippi delta. *Am. Ass. Petrol. Geol. Bull.* 40: 2537—2623.

SHUMM, S. A. and H. R. KHAN, 1972: Experimental study of channel pattern: *Geol. Soc. Am. Bull.* 83: 1755—1770.

SMITH, N. D., 1970: The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians. *Geol. Soc. Am. Bull.,* 81: 2993—3014.

— 1971: Transverse bars and braiding in the lower Platte River, Nebraska. *Geol. Soc. Am. Bull.* 82: 3407—3420.

STEEL, R. J., 1974: Cornstone (fossil caliche) — its origin, stratigraphic, and sedimentological importance in the New Red Sandstone, Western Scotland. *J. Geol.* 82: 351—369.

STEEL, R. J. and A. C. WILSON, 1975: Sedimentation and tectonism (? Permo-Triassic) on the margin of the North Minch Basin, Lewis. *J. Geol. Soc.* 131: 183—202.

THOMPSON, W. O., 1937: Original structures of beaches, bars, and dunes. *Geol. Soc. Am. Bull.* 48: 723—752.

WALTHER, J., 1894: *Lithogenesis der Gegenwart Beobachtungen über die Bildung der Gesteine an der heutigen Erdoberfläche, Dritter Teil einer Einleitung in die Geologie als historische Wissenschaft:* 535—1055. Jena. Verlag Gustav Fischer.

WILLIAMS, P. F. and B. R. RUST, 1969: The sedimentology of a braided river. *J. Sedim. Petrol.* 39: 649—679.

WOODWARD, A. S., 1900: Notes on Fossil Fish-Remains collected in Spitzbergen by the Swedisch Arctic expedition, 1893. Stockholm 1900, 7 pp. — *Stockholm. Vet. — Ak. Bih.* 25, Afd IV (5).

WORSLEY, D. and M. B. EDWARDS, 1976: The Upper Palaeozoic succession of Bjørnøya. *Norsk Polarinstitutt Årbok* 1974: 17—34.

Origin of carbonate in marine shales of the Janusfjellet Formation, Svalbard

By HENNING DYPVIK[1]

Abstract

In order to study the mechanisms of formation and diagenesis of the carbonate beds in the Janusfjellet Formation (Jurassic-Cretaceous), Svalbard, petrographical and geochemical analyses have been carried out.

The carbonate horizons were originally deposited at shallow depths in periods with small or neglectable clastic sedimentation. After deposition and burial to minor depth sideritisation and dolomitisation took place. Generally the carbonate horizons from the Rurikfjellet Member are more sideritic than the silty carbonates from the Agardhfjellet Member.

Introduction

The Janusfjellet Formation, which mainly consists of dark, marine shales with interbedded discontinuous carbonate horizons, is divided into two members: The Upper Jurassic Agardhfjellet Member and the Lower Cretaceous Rurikfjellet Member (Fig. 1). After deposition of the marine Agardhfjellet Member, a period of nondeposition, faulting and volcanic activity followed (Parker 1966). Doleritic intrusions were probably emplaced throughout Svalbard in a single event at that time (Gayer et al. 1966; Tyrell and Sandford 1933). The overlying Rurikfjellet Member was deposited after this break in sedimentation.

Discontinuous carbonate beds and nodules in the Rurikfjellet Member are generally dark red coloured; in the middle and lower Agardhfjellet Member carbonate horizons are more silty and usually have a lighter, yellow colour, reflecting different mineralogical composition. As described by Parker (1967) red carbonate horizons are found in the upper part and the lowermost ∾ 20 m of the Agardhfjellet Member. In the uppermost beds of the Rurikfjellet Member dark (grey-brown) spherical carbonate nodules (five to ten centimetres in diameter) are found.

Twentyone of these carbonate horizons, in addition to adjacent shales, were sampled during the summer of 1976, when the University of Oslo «Svalbard project group», organized an expedition to the Sassenfjorden area. Carbonate beds were sampled in two sections at Knorringfjellet and Wimanfjellet

[1] Institutt for geologi, Universitetet i Oslo.

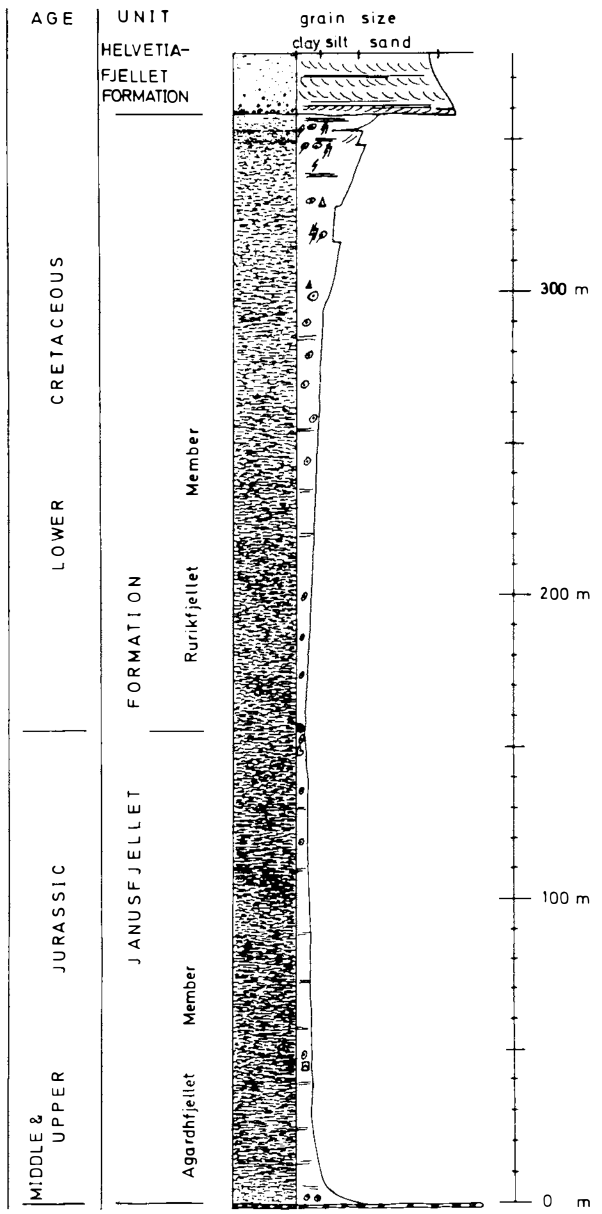


Fig. 1. *Lithological column for the Janusfjellet Formation, Isfjorden, Svalbard. Scale in m to the right.*

(Fig. 2). In order to study the mechanisms of formation and diagenesis of these units, petrographical and geochemical analyses of the carbonates were carried out. The results of these analyses combined with field relations, are presented in this paper (Tables 1 and 2).

The petrology has been studied in thin section and by X-ray diffraction analyses, while major and trace elements have been determined by X-ray fluorescence analyses.

Table 1.

Main elements in carbonate samples from the Janusfjellet Formation, Wimanfjellet (WIM) and Knorringfjellet (KF) sections. Concentrations determined by X-ray fluorescence. Values in %. Ign. loss = Ignition loss.

SAMPLE	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	ign. loss	Σ
KF 5-76	28.0	0.49	7.3	23.2	0.2	3.4	11.0	0.2	1.3	0.17	23.01	98.27
KF 18-76	23.9	0.46	6.2	31.6	0.2	7.1	3.0	0.1	1.1	0.22	24.27	98.35
KF 20B-76	18.8	0.45	5.7	30.0	0.2	8.0	3.9	0.4	1.1	0.35	28.22	97.12
KF 28-76	35.0	0.47	7.0	5.3	0.1	8.9	14.0	5.0	1.6	0.19	23.94	101.50
KF 31-76	21.0	0.39	6.5	4.9	0.1	11.4	20.4	0.3	1.0	0.25	31.64	97.88
KF 35-76	48.0	0.91	11.9	18.0	0.1	2.9	1.7	0.1	1.8	0.08	13.84	99.35
KF 36-76	24.0	0.45	5.9	23.3	0.1	6.0	10.2	0.2	0.9	0.48	26.13	97.66
WIM 10-76	33.3	0.58	10.3	12.1	0.1	2.0	16.8	0.4	1.5	0.27	21.94	99.29
WIM 12C-76	23.0	0.19	2.3	19.6	0.3	2.0	20.8	0.1	0.5	0.41	28.73	97.93
WIM 24-76	21.1	0.42	5.4	33.5	0.3	4.7	5.0	0.1	0.8	0.89	26.81	99.02
WIM 36B-76	18.3	0.38	5.1	29.7	0.2	9.7	5.8	0.2	1.0	0.90	29.66	100.94
WIM 55-76	25.7	0.39	6.4	4.0	0.1	12.5	18.5	0.3	1.2	0.15	29.76	99.00
WIM 57-76	22.6	0.36	6.2	2.6	0.1	14.6	18.5	0.3	0.9	0.34	33.36	99.86

Table 2.

Trace elements in carbonate samples from the Janusfjellet Formation, Wimanfjellet (WIM) and Knorringfjellet (KF) sections. Concentrations determined by X-ray fluorescence. Values in ppm. n.d. = not detected.

SAMPLE	Cr	V	Rb	Sr	Ba	Ni	Co	Zr
KF 5–76	90	171	5	233	436	n.d.	66	74
KF 18–76	129	170	n.d.	48	534	< 5	108	5
KF 20B–76	148	209	n.d.	65	585	13	104	21
KF 28–76	65	168	29	547	432	38	13	138
KF 31–76	73	201	20	648	283	230	14	118
KF 35–76	265	182	24	103	467	178	62	205
KF 36–76	157	166	2	195	437	62	74	55
WIM 10–76	61	207	14	337	472	24	34	149
WIM 12C–76	80	205	n.d.	882	577	n.d.	55	71
WIM 24–76	114	222	n.d.	134	425	n.d.	112	29
WIM 36B–76	148	168	n.d.	82	603	n.d.	99	18
WIM 55–76	60	111	18	551	425	32	10	139
WIM 57–76	61	102	19	1120	462	35	5	129

Results

Lihology

The spherical nodules in the upper part of the Rurikfjellet Member consist of calcite and siderite with some additional clastic material. The reddish «concretionary» ironstone beds from Rurikfjellet and Agardhfjellet Members consist mostly of siderite in addition to minor amounts of clastic grains. Thin sections of siderite-rich carbonate horizons, coloured with Alizarin red S and hexacyanoferrate (Evamy 1969) indicate iron-rich sparry calcite as commonly occurring between the microsparitic siderite and calcite grains.

The clastic content in all the analysed samples was always less than 30 vol. % (about 400 points counted in thin sections) and normally below 40 weight % (crude estimates from chem.anal.). The Agardhfjellet Member carbonate horizons generally have a higher clastic content than similar beds from the Rurikfjellet Member. Moulds of ammonites and bivalves have been found in or close to several of the carbonate beds, and high concentrations of *Buchia* sp. are especially common in those close to the Jurassic/Cretaceous boundary. Mostly belemnites have been found in the Rurikfjellet Member.

Based on field relations and petrological analyses (Fig. 3), it is possible to separate the carbonate beds and nodules from both sections into three main units.

A) Carbonate horizons in the uppermost 50—100 m of the Rurikfjellet Member consist of microspar, siderite, and clastic grains (quartz and clay-minerals) rimmed by iron-rich sparry calcite. Clots of framboidal pyrite are seen to grow on the siderite together with calcite. Sparry calcite is also found filling cavities in the samples. Cuticular remnants and other organic debris are found dispersed in these beds.

B) In the middle part of the formation reddish carbonate horizons are found. These sediments (Fig. 3) consist of micro-sparitic siderite with dispersed clastic grains of quartz and clay-minerals, the quartz grains often showing undulating extinction. In these samples minor amounts of pyrite are seen.

C) In the middle and lower parts of the Agardhfjellet Member, mainly yellowish beds of dolomite are found. The samples contain at the most about 20 to 30 vol. % clastic grains. Siderite and sparry calcite are occasionally found as cavity fill. The carbonates in the lowest part of this unit are mainly siderite and dolomite. In all samples from this unit pyrite are seen to grow on clastic grains.

The paleontological and mineralogical results of Pchelina (1970 a,b) indicate the above mentioned unit A to represent Hauterivian sediments, unit B

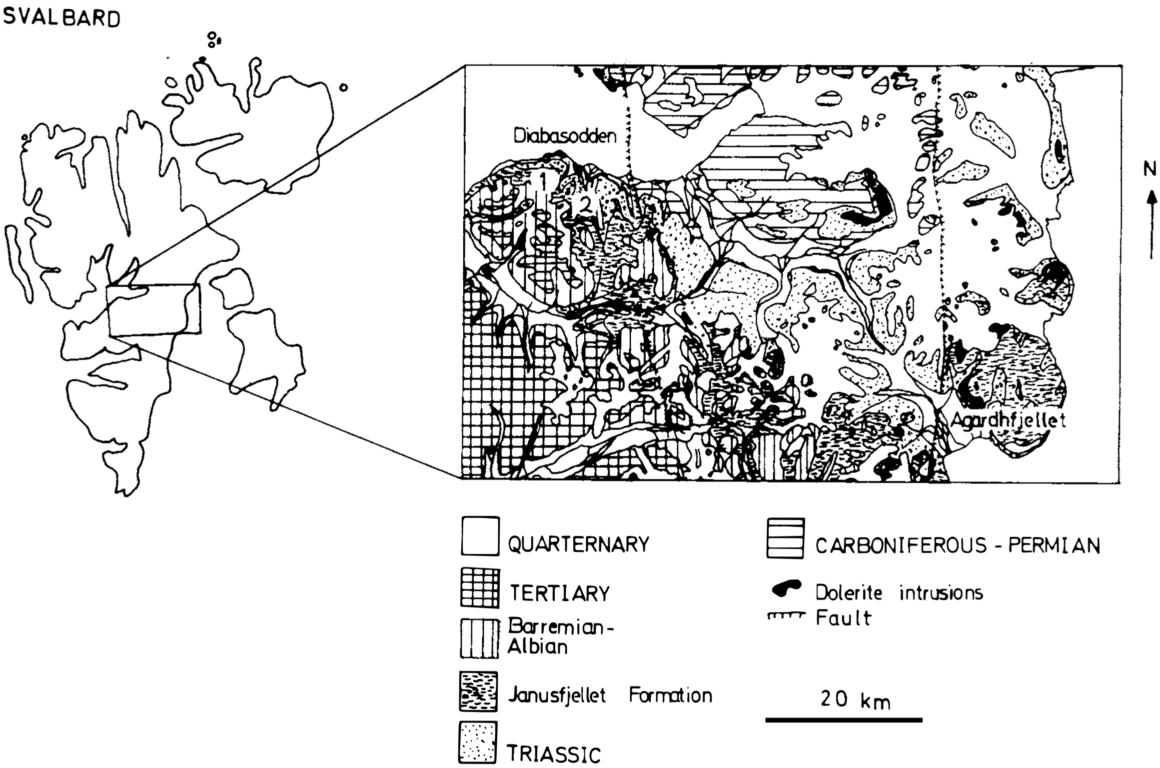


Fig. 2. *Geological map of the Isfjorden — Sassendalen area, Svalbard. Based on Flood et al. (1971). 1. Wimanfjellet; 2. Knorringfjellet.*

Valanginian and Volgian layers, and unit C Kimmeridgian, Oxfordian, and probably Callovian beds.

Geochemistry

Geochemical analyses of major and trace elements have been performed on thirteen samples (Tables 1 and 2).

The SiO_2, TiO_2, Al_2O_3, Na_2O, K_2O, Rb and Cr variations broadly reflect those of the clastic fraction, while Fe_2O_3, CaO, MnO, MgO, Sr, and Co mainly are associated with the carbonates. The analysed carbonates are enriched in P_2O_5 compared to the surrounding shales. Both mineralogical and geochemical trends are dissimilar to those of the shales in the same succession with the exception of Zr. In both carbonates and shales, the Zr content decreases upwards in the Agardhfjellet Member and increases upwards in the Rurikfjellet Member.

Co and Fe_2O_3 are always positively correlated, Fe being either bound in siderite or pyrite. Ni is, however, mainly associated with Fe in pyrite. Sr is mainly bound in calcite in unit A and dolomite in unit C. The V and Ba varia-

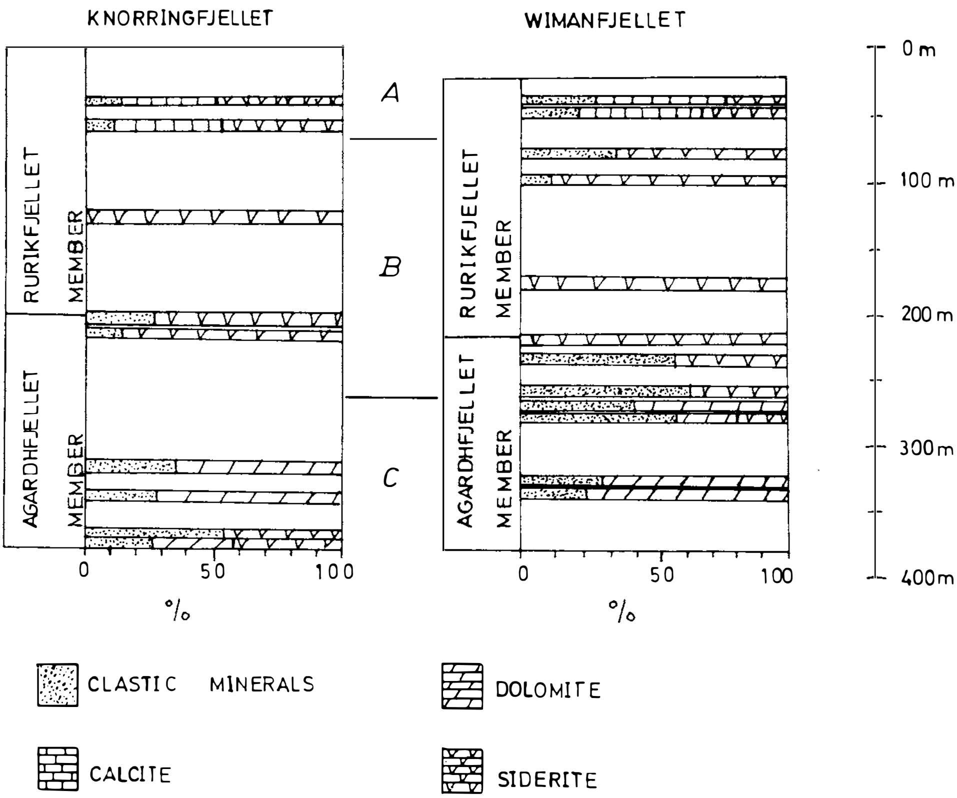


Fig. 3. *Fig. 3 is constructed based on semiquantitative calculations from X-ray diffraction analyses. The different samples are stratigraphically plotted. Note the similar lithological developments in both sections. Three different groups, A, B and C (p. 104), are separated. Scale in m to the right.*

tions are rather difficult to interpret, but they probably reflect variations in the clastic fraction. Shales above and below the carbonates do not display special depletions or enrichments of the different elements, e.g. above and below the different carbonate beds both Sr and Ba are found in similar quantities to those seen within the beds.

Discussion

The discontinuous carbonate beds with moulds of ammonites and bivalves indicate periods when little clastic material accumulated and winnowing by current and/or wave activity removed fine grained clastic material. Shells or skeletal fragments of aragonite and Mg-calcite were deposited, as most of the ammonites and bivalves were originally composed of that $CaCO_3$ modification (Horowitz and Potter 1971). Both macrofossils and microfossils (Bjærke 1978), verify the marine origin of these beds. Based on the stability diagram with pH, Eh and pS^{2-} variations in marine and non-marine environments, Berner (1971), however, concluded that primary siderite deposition takes place in continental environments, while iron sulphide deposition is typical of marine environments. This indicates a secondary diagenetic siderite formation in the Janusfjellet Formation.

The almost completely spheroidal nodules of unit A, occur dispersed in a zone of silty shale and show a rather constant size; they contain no skeletal remains and show a homogenous microspar microtexture; they most probably have a diagenetic origin. The other carbonate «concretions» of unit A, B, and C are found in more irregular zones often with moulds of dissolved skeletal fragments. These carbonate beds from the middle and lower parts of the Rurikfjellet Member and the Agardhfjellet Member were originally probably deposited as beds or banks of bivalves and ammonites. Iron oxide/hydroxide compunds were also deposited in these beds. Clastic sedimentation during these periods was of minor importance, but was, generally higher in the Agardhfjellet than the Rurikfjellet Member.

Iron supply as colloids of iron oxides/hydroxides or oxide coatings on clay particles may represent weathering products of source areas. Remnants of organic material in several samples indicate well developed vegetation in adjacent areas. The Svalbard area probably lay in the northern humid climatic belt during the Jurassic, with resulting kaolinite formation in weathering horizons. Such horizons are found in areas as Andøya (Dalland 1975) and East Greenland (Håkanson et al. 1971).

The iron supply may, however, also have had a volcanic origin, either from volcanic exhalation or from the weathering of iron-rich volcanics. At the Jurassic/Cretaceous boundary doleritic magmas intruded the Svalbard area. The high Fe concentrations in sediments at this startigraphical level point to a volcanic iron source. Upwards decreasing Fe concentrations in the Rurikfjellet Member may indicate a decreasing influx of volcanic derived material. The fact that both shales and carbonates from the Rurikfjellet Member generally contain more Fe_2O_3 and siderite than the underlying Agardhfjellet Member also suggests such a volcanic source for these sediments. Iron is probably derived mainly from the weathering of volcanic rocks, a volcanic exhaltive origin being less likely (Dypvik 1978). According to this theory siderite enrichments in the uppermost part of Agardhfjellet Member may indicate a Kimmerdgian start of the volcanic episode or a generally increased weathering intensity.

In both members iron is probably mostly derived from weathering profiles. Weathering of newly formed dolerites would explain the higher Fe_2O_3 amounts in the post volcanic uppermost Agardhfjellet and Rurikfjellet Members than in the middle- and lowermost Agardhfjellet Member. The Fe colloids formed by such mechanisms contained absorbed Co^{3+} compounds, may form colloides with Fe^{3+}, it is difficult for Ni, which does not easily form Ni^{3+} compounds (Carvajal and Landergren 1969). Ni may, however, be enriched with iron in sulphides, such as pyrite.

The ferric iron colloids were transported out into the sedimentary basin and deposited slowly. Friedman et al. (1968) found that reducing contitions prevail in outer shelf muds between 20 cm and 40 cm below the sediment-water interface. Consequently when buried to such depths, the ferric iron oxides/hydroxides may have been reduced and iron and cobalt mobilised as divalent ions. S^{2-} or SO_4^{2-} concentrations were probably low because of earlier pyrite formation in anarobic environments near the sediment water interface. The ferrous iron liberated may therefore have sideritised the original carbonates or it was precipitated directly as siderite together with CO_3^{2-} formed by bacterial decay, as described by Sellwood (1971) for sideritic beds in the Yorkshire Lias. Co^{2+} joined these reactions. This siderite formation took place in the Rurikfjellet Member and in the uppermost- and a few of the lowermost carbonate beds of the Agardhfjellet Member.

Only minor amounts of Ni joined these reactions due to minor Ni supply and to Ni enrichments in earlier precipitated sulphides. Such pyrite and siderite formation explains the geochemical separation of Ni and Co in these samples. The result is in good agreement with the theories presented by Carvajal and Landergren (1969).

Because of minor Fe supply in the middle and most of the lower part of the Agardhfjellet Member, only minor sideritisation took place and the original unstable carbonates (Mg-calcite and aragonite) were mainly dolomitised. During the deposition of these carbonates clastic supply was minor, and the often highly bioclastic beds indicated by high enrichments of skeletal moulds and minor amounts of finer particles, probably were exposed to wave and/or current action. This indicates shallow conditions and the possibility of so called Dorag dolomitisation (Badiozamani 1973) in the mixed zone between meteoric phreatic and marine phreatic waters. The shallow depths in which these beds were deposited make such a mixturing of fresh and marine water probable. In this mixing zone a Mg^{2+}/Ca^{2+} ratio about one and Mg^{2+} supply from marine water may quickly dolomitise the original carbonates (Land 1973; Steinen and Matthews 1973). In thin sections only minor amounts of these iron rich dolomites are seen to be dedolomitised.

The geochemical analyses show that the elements analysed are associated with the clastic fraction (Si, Ti, Al, Na, K, Rb, Cr, Zr, V, and Ba) and the carbonates such as siderite (Fe, Mg, Mn, Co), dolomite (Mg, Ca, Sr), and calcite (Ca, Sr). The major part of Ni and some Fe are found in pyrite.

Conclusion

Probably immediately after deposition of shells and skeletal fragments, diagenetic formation of Ni rich pyrite took place. After burial to minor depth sideritisation took place in a reducing environment. At this time the S^{2-} activity was of minor importance, because the major part of it was already bound in early diagenetic pyrite. The iron which formed siderite was orginally mainly derived as colloids from weathering profiles. In the post volcanic sediments of the Rurikfjellet Member there was a higher iron supply than in the middle and lower parts of the Agardhfjellet Member, because of influx of weathered iron-rich volcanic material. In the Rurikfjelllet Member, and in the upper and lowermost beds of the Agardhfjellet Member, ferric compounds relatively enriched in Co and depleted in Ni, after minor burial, were reduced and ferrous iron sideritised the original carbonates and probably also some siderite precipitated. There was probably a recrystallisation episode which formed microsparitic siderite and left organic material and clastic grains relatively unaltered.

The sideritisation episode was followed by later minor calcitisation reactions which took place in the most permeable parts of the sediments. These processes demand reducing conditions as the iron liberated formed iron sulphides and framboidal pyrite relatively rapidly after its liberation.

In most of the Agardhfjellet Member, however, the iron supply was minor, and, due to shallowing, the winnowed carbonate beds may have been dolomitised in the mixed phreatic zone by Dorag dolomitisation (Badiozamani 1973).

The carbonate beds and nodules from Knorringfjellet and Wimanfjellet display similar lithological developments. (Fig. 3). This points to a wider, more regional, explanation for the formation of the carbonate units.

Based on these reflections it is reasonable to regard the carbonate horizons as originally deposited at shallow depth in periods with small or neglectable clastic sedimentation. Consequently the beds may be interpreted as more or less regional breakmarkers in the clastic sedimentation. This is also confirmed by the high concentration of P_2O_5 in most of the carbonate units. P_2O_5 enrichments are often associated breaks in clastic deposition (D'Anglejan 1967; McKelvey 1967). After deposition the original carbonate mineralogy was changed by several diagenetic alterations.

Acknowledgements

I wish to thank cand. reals. B. Bue, N. M. Hanken, and T. Høy and Drs. K. Bjørlykke and D. Worsley for valuable suggestions and reviews of the present and earlier drafts of the paper. I would also like to thank cand. real. T. Bjærke for valuable cooperation and discussion during fieldwork in the summer of 1976.

References

BADIOZAMANI, K., 1973: The Dorag dolomittization model — application to the Middle Ordovician of Wisconsin. *Journ. Sed. Pet.* 43: 965—984.

BERNER, R., 1971: *Principles of Chemical sedimentology.* McGraw-Hill, New York. 240 pp.

BJÆRKE, T., 1978: Mesozoic Palynology of Svalbard III. Dinoflagellates from the Rurikfjellet Member, Janusfjellet Formation (Lower Cretaceous) of Spitsbergen. In prep.

CARVAJAL, M. C. & S. LANDERGREN, 1969: Marine sidimentation processes. The interretationships of manganese, cobalt and nickel. *Storckh. Contrib. Geol.* 18: 99—122.

D'ANGLEJAN, B. F. D., 1967: Origin of marine phosphorites off Baja California, Mexico. *Marine Geol.* 5: 15—44.

DALLAND, A., 1975: The Mesozoic Rocks and Andøy, Northern Norway. *Norges geol. Unders.* 316: 271—287.

DYPVIK, H., 1978: Metamorphic changes in Middle Triassic black shales during Early Cretaceous dolerite intrusion at Sassenfjorden, Svalbard. *Chem. Geol.* (in press).

EWAMY, B. D., 1969: The precipitational environment and correlation of some calcite cements deduced from artificial staining. *Journ. Sed. Pet.* 39: 787—793.

FLOOD, B., J. NAGY & T. S. WINSNES, 1971: Geological Map, Svalbard, 1 : 500 000. Sheet 1G, Spitsbergen, Southern Part. *Norsk Polarinstitutt Skrifter* Nr. 154A.

FRIEDMAN, G. M., B. P. FABRICAND, E. S. IMBIMBO, M. E. BREY, and J. E. SANDERS, 1968: Chemical changes in interstitial waters from continental shelf sediments. *Journ. Sed. Pet.* 38: 1313—1319.

GAYER, P. A., D. G. GEE, W. B. HARLAND, J. A. MILLER, H. R. SPALL, R. H. WALLIS & T. S. WINSNES, 1966: Radiometric age determinations of rocks from Spitsbergen. *Norsk Polarinstitutt Skrifter* Nr. 137.

HOROWITZ, A. S. & P. E. POTTER, 1971: *Introductory Petrography of fossils.* Springer Verlag, Berlin. 302 pp.

HÅKANSON, E., T. BIRKELUND, C. HEINBERG & P. WILLUMSEN, 1971: Preliminary results of mapping the Upper Jurassic and lower Cretaceous sediments of Milne Land. *Grønl. Geol. Unders.* 37: 32—41.

McKELVEY, V. E., 1967: Phosphate Deposits. *U.S. Geol. Surv. Prof. Paper* 1252-D. 21 pp.

LAND, L. S., 1973: Holocene meteoric dolomittization of Pleistocene limestones. North Jamaica. *Sedimentology* 20: 411—424.

PARKER, J. R., 1966: Folding, faulting and dolerite intrusions in the Mesozoic rocks of the fault zone of central Spitsbergen. *Norsk Polarinstitutt Årbok* 1964: 47—55.

— 1967: The Jurassic and Createaceous Sequence in Spitsbergen. *Geol. Mag.* 104: 487—505.

PCHELINA, T. M., 1970a: Stratigraphy and composition of the Mesozoic deposits in central Vestspitsbergen. In: W. B. Harland (ed.): *Geology of Spitsbergen 1965, Boston, England, 1970:* 131—154.

— 1970b: Mesozoic deposits around Van Keulenfjorden, Vestspitsbergen. In: W. B. Harland (ed.): *Geology of Spitsbergen 1965. Boston, England,* 1970: 155—181.

SELLWOOD, B. W., 1971: The genesis of some sideritic beds in the Yorkshire Lias (England). *Journ. Sed. Pet.* 41: 854—858.

STEINEN, R. P. & R. K. MATTHEWS, 1973: Phreatic vs. vadose: Stratigraphy and mineralogy of a cored borehole on Barbados, *W. I. Journ. Sed. Pet.* 43: 1012—1020.

TYRELL, G. W. & K. S. SANDFORD, 1933: Geology and Petrology of the Dolerite of Spitsbergen. *Proc. R. Soc. Edinburgh* 53: 284—312.

Helvetiafjellet Formation (Barremian) at Festningen, Spitsbergen — a field guide

By RONALD J. STEEL[1], JOHN GJELBERG[1] and GEIR HAARR[1]

Abstract

Helvetiafjellet Formation (Barremian) has been re-examined at Festningen (Isfjorden), and has been interpreted in terms of facies sequences. The succession consists of a complex interfingering of thick sets of cross-stratified coarse sandstone, thinner sets of cross-stratified fine/medium sandstone, very thin sets of ripple laminated siltstone/fine sandstone and shales. The context of the formation together with the vertical organisation of the first category into upward fining sequences and much of the other three categories into upward coarsening sequences, suggest a delta plain environment with distributary channel sandstones, crevasse channel sandstones, other bay-fill sandstones (levees, crevasse splays) and interdistributary bay fines, respectively. Vertical variability in the formation together with some preliminary regional palaeocurrent evidence, suggest that, despite its apparently sheet-like form, the sequence is internally complex, resulting from lateral coalescence of a number of fluvial-dominated, platform delta systems around the basin edges.

Introduction

Previous work

The Helvetiafjellet Formation, probably largely of Barremian age (Pchelina 1965), consists of a sequence of sandstones, shales and coals. The type section occurs on Helvetiafjellet on the northern side of Adventdalen, but the formation has been formally divided by Parker (1967) into a lower Festningen Sandstone Member and an upper Glitrefjellet Member. The choice of Festningen (Fig. 1) as type locality for the lower member was presumably due to the good exposure, to a much earlier informal «Festningen Sandstone» designation of Nathorst (1913), and to the subsequent detailed examination and description of the profile there (e.g. Frebold 1928, 1931; Hoel and Orvin 1937; Frebold and Stoll 1937). Elsewhere in Spitsbergen the Formation has been studied in some detail around Adventdalen (Parker 1967; Major and Nagy 1972; Smith and Pickton 1976; Steel 1977), in Kjellströmdalen (Hagerman 1925), along Van Keulenfjorden (Pchelina 1965; Nysæther 1966), in Torell Land (Birkenmajer 1975), and in Sørkapp Land (Edwards 1976).

There has been little attempt at a detailed interpretation of the sequence apart from work by Edwards (1976) and Steel (1977).

[1] Geological Institute (Avd. A), University of Bergen.

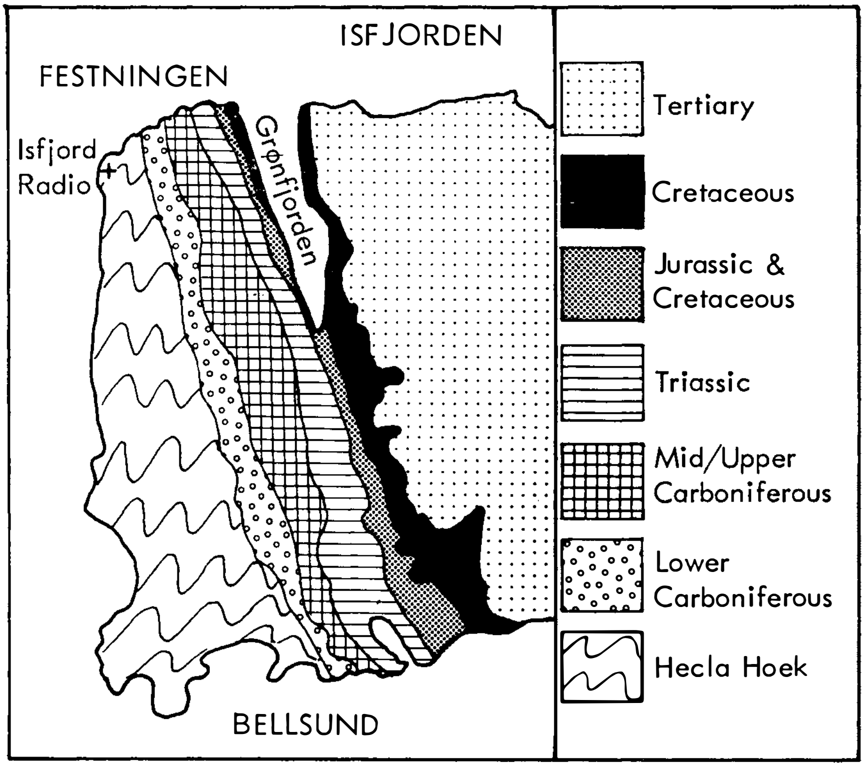


Fig. 1. *Simplified geological map of the area between Isfjorden and Bellsund (after Flood et al. 1971), showing Cretaceous outcrop and the study locality at Festningen.*

Aims of the present study

The primary aim here is to present a facies analysis of the Helvetiafjellet Formation at this easily accessible and often visited locality (Fig. 2). Although part of this section has been appointed type locality for part of the Formation, it is more than 40 years since it was described (Hoel and Orvin 1937), long before we had much notion of the significance of facies sequences. It is hoped that the present description will provide a dynamic framework for future discussion of this section at Festningen. Subsidiary aims are to test some earlier ideas as to the possible delta plain origin of this formation (Steel 1977), and to present briefly some more regional evidence suggesting that the Festningen Sandstone is neither a single sheet nor derived from a single source area. The present study (summer 1977) is part of a larger research programme (Geological Institute, University of Bergen) aimed at a regional facies and petrographic analysis of the Lower Cretaceous strata in Svalbard.

General interpretation

The most obvious and traditional division of the formation has been into a lower sandstone member (Festningen promontory) and an upper coal-shale

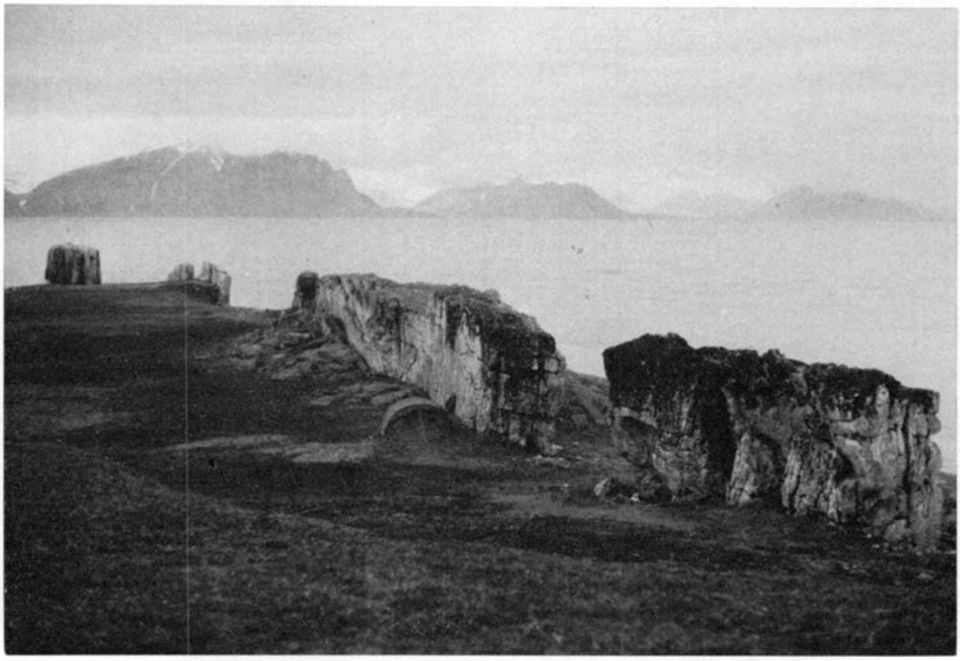


Fig. 2. *The vertically dipping strata of the first distributary channel sandstone body at Festningen.*

member. This division is oversimplified, based more on weathering characteristics of the strata than on lithology, and takes account neither of an equally thick,equally coarse-grained sandstone body in the uppermost portion of the formation nor of a number of other thinner, cross-stratified channel sandstone bodies in the middle reaches of the succession (Fig. 3). This weakness in Parker's (1967) formal subdivision of the formation, manifest in a certain confusion about the recognition of the upper boundary of the Festningen Sandstone Member (e.g. compare Parker 1967; Major and Nagy 1972; and Smith and Pickton 1976), has been noted previously by Smith and Pickton (1976) and by Steel (1977). The division made here, based on grainsize, cross-stratal set thickness and facies sequence, suggests a complex interfingering vertically between channel sandstones with large-scale cross-strata, and strata dominated by coal, shale, and siltstone (Fig. 3).

Fig. 4, based on data from more than 100 cosets of strata representative of the entire formation, is an attempt at summarising he differences between three main types of facies sequence present. It shows that the coarses sandstones and immediately associated strata also have the thickest cross-strata, sandstone sequences of intermediate coarseness have intermediate set thickness, while the finest strata are also organised into extremely thin sets. These three groups of sequences are interpreted in terms of:

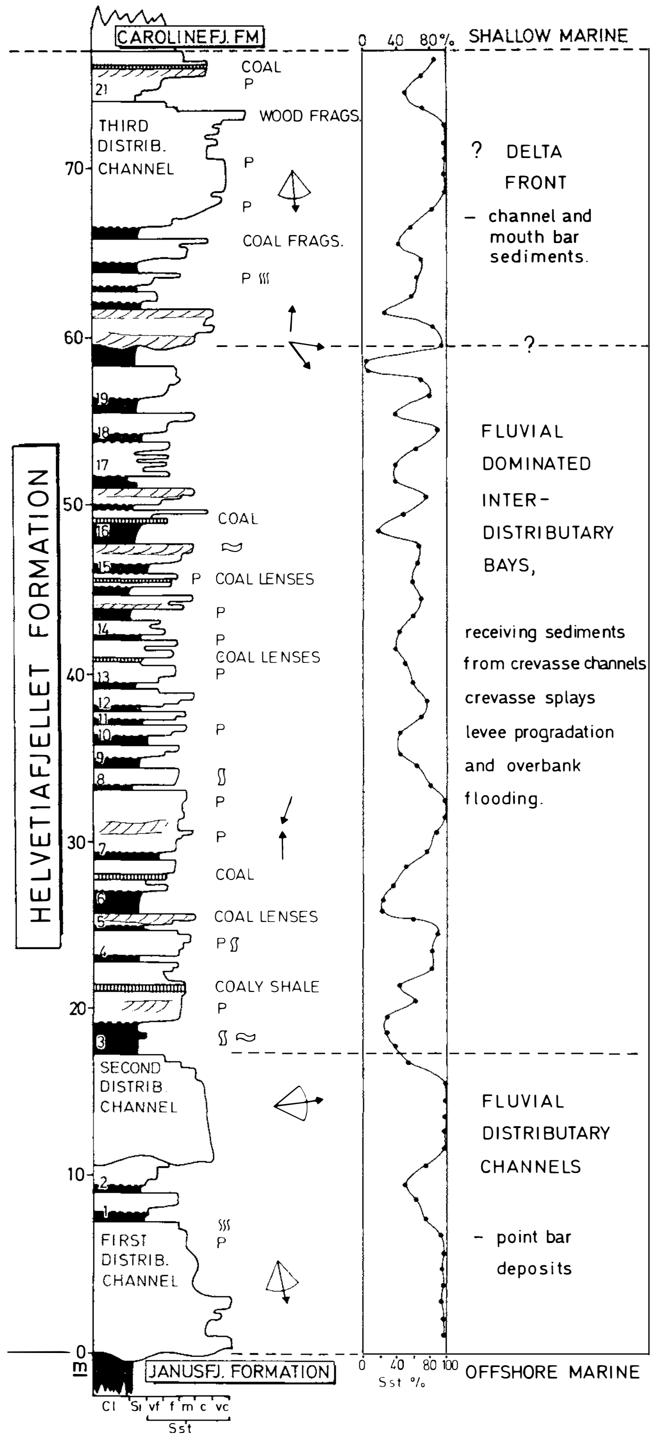


Fig. 3. *Simplified profile through Helvetiafjellet Formation at Festningen, showing the main channel sandstone units, minor channel sandstones (cross-stratified pattern) and alternating shales (black) with ripple laminated sandstones (blank). Generalised palaeocurrents (arrows), a sandstone percentage curve and an interpretation are also shown. The numbers refer to bay sequences, shown in detail in Fig. 10.*

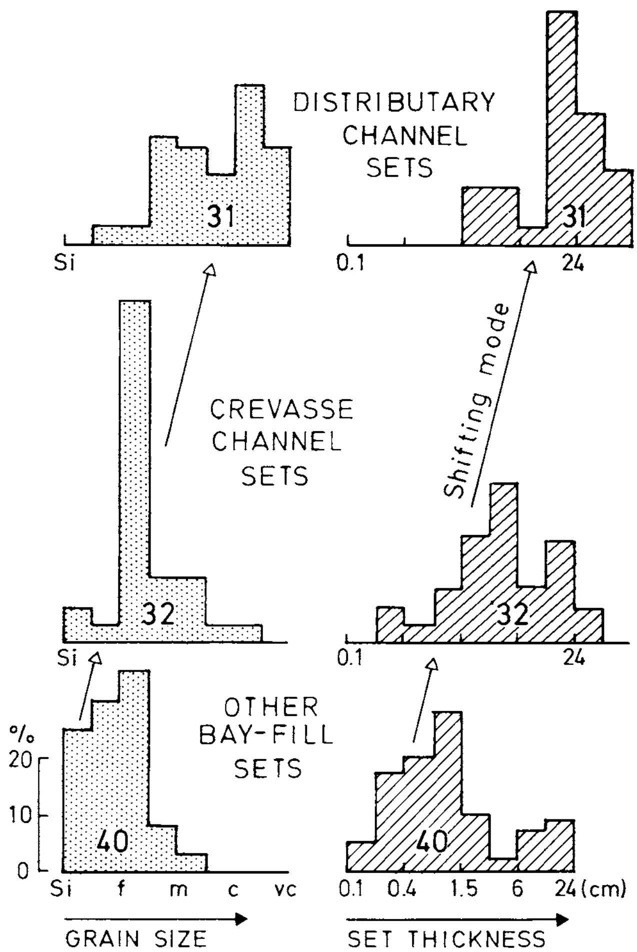


Fig. 4. *Histograms showing the three main groups of sandstone deposits in terms of grain size and cross-stratal set thickness. The numbers refer to the total of cosets recorded in the case of «other bay-fill sets».*

1. Distributary channel sandstones
2. Crevasse channel deposits
3. Other bay-fill sequences e.g. products of overbank flooding, levee progradation or crevasse splay.

These interpretations are discussed more fully below.

The distributary channel sandstone bodies

There are three sandstone bodies, 6.7 m, 5.5 m and 6.2 m thick, respectively (Fig. 3), which are interpreted as having originated partly or wholly from point-bar accretion in high sinuousity distributary channels.

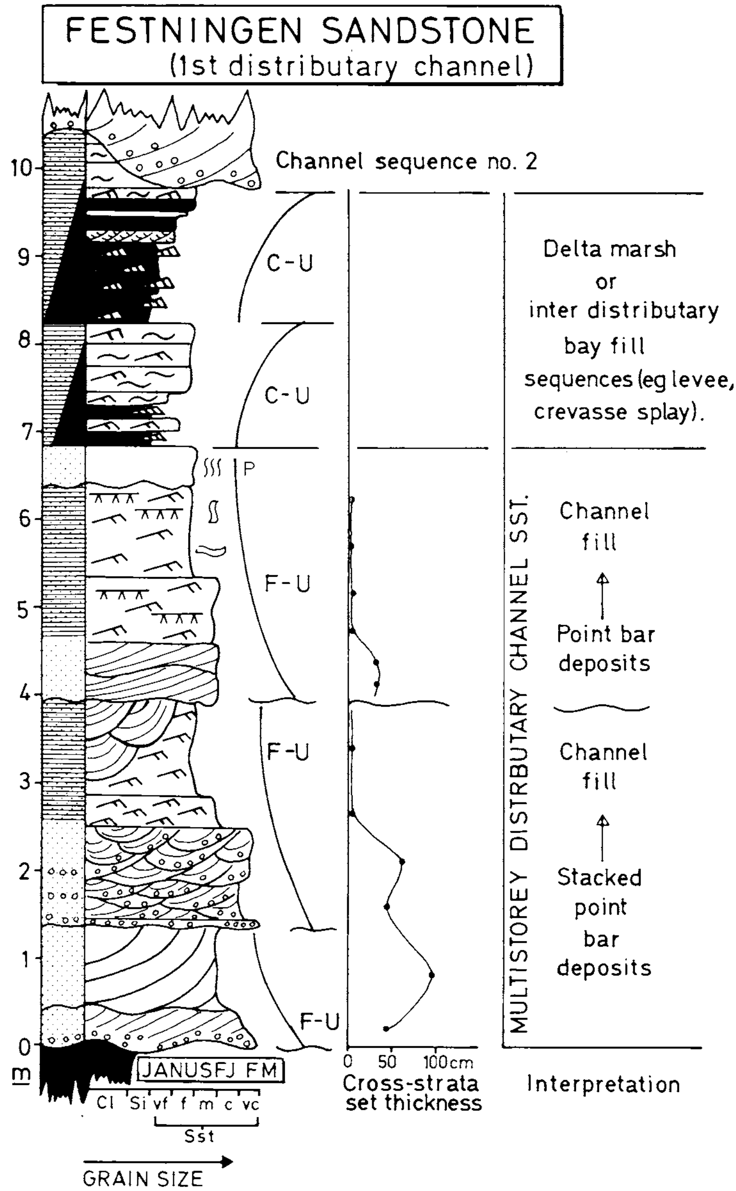


Fig. 5. *Vertical log through the first distributary sandstone body (for legend see Fig. 6).*

The first sandstone body

The lowest sandstone body (0 to 6.7 m in Fig. 3), probably the original Festningen Sandstone of Nathorst (1913), is clearly multistorey (Fig. 5), consisting of at least three smaller upwards fining (and upwards thinning in places) sequences. The uppermost portion of the body tends to be massive due to bioturbation and rootlet development (Fig. 5). In situ rootlets and horizon-

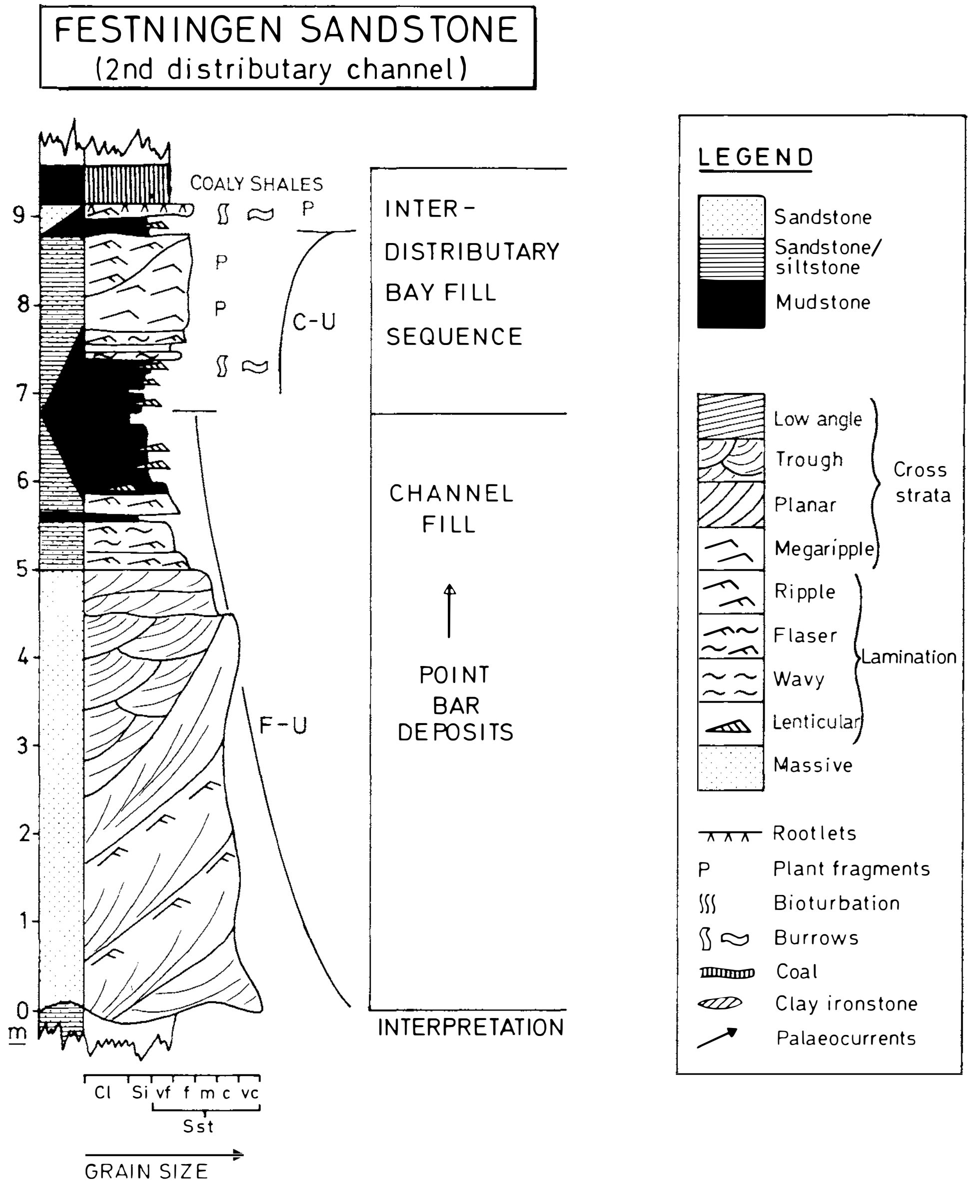


Fig. 6. *Vertical log through the second distributary sandstone body.*

tal and vertical burrows are not uncommon in the ripple laminated horizons near the top of the sandstone sequence.

This lowermost sandstone body tends to vary in thickness laterally, and in places (particularly looking along the length of the body from the highest point on it) it appears as though it may possibly represent one single, very large-scale cross-stratified unit, where the individual cross-stratified subse-

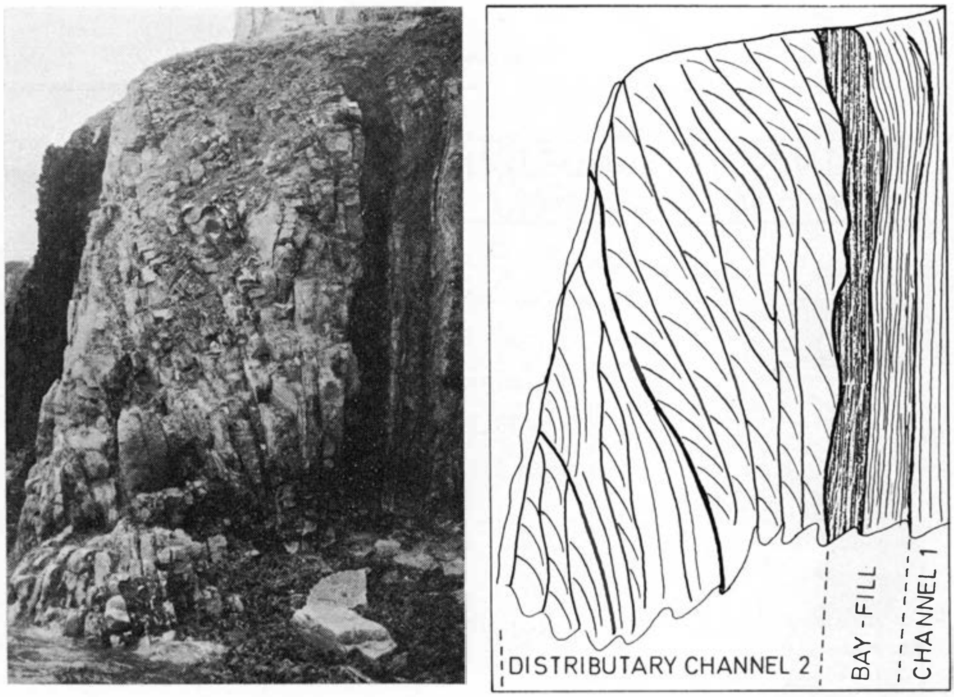


Fig. 7. *The second distributary channel sandstone body seen as a single, internally complex,* epsilon *cross-stratified set.*

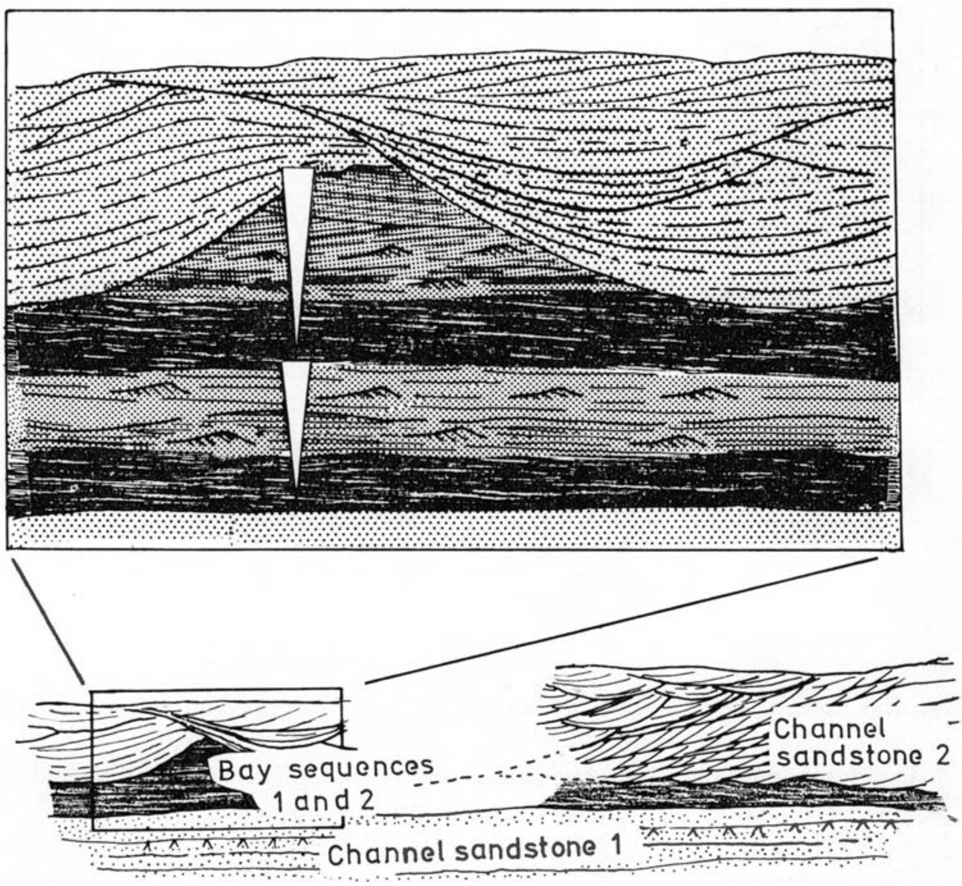


Fig. 8. *Lateral variation within the second distributary channel sandstone body, together with some details from the underlying bay sequences.*

quences already referred to are actually foresets within it. This would imply a simple point-bar development as an alternative to a more complex, multistorey type. In places there is also a tendancy for the fine-grained sequence between the first and second sandstone bodies to disappear, giving the impression of a much thicker single sandstone body.

The lower boundary of the sandstone sequence, with the underlying shales of the Janusfjellet Formation, appears to be sharp. It is probably also significantly erosive, with a minimum of 5—7 m of the underlying shales removed, because the sandstone unit thickness is roughly equivalent to the river channel depth, particularly if the entire unit is a low-angle cross-stratified set.

The second sandstone body

The second sandstone body (11 m to 16.5 m in Fig. 3) clearly consists of a single, large-scale cross-stratified set (Fig. 6). This one can be more closely examined in the field and it can be demonstrated that individual low-angle foresets are themselves cross-stratified illustrating the complex accretion history of the unit (Fig. 7). Between adjacent foresets there is also sometimes developed finer sediments which are ripple laminated, with direction of ripple migration at a high angle to the direction of the major foreset accretion. This is a good example of *epsilon-type* cross-stratification (Allen 1965), typically developed from the lateral accretion of point bars in sinuous channels. The situation is somewhat complicated here in that this major unit is itself truncated by a deeply eroding unit of trough cross-stratified sandstones (Figs. 6, 7, 8). This latter unit may be symptomatic of variable stream discharge here. Point bar surfaces with a «stepped» profile can result from channel incision and chute-bar development (e.g. McGowan and Garner 1970), a product of the flood flow trying to shorten its route by cutting across the point bar surface.

The uppermost meter or so of this second sandstone body, is much finer grained and ripple laminated, with some development of flazer and wavy bedding. These sediments may represent a channel filling phase after abandonment and re-establishment of the distributary elsewhere (Fig. 6).

The third sandstone body

The third major sandstone body, occurring high on the succession, immediately below the transition to Carolinefjellet Formation (67 m to 73.2 m in Fig. 3), is of a different type. It is not erosively based, but rather developes out of an upward coarsening sequence (Fig. 9). It is also distinctly two-tier, with a lower, low-angle cross-stratified portion (probably developed in troughs) and an upper, coarser portion consisting of more than 12 sets of mostly tabular cross-stratified sandstone (Fig. 9). The upper portion tends to become finer and thinner upwards and contains lag conglomeratic lenses and tree fragments. Because of these features the upper portion is interpreted as a multistorey distributary channel sandstone. It is suggested that

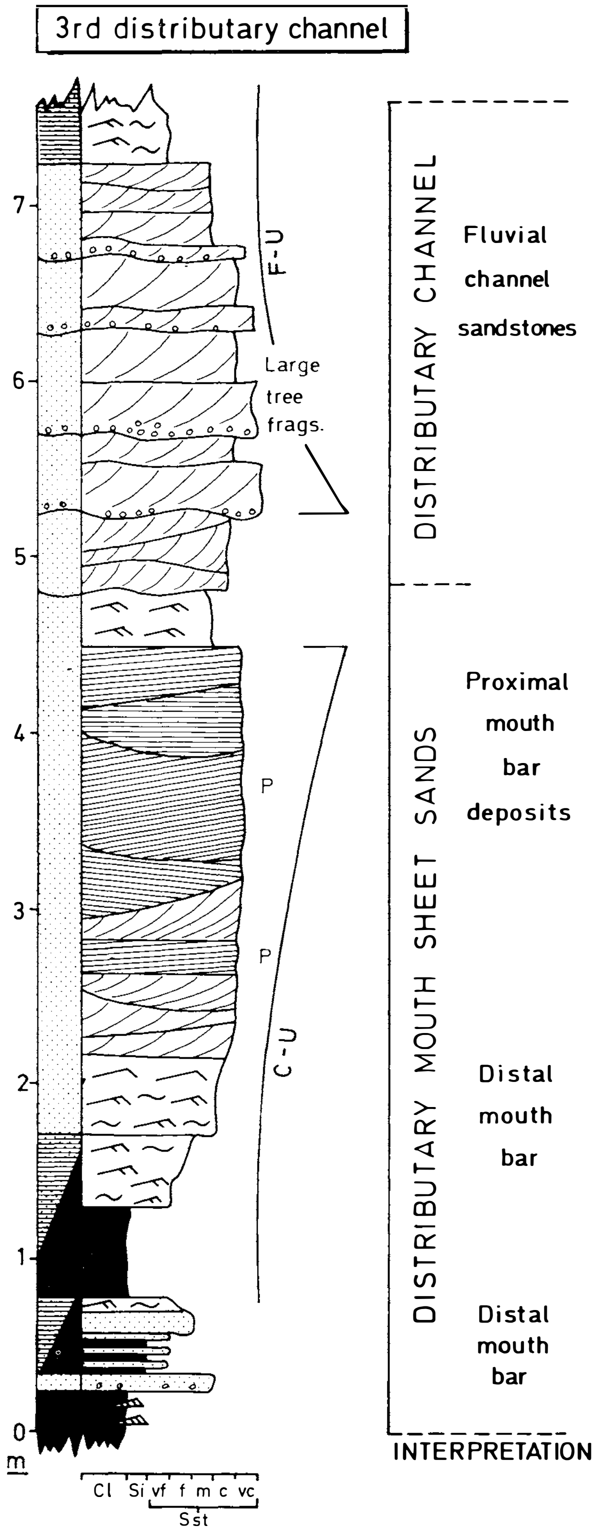


Fig. 9. *The third distributary sandstone body. See Fig. 6 for legend.*

the lower portion represents distributary mouth sheet sandstones, developed by an interaction from river-generated, sediment-laden incursions from the distributary and wave-reworking on the mouth bars. It has not been demonstrated that the underlying fine sediments, out from which this sequence developes, are of prodelta origin. On the contrary they are not unlike the thick underlying sequence of interdistributary bay sediments, discussed below. However, the distributary channel here may have issued into a relatively protected area on the delta. In addition, it should be noted that this distributary channel-mouth bar system occurs within a transition zone to the overlying shallow marine deposits of the Carolinefjellet Formation (Fig. 3), so a delta front origin is not unlikely.

Palaeocurrents

Because of the present vertical dip of the strata here at Festningen, accurate palaeocurrent measurements are difficult to make. However, it appears that the first and third distributary channels transported sediment mainly south and south-eastwards while the second channel flowed eastwards (Figs. 3, 14).

It is of interest to compare the sandstone bodies here with similar one within the Helvetiafjellet Formation elsewhere. Where they are developed on Carolinefjellet and Wimanfjellet (Steel 1977) the distributary channel bodies are of the same order of thickness (5—10 m), sediment transport is towards south and southwest (Steel 1977, fig. 3), the lowermost body shows excellent development of epsilon cross strata and it can be demonstrated here that the two lower bodies thin out laterally into interdistributary bay sediments in a direction transverse to the channel axes.

The delta plain sub-delta systems

The fine-grained sediments lying between the channel sandstone bodies, particularly in the thick sequence between the second and third channels, are classed as the deposits of sub-delta systems, because they suggest essentially quiescent areas into which there was a frequent influx of flood-generated sediment from the adjacent distributaries, during periods of high discharge. Because these fine grained sediments which occur between the distributary sandstones contain many thin coal horizons and are essentially organised into small scale (generally less than 2.0 m thick) upward coarsening sequences (Fig. 3), they are interpreted collectively as interdistributary bay deposits (see also Elliott 1974). The numerous small sandstone bodies, interpreted as prograding from main channels into the bays, represent a variety of overbank flood units, crevasse splays, levees, minor mouth bars and crevasse channels. A representative number of such sequences are shown in detail in Fig. 10. The sandstone percentage curve for the succession (Fig. 3) shows that these facies sequences, in general, have a relatively high content of fines, al-

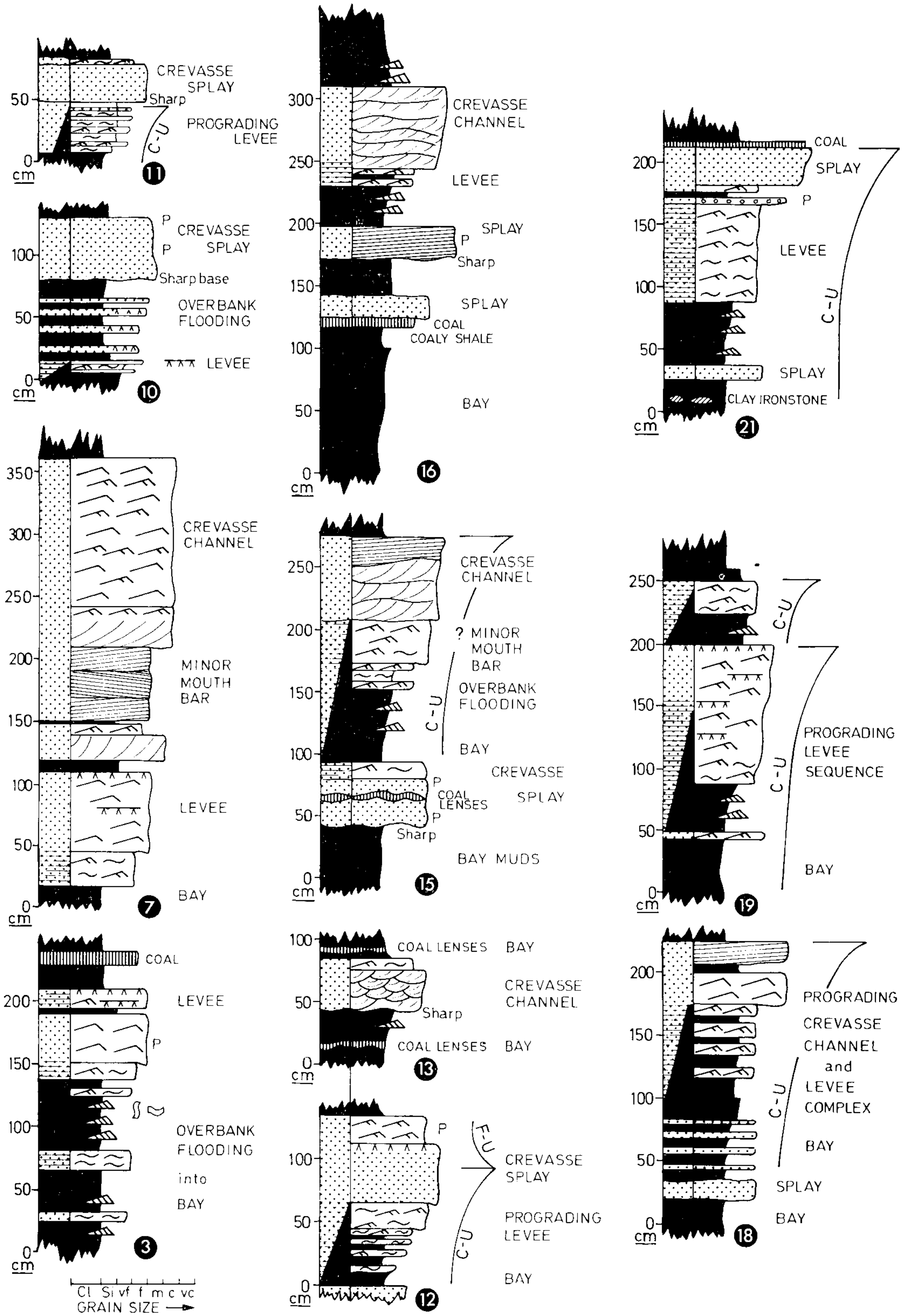


Fig. 10. *Representative interdistributary bay sequences (see Fig. 3 for locations).*

though individual thick units of shale are often more closely associated with the coarsest channel sandstones.

Crevasse channel sequences

Crevasse channel sequences tend to be intermediate in sequence thickness, in grain size and in typical set thickness between the distributary channel bodies and the other, minor bay filling sequences (Fig. 4). This is because they originate from semi-permanent stream flow and often from incipient distributary channel systems. The channels themselves tend to be erosive-based, and commonly cut into a levee sequence (eg. Fig. 10 sequence 16). In other instances there is a more gradual upwards coarsening sequence developed, interpreted in terms of minor mouth bar — crevasse channel couplets (e.g. Fig. 10 sequences 7, 15). This trend is due to the progradation of the mouth bar and its parent crevasse channel into the bay. These types of systems have been well described by Coleman et al. (1964) from the Mississippi delta plain.

Overbank flooding/levee sequences

Overbank flooding causes sediment-laden water to flow over the distributary channel banks. Adjacent to the channels small-scale (cm) upwards fining units or alternating coarse and fine grained layers, are deposited on the levees, while farther out only fine material is deposited over much of the bays. The levee units, characterised by rootlet development (Fig. 11) commonly prograde into the bays, producing small upward coarsening sequences (Fig. 12 and sequences 12, 18, 19 in Fig. 10). These sequences commonly consists of flazer, wavy, or lenticular ripple bedding, and sometimes of climbing ripple lamination. Good examples can be examined in the fine sediments between the first and second distributary channel sandstone bodies (Fig. 8).

Crevasse splay units

These are normally relatively thin, discrete sandstone beds, characterised by sharp (often erosive) base and a massive or normal graded interior (e.g. see sequences 10, 11, 12, 15, 16, in Fig. 10). They are closely associated with levee development and originate from short period (in contrast to crevasse channel flow), discrete floods of sediment-laden water into the bays.

Upper and lower boundaries of Helvetiafjellet formation

There appears to be a gradual transition from Helvetiafjellet Formation up to Carolinefjellet Formation at Festningen. If the usual criteria for identification of beds in the latter formation are used, e.g. the appearance of compact, yellow-weathering fine sandstone beds with well developed wave-generated ripple and plane parallel lamination, then the boundary is placed several metres lower down than it would be if the disappearance of coaly shales is used as the criterion. This transition takes place near the base of a well-

Fig. 11. *Rootlets in levee sandstones (Isryggen).*

Fig. 12. *Upwards thickening and coarsening levee sequence (Isryggen).*

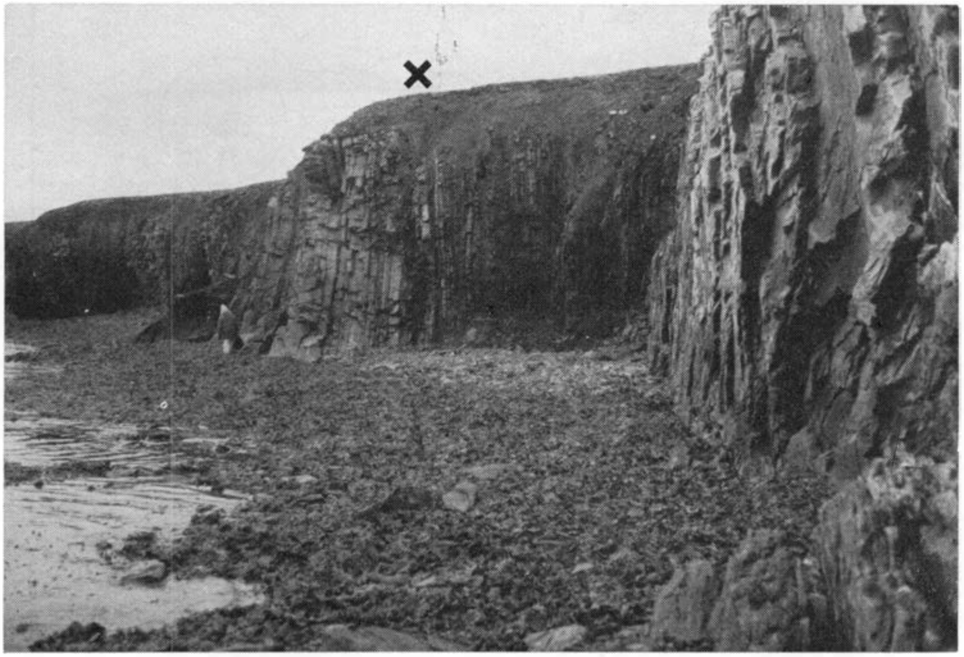


Fig. 13. *Carolinefjellet Formation/Helvetiafjellet Formation boundary, east of Festningen. The cross marks a prominent upward coarsening sequence within Carolinefjellet Formation. The formation boundary should be placed at the base of this sequence.*

defined upwards coarsening sequence of shallow marine (probably offshore bar) origin, and is shown in Fig. 13. This transition, already heralded by the nature of the third distributary channel sandstone body near the top of Helvetiafjellet formation, raises an interesting question as to the possibility of the Carolinefjellet marine upward-coarsening sequences (see Fig. 2 in Steel 1977) being wave-dominated, delta front sand sheets.

As mentioned below, the lower boundary of Helvetiafjellet Formation, with Janusfjellet Formation shales, is sharp and erosive. This is similar to the situation in the northeastern portion of the basin, around Adventdalen (see Figs. 2, 3 in Steel 1977), but contrasts with the apparently transitional boundary in the southern portion of the basin. Along the southwestern edge of the basin, particularly in Van Keulenfjorden (Rozycki 1959), in the Hornsund area (Birkenmajer 1975), and near Sørkapp (Edwards 1976), the upper portion of the underlying Janusfjellet Formation is sandy and organised into large-scale upward coarsening sequences of shallow marine (possibly delta front) origin (see Edwards 1976).

Discussion

The Helvetiafjellet Formation has been interpreted largely in terms of a delta plain setting. The presence of underlying and overlying marine sequences is consistent with this. In the absence, as yet, of evidence as to the

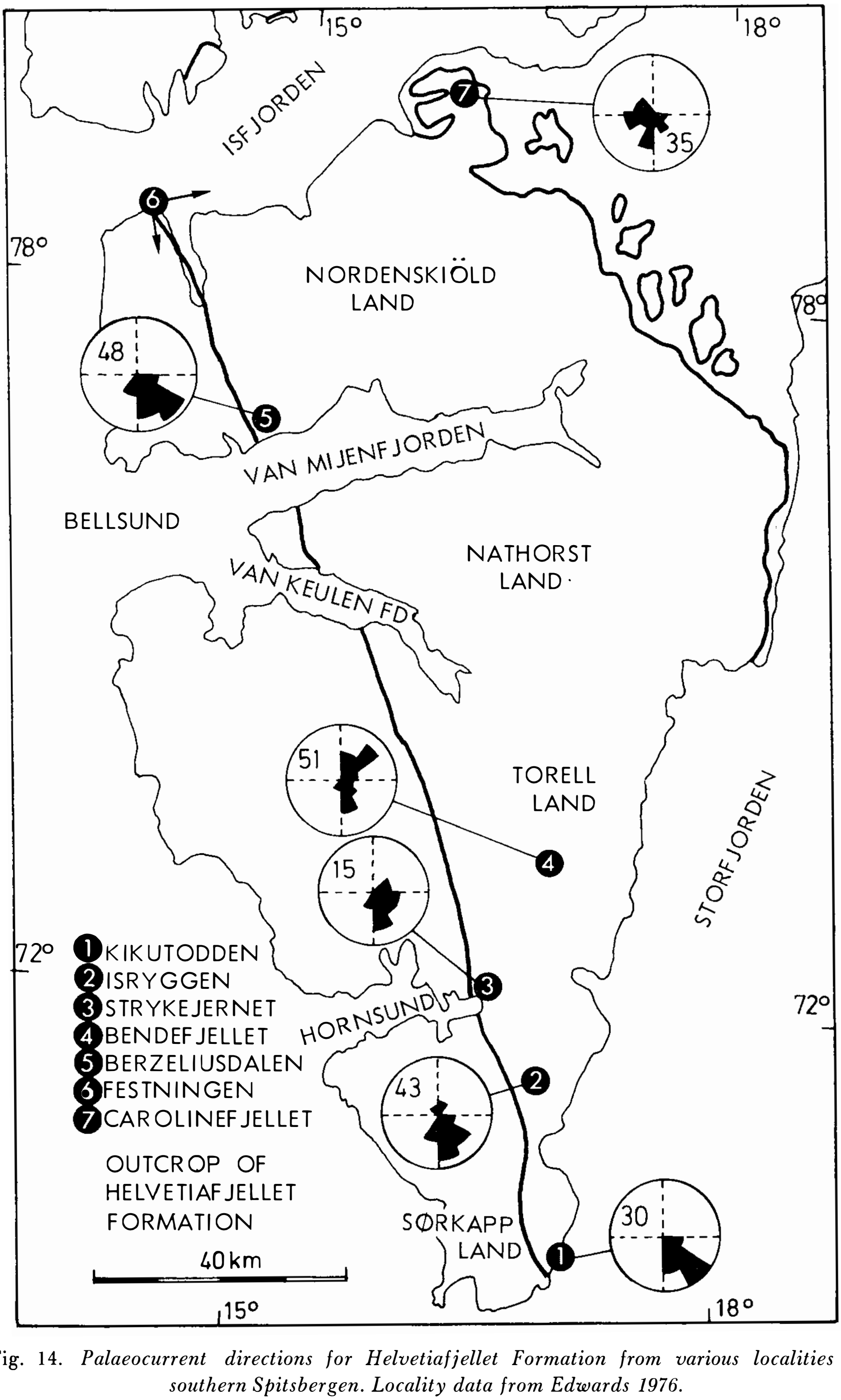


Fig. 14. *Palaeocurrent directions for Helvetiafjellet Formation from various localities in southern Spitsbergen. Locality data from Edwards 1976.*

geometry of the system, however, a fluvial dominated coastal plain interpretation cannot be excluded. Edwards (1976), on the other hand, has put a purely fluvial interpretation on the formation, where it occurs near Sørkapp.

A number of questions arise in connection with the deltaic interpretation. Is the entire formation thick enough to justify a deltaic interpretation and how does one explain the apparent sheet-like occurrence of the formation over much of southern Spitsbergen? These questions will be answered more fully by work in progress but at the present stage it is clear that the relative thinness of Helvetiafjellet Formation is symptomatic of a relatively stable tectonic setting. It is well known (e.g. see Fisher and McGowan 1967) that shallow water cratonic or platform delta systems prograde extensively, giving rise to rapid vertical facies changes, whereas delta systems in rapidly subsiding basins marginal to deep water do not necessarily prograde markedly, resulting in thick vertical persistence of facies.

Relatively thin, shallow water cratonic delta systems are probably the best documented type of ancient delta, particularly from the Carboniferous of North America, (e.g. Wanless et al. 1970) and Europe (e.g. Elliott 1975). In the case of the Helvetiafjellet Formation it is also clear that the delta system was fluvial dominated. In this connection the distribution of palaeocurrents for the formation in southern Spitsbergen (Fig. 14) suggests that the apparent sheet-like extension results from the coalescence of a number of delta systems along the basin margins rather than from a sheet spreading out from a single source area. This notion is consistent with the complex internal nature of the «sheet». It has earlier been shown (Steel 1977) that individual component sandstone bodies vary in number from place to place and can be laterally discontinuous.

Acknowledgements

This work is part of the Geological Institute's (Bergen) Svalbard Project, financed by Norges Teknisk Naturvitenskapelige Forskningsråd. In addition we are indebted to Statoil for helicopter support at Festningen in 1977 and to Norsk Polarinstitutt for support to one of us (J.G.). We are also grateful to Knut Bjørlykke for discussion and comment on the manuscript.

References

ALLEN, J. R. L., 1965: The sedimentation and palaeogeography of the Old Red Sandstone of Anglesey, North Wales. *Proc. Yorks. Gel. Soc.* 35: 139—185.

BIRKENMAJER, K., 1975: Turassic and Lower Cretaceous sedimentary formations of SW Torell Land, Spitzbergen. *Studia Geol. Polon.* 44: 7—42.

EDWARDS, M. B., 1976: Depositional Environments in Lower Cretaceous regressive sediments, Kikutodden, Sørkapp Land, Svalbard. *Norsk Polarinstitutt Årbok* 1974: 35—50.

ELLIOT, T., 1974: Interdistributary bay sequences and their genesis. *Sedimentology* 21: 61—622.

— 1975: The sedimentary history of a delta lobe from a Yoredale (Carboniferous) cyclothem. *Proc. Yorks. Geol. Soc.* 40: 505—536.

FISHER, W. L. and J. H. McGOWAN, 1967: Depositional systems in the Wilcox Group of Texas and their relationship to occurrence of oil and gas. *Gulf Coast Assoc. Geol. Soc. Trans.* 17: 105—125.

FLOOD, B., J. NAGY, and T. S. WINSNES, 1971: Geological Map Svalbard 1 : 500 000. Sheet 1G Spitsbergen, Southern part. *Norsk Polarinstitutt Skrifter* Nr. 154 A, Oslo.

FREBOLD, H., 1928: Das festungsprofil auf Spitzbergen. Jura und Kreide. II, Die stratigraphie. *Skrifter om Svalbard og Ishavet* Nr. 19.

— 1931: Fazielle Verhaltnisse des Mesozoikums im Eisfjordgegnet Spitzbergens. I Teil. *Skrifter om Svalbard og Ishavet* Nr. 37.

FREBOLD, H. and E. STOLL, 1937: Das Festungsprofil auf Spitzbergen III, Stratigraphic und Fauna des Jura und der Unterkreide. *Skrifter om Svalbard og Ishavet* Nr. 68.

HAGERMAN, T. H., 1925: Results of the Swedish Expedition to Spitzbergen 1924, II. Stratigraphic and structural investigations within southwestern Spitzbergen. *Geogr. Annal.* 7: 195—221.

HOEL, A., and A. K. ORVIN, 1937: Das Festungsprofil auf Spitzbergen. Karbon-Kreide I. Vermessungsresultate. *Skrifter om Svalbard og Ishavet* Nr. 18

MAJOR, H. and J. NAGY, 1972: Geology of the Adventdalen Map Area. *Norsk Polarinstitutt Skrifter* Nr. 138.

McGOWEN, J. H. and L. E. GARNER, 1970: Physiographic features and stratification types of coarse-grained point bars: Modern and ancient examples. *Sedimentology* 14, 77—111.

NATHORST, A. G., 1913: Die pflanzenführenden Horizonte innerhalb der Grenzschichten des Jura und der Kreide Spitzbergens. *Geol. Føren. Stockh. Førh.* 35 (4): 273—282. Stockholm.

NYSÆTHER, E., 1966: *Petrografisk undersøkelse av sedimentære bergarter fra tidsperioden kritt-tertiær i Nathorst Land, Vest Spitsbergen.* Cand. real. thesis, Univ. Bergen, 167 pp.

PARKER, J. R., 1967: The Jurassic and Cretaceous sequence in Spitzbergen. *Geol. Mag.* 104: 487—505.

PCHELINA, T. M., 1965: Mesozoic deposits around Van Keulenfjorden, Vestspitzbergen. *Geology of Spitzbergen* 1965: 155—181. National Lending Library for Science and Technology (issued 1970).

ROZYCKI, S. Z., 1959: Geology of the northwestern part of Torrell Land, Vestspitsbergen. *Studia Geol. Polon.* 2.

SMITH, D. G. and C. A. G. PICKTON, 1976: The Helvetiafjellet Formation (Cretaceous) of North East Nordenskiöld Land, Spitsbergen. In: Some coalbearing strata in Svalbard. *Norsk Polarinstitutt Skrifter* Nr. 164.

STEEL, R. J., 1977: Observations on some Cretaceous and Tertiary sandstone bodies in Nordenskiöld Land Svalbard. *Norsk Polarinstitutt Årbok* 1976: 43—68.

Cenozoic plateau lavas of Spitsbergen — a geochemical study

By TORE PRESTVIK[1]

Abstract

The plateau lavas around Woodfjorden, northern Spitsbergen, are found to be of upper Tertiary age. Two new K/Ar datings gave 11.5 ±1.2 and 10.4 ±1.1 m.y. These plateau lavas are transitional olivine basalts. Both *ne*- and *hy*-normative types occur. They are especially characterized by low CaO, TiO_2, and Sc contents and REE patterns where the light elements are relatively enriched. It is concluded that the lavas represent different degrees of partial melting of a mantle source where clinopyroxene was a residual phase. Trace element data suggest that some of the basalt magmas were contaminated by crustal material.

Introduction

In the recent years the Cenozoic volcanism in the North-Atlantic area has been discussed in connection with the plate tectonic evolution of this area (see Brooks and Jakosson 1974, and Noe-Nygaard 1974, for a detailed reference list). Inspired by the work of Hoel and Holtedahl (1911), Goldsmith (1911), and Hoel (1914) on plateau lavas from northern Spitsbergen, the author found that a reexamination of these lavas could be a valuable contribution to this discussion.

It is difficult to arrange field expeditions to the actual area, so the present petrographic and geochemical study is mainly based on the material brought back by A. Hoel and O. Holtedahl in 1910 and 1912. This material, which is kept at the Geological Museum in Oslo, is probably still one of the best collections in the world of these plateau lavas. In addition samples from Eidsvollfjellet collected by Th. Winsnes in 1967 were incorporated in the study.

Because no comprehensive discription of the magmatism of the Svalbard area is easily available, a short review of the literature on this matter seems justified in order to elucidate the relationship between the plateau lavas and the other volcanic rocks of the area.

Harland (1973a) discussed the magmatic activity of the Svalbard area and divided the post-Paleozoic activity into three groups:

[1] Geologisk Institutt, N-7034 Trondheim — N.T.H.

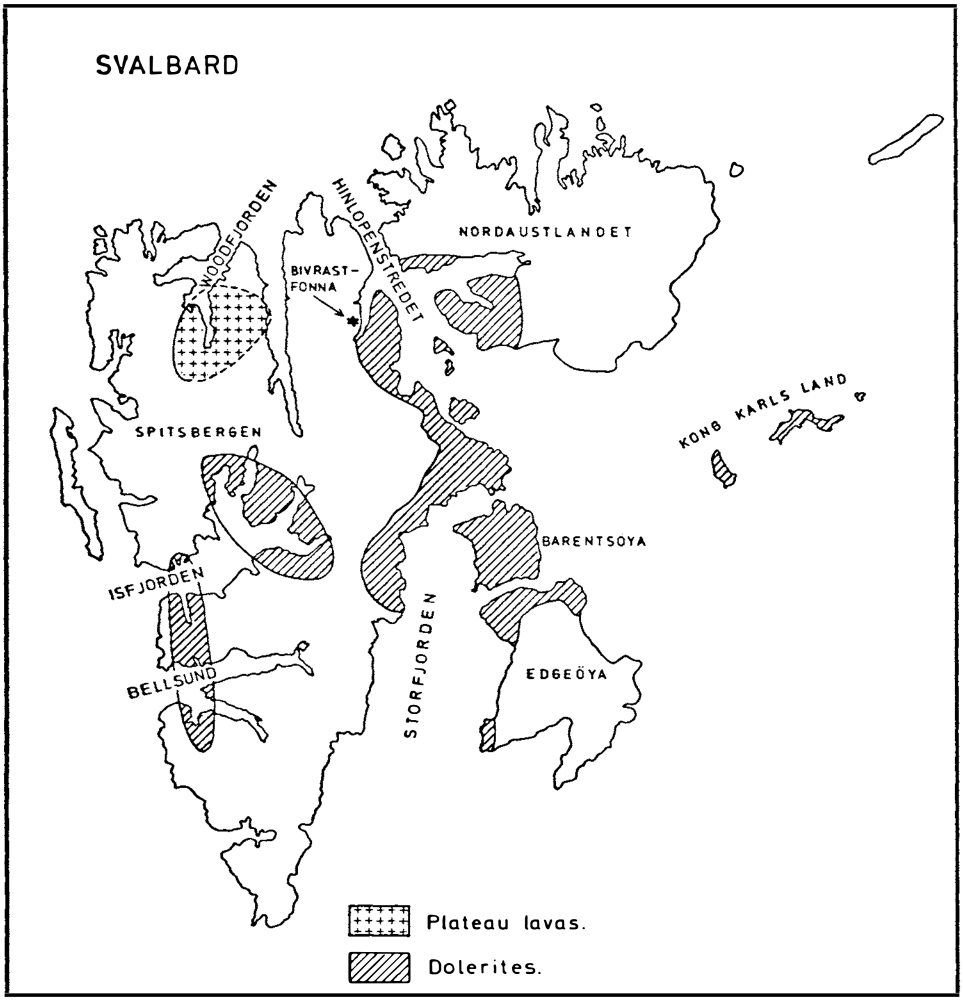


Fig. 1. *Map of Svalbard. The areas where Mesozoic dolerites and Cenozoic plateau lavas occur are marked out.*

A. *Basic lavas and sills (dolerites) of Mesozoic age.*

The Mesozoic activity is very abundant on both sides of Storfjorden and Hinlopenstretet (Fig. 1) and on Kong Karls Land. Some dolerites also occur around the inner part of Isfjorden and in the Mesozoic complex of the Isfjorden — Bellsund area. These Mesozoic dolerites are mainly q-normative tholeiites which are sometimes rather differentiated with high TiO_2 (3.60%) and low MgO (<5.65%) contents (Tyrrell and Sandford 1933; Burov and Livšic 1965). The age relationships of the dolerites have been discussed by many authors. Tyrrell and Sandford (1933) supposed that the dolerites intruded in Late Jurassic or Early Cretaceous, whereas Orvin (1940) drew parallels between the dolerites and lava flows (plateau lavas) around Woodfjorden and proposed a Late Cretaceous to Tertiary age. Gayer et al. (1967) considered the dolerites to be Late Jurassic (149—144 m.y.), while Harland (1973a) found that all the evidence is consistent with a late Volgian to Berriasian or early Valanginian age (145—130 m.y.) for most dolerites and that the youngest lavas of Kong Karls Land are Barremian or younger (<120 m.y.). Based on radiometric age determinations Burov et al. (1977) concluded that the intrusion of dolerites took place in two phases corresponding to 145 ± 5 m.y. and 105 ± 5 m.y.

B. *Cretaceous and/or Cenozoic lavas (plateau lavas).*

Hoel and Holtedahl (1911), Goldschmidt (1911), and Hoel (1914) described the flatlying olivine-basalts capping some of the highest mountains in Andrée Land, east of Woodfjorden (Fig. 2). Hoel (1914) concluded that the olivine-basalts postdated early Cretaceous peneplantation and could be as young as Miocene. Harland (1973a) concluded that these rocks could all be Tertiary plateau lavas, but some might correspond to Barremian or a later Cretaceous phase. He also included the olivine-basalts of Bivrastfonna west of Hinlopenstretet (Fig. 1) among the plateau lavas. Two K/Ar dates obtained for olivine-basalts from Prismefjellet (Fig. 2) by Burov and Zagruzina (1976) gave very different Tertiary ages, 60 ± 25 and 22 ± 10 m.y.

In order to further elucidate the age relation of these basalts two samples from Tavlefjellet and Eidsvollfjellet were subjected to K/Ar dating. The results are presented in Table 1. The analysed samples are very fresh. The only sign of alteration is colouring of matrix olivine crystals. This is thought to be due to a deuteric oxidation process rather than secondary alteration because the colouring is especially developed in the vesicular parts of the flows. The obtained dates are therefore interpreted as primary.

The very similar age of samples from these distant localities indicates that lavas from other localities in the area may be of the same age. Even though the dated sample from Tavlefjellet represents the upper part of the lava succession (flow No. 3 of Hoel 1914) the whole succession may have formed in a relatively short period of time, because there are no reports of erosional features or sedimentary layers between the lava flows. There is thus a discrepancy between the new dates and those obtained by Burov and Zagruzina (1976).

It cannot be denied that some of the plateau lavas formed during the lower parts of Tertiary, but because of the high uncertainty of the dates of the latter authors, it is tempting to regard the obtained ∾ 11 m.y. age as representative for most of the plateau volcanism. However, further dating is needed to clear up this point.

C. *Quaternary volcanic rocks and hot springs.*

Hoel (1914) concluded that the Sverrefjellet basanite (in earlier literature often described as trachydolerite) volcano in Bockfjorden (Fig.2)

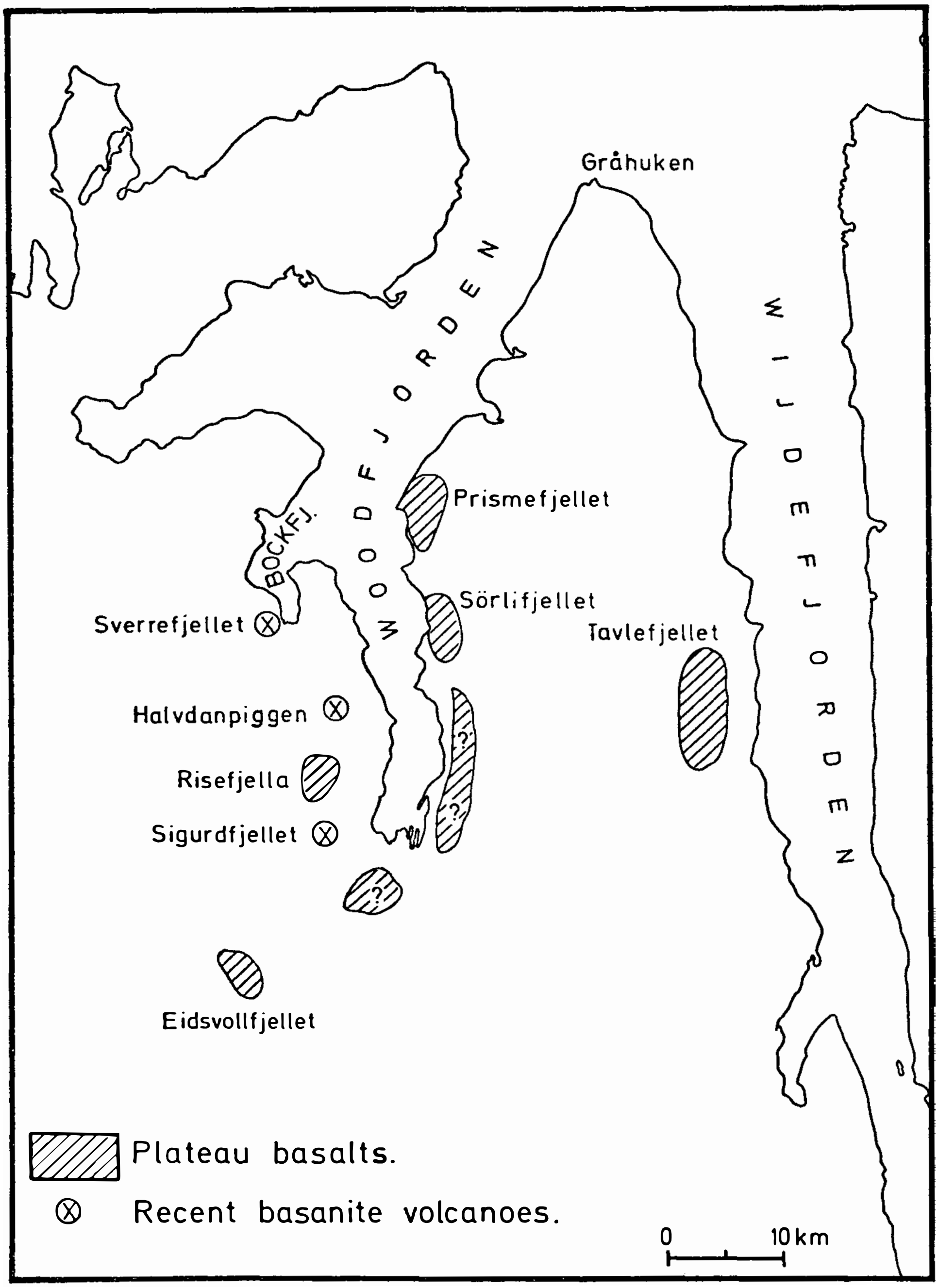


Fig. 2. *Map of the Woodfjorden area showing the distribution of known occurrences of plateau lavas and basanite volcanoes.*

Table 1
Argon and potassium analyses and K/Ar dates of two plateau lavas.

	Radiogenic Ar^{40}, ppm	%K	K^{40}, ppm	Rad.Ar^{40}/K^{40}	Age, m.y.
Sample 250, Tavlefjellet	0.000332	0.403	0.492	0.000673	11.5 ± 1.2
Sample 255, Eidsvollfjellet	0.000420	0.564	0.688	0.000610	10.4 ± 1.1

Argon and potassium analyses were performed in duplicate.
Constants used: $\gamma\beta = 4.72 \cdot 10^{-10}$/year
$\gamma_e = 0.585 \cdot 10^{-10}$/year
$K^{40}/K = 1.22 \cdot 10^{-4}$

Analyst: Krueger Enterprises, Inc. Geochron Laboratories Division, Cambridge, Ma. U.S.A.

is Quarternary and possibly postglacial. Based on the occurrence of basanite lava in marine terraces and C^{14} dating of corresponding terraces elsewhere in Spitsbergen, Semevskij (1965) assumed that the volcano was formed in the period 4,000—6,500 y.B.P. Based on paleomagnetic data Halvorsen (1972) concluded that the Sverrefjellet rocks formed during the Bruhnes normal polarity epoch (<700, 000 y). The still occurring low temperature hydrothermal activity close to Sverrefjellet (Hoel 1914) is another evidence of quite recent magmatic activity of the area. In addition Burov and Zagruzina (1976) dated the scoriaceous Sverrefjellet basantite to less than one million years B.P. Some of the structures of the Sverrefjellet volcano described by Gjelsvik (1963) suggest that the eruption could have been — at least partly — subglacial, a feature that further substantiates the impression that this volcano formed during the Quaternary. Both Sverrefjellet and two other occurrences west of Woodfjorden (Halvdanpiggen and Sigurdfjellet) are characterized by having abundant spinel-lherzolite nodules (Backlund 1911; Gjelsvik 1963; Burov 1965).

The plateau lavas

According to the descriptions of Hoel and Holtedahl (1911), Hoel (1914), geological maps (Orvin 1940; Harland 1973a) and personal communications (Gjelsvik and Winsnes, Norsk Polarinstitutt) the known occurrences of plateau lavas in the Woodfjorden — Andrée Land area are plotted on the map, Fig. 2.

Most of these lavas are underlain by Devonian sediments. Structurally this area is a graben of which the eastern part is a monocline (Sokolov et al. 1968). The graben is controlled by N—NW trending normal faults. According to Orvin (1940) these faults were probably active as late as Tertiary.

Based on the known occurrences (Eidsvollfjellet not included) Hoel (1914) calculated the original extension of the plateau lavas to at least 4000 km^2. The thickness of the lava succession is not well established: Hoel and Holtedahl (1911) reports a total thickness of 155 m at Sørlifjellet, whereas Burov and Zagruzina (1976) refer to the basalts as «fragments of an up to 275 m thick lava succession». At most localities there are many lava flows. Hoel (1914) reports at least 15 lava flows at Tavlefjellet with layers of scoriaceous material in between. The lavas vary from dense to highly vesicular, and in contrast to the younger basanites no lherzolite nodules are known to occur in the plateau lavas.

Petrography

Modal analyses of 11 samples are shown in Table 2. Olivine is invariably present as both a phenocryst and a matrix phase. The composition of olivine (microprobe analysis) varies from Fo_{83} to Fo_{77} for phenocrysts, Fo_{76} to Fo_{74} for microphenocrysts and Fo_{61} to Fo_{48} for matrix olivines. Some of the olivine phenocrysts are partly resorbed. Plagioclase phenocrysts are found in all but one *hy*-normative samples (See Table 2), but are characteristically absent in the *ne*-normative samples 245, 246 and 248. Most plagioclase crystals are slightly zoned. The composition varies from An_{67} to An_{57} in phenocrysts and microphenocrysts and An_{58} to An_{55} in groundmass plagioclase. The latter values represent the compostion in the centres of small plagioclase laths, but marginal zoning indicates that the crystal rims are more sodic. Clinopyroxene never occurs as a true phenocryst, but is always present in the matrix. Microprobe analysis shows that this mineral is an augite with somewhat varying composition: $Wo_{39-45}En_{35-44}Fs_{16-20}$. The clinopyroxene of the *ne*- normative samples is systematically higher in Ti and Al and usually also in Ca than what is found in clinopyroxenes of the *hy*-normative rocks. This corresponds well to what is generally observed in alkaline rocks (Barberi et.al. 1971). Opaque mine-

Table 2
Modal analyses of plateau lavas.

Sample	Prismefjellet			Risefjella		Tavlefjellet				Eidsvollfjellet	
	242	243	244	245	246	247	248	249	250	254	255
Olivine, phenocryst	7.8	3.0	7.3	5.1	9.2	5.7	8.8	10.2	6.7	7.2	4.6
Plagioclase «	–	12.3	7.6	–	–	1.7	–	24.4	8.7	0.8	2.1
Plagioclase, matrix	63.7	50.0	52.4	46.3	67.7	50.3	65.8	36.9	46.0	62.7	50.9
Olivine «	14.4	15.3	8.2	12.3	tr	19.5	5.5	5.2	15.1	14.5	11.6
Clinopyroxene «	10.4	14.2	13.0	19.4	14.0	14.3	13.5	17.6	14.1	8.9	20.8
Oxides «	3.7	4.0	11.5	5.4	9.1	8.5	6.4	5.7	9.4	5.9	3.3
Others «	–	1.2	–	11.5	–	–	–	–	–	–	6.7

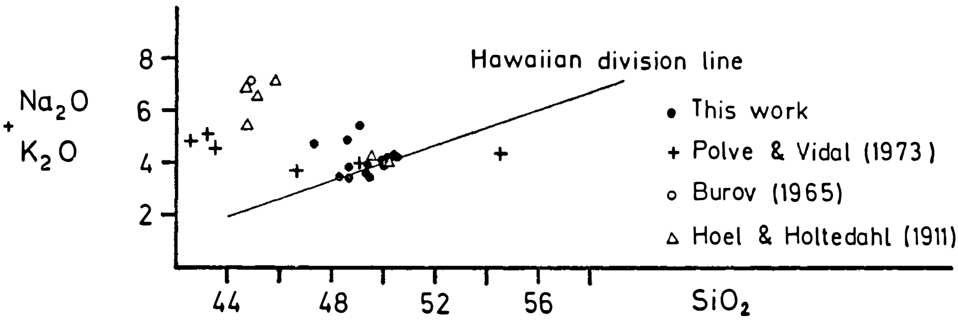


Fig. 3. *Total alkalies/silica diagram. The plateau lavas analysed here are marked with filled circles. Hoel and Holtedahl (1911) also analysed two plateau basalts (open triangles). Two analyses (crosses) of Polve and Vidal (1973) resemble the plateau lavas of this study. Basanite analyses of Hoel and Holtedahl (1911), and Burov (1965) are somewhat higher in total alkalies than three samples analysed by Polve and Vidal (1973). Hawaiian division line after MacDonald (1968).*

rals occur in all samples and are Fe-Ti-oxides close to ilmenite in composition.

The rocks are usually fresh and alteration of olivine is found only in a few samples. Occasionally secondary calcite occurs in vesicles. In some samples green or brown alteration minerals occur in the matrix. These represent alteration of matrix olivine or, eventually glass? A few samples contain minerals that are heavily stained by dust of brown iron oxides. This is found in some of the most vesicular samples and is probably due to secondary oxidation during cooling of flow surfaces.

Most lavas are holocrystalline and the texture varies from pilotaxitic to subophitic.

Chemistry

Mayor element data and CIPW norms of the analysed samples are presented in Table 3. The rocks are transitional to alkaline (Fig. 3). Although most samples are *hy*-normative like olivine tholeiites, mineralogical features such as abundant matrix olivine stress the similarity with alkali-basalts. The occurrence of *ne*-normative basalt (sample 245) together with dominantly *hy*-normative rocks among the Tavlefjellet flows, further emphasize the alkaline affinity of the plateau lavas.

Except for the *n*e-normative samples from Tavlefjellet and the Risefjella area (Table 3) there is very little chemical variation among the rocks from different localities. Compared with most basalts (Manson 1967), the CaO content is low, a feature which is at least partly reflected by the plagioclase composition. *Ne*-normative samples, which lack plagioclase phenocrysts, are even lower in CaO. The *ne*-normative samples are higher in alkalies, TiO_2 and P_2O_5 than the *hy*-normative rocks.

Table 3
Major element composition and CIPW norms of the plateau lavas.

	Prismefjellet				Risefjella		Tavlefjellet						Eidsvollfjellet		
	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255
SiO_2	50.40	50.25	50.42	49.78	48.53	47.20	49.44	49.02	49.30	49.24	48.16	48.64	48.60	50.05	50.50
TiO_2	1.53	1.13	1.57	1.14	1.70	1.58	1.11	1.70	1.47	1.09	1.22	1.23	1.24	1.35	1.27
Al_2O_3	14.77	15.72	15.32	15.80	15.48	15.10	15.99	15.27	15.45	16.28	16.34	16.55	16.37	16.08	15.80
Fe_2O_3	2.07	2.79	1.34	2.94	4.22	3.20	4.38	3.48	6.70	3.91	5.75	7.20	10.12	7.04	2.34
FeO	8.64	8.15	9.00	7.85	7.42	7.51	7.02	7.92	5.32	6.87	6.12	4.30	1.46	4.10	8.26
MnO	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.16	0.16	0.16	0.18	0.17	0.17	0.17	0.17
MgO	10.26	9.04	9.83	8.76	8.49	9.78	8.79	8.63	8.35	8.81	8.10	7.84	8.00	7.26	8.26
CaO	8.00	8.30	8.02	8.40	7.73	7.60	8.81	7.78	7.54	8.86	8.04	8.62	8.22	8.50	8.86
Na_2O	3.34	3.28	3.58	3.42	3.74	3.78	2.88	4.26	3.11	3.04	2.87	3.18	3.10	3.08	3.51
K_2O	0.70	0.80	0.73	0.80	1.12	0.98	0.50	1.18	0.75	0.49	0.55	0.53	0.75	0.83	0.75
P_2O_5	0.28	0.19	0.31	0.20	0.43	0.31	0.15	0.43	0.23	0.15	0.18	0.17	0.22	0.22	0.21
H_2O^+	0.18	0.20	0.10	0.27	1.12	2.74	0.63	0.14	1.52	0.50	1.41	0.95	1.20	0.89	0.20
H_2O^-	0.10	0.10	0.08	0.09	0.23	0.51	0.26	0.10	0.33	0.22	0.72	0.57	0.52	0.44	0.07
CO_2	*0.0	*0.0	*0.0	0.03	*0.0	*0.0	*0.0	*0.0	0.24	*0.0	*0.0	0.11	0.08	*0.0	0.04
Total	100.43	100.11	100.46	99.64	100.37	100.45	100.13	100.07	100.47	99.62	99.64	100.06	100.05	100.01	100.24
	Fe_2O_3/FeO was normalized to 0.15 before norm calculation.														
Or	4.14	4.73	4.31	4.73	6.62	5.79	2.96	6.97	4.43	2.90	3.25	3.13	4.43	4.91	4.43
Ab	28.26	27.75	30.29	28.94	29.40	25.95	24.37	28.21	26.32	25.72	24.29	26.91	26.23	26.06	29.70
An	23.24	25.81	23.58	25.40	22.14	21.34	29.23	19.06	25.98	29.33	30.08	29.32	28.54	27.60	25.14
Ne	–	–	–	–	1.22	3.27	–	4.24	–	–	–	–	–	–	–
Cpx	11.86	11.52	11.51	12.06	10.95	11.64	11.03	13.66	6.88	11.13	7.08	9.54	8.43	10.77	14.04
Opx	10.09	8.62	6.23	4.77	–	–	14.07	–	17.67	10.31	15.03	9.37	10.51	15.72	5.43
Ol	16.94	16.62	18.72	18.53	22.06	23.41	12.76	21.16	10.78	14.86	12.48	14.67	14.27	8.01	16.16
Mt	2.00	2.03	1.94	2.00	2.13	1.99	2.09	2.10	2.18	1.97	2.15	2.04	2.00	1.99	1.97
Il	2.91	2.15	2.98	2.17	3.23	3.00	2.11	3.23	2.79	2.07	2.32	2.34	2.36	2.56	2.41
Ap	0.66	0.45	0.73	0.47	1.02	0.73	0.36	1.02	0.55	0.36	0.43	0.40	0.52	0.52	0.50
Cc	–	–	–	0.07	–	–	–	–	0.55	–	–	0.25	0.18	–	0.09

* = negative test for CO_2

Trace element data are presented in Table 4. The same grouping as recognized among the major elements is found: The *ne*-normative samples have higher contents of incompatible elements as Rb, Zr, Ta, Ba, Th, and U than do the *hy*-normative rocks. Sr follows the same pattern, whereas Sc follows Ca and is lowest in the *ne*-normative rocks. Ni and Cr is generally high, and both these elements covariate with MgO (Fig. 4).

Chondrite normalized plots of REE are shown in Fig. 5. All samples are characterized by relative enrichment of the light REE, and especially two samples, one *hy*-normative (241) and one *ne*-normative (248), show a positive Eu-anomaly. The *ne*-normative samples are more enriched in light REE than the *hy*-normative rocks, whereas both types have similar consentration of the heavy REE.

Table 4
Trace element contents of the plateau lavas.

	Prismefjellet				Risefjella		Tavlefjellet						Eidsvollfjellet		
	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255
Ni	315	225	295	230	230	235	215	210	335	190	200	155	160	140	165
Cr	350	285	325	245	265	265	290	245	305	285	275	260	235	225	260
Sc	21.1	20.1	–	–	16.2	–	–	15.5	–	23.3	–	–	–	–	21.0
Sr	327	283	342	291	600	426	266	580	352	271	266	315	268	299	325
Rb	< 10	15	12	14	21	17	18	21	17	11	< 10	< 10	15	13	16
Ba	80	150	–	–	410	–	–	300	–	100	–	–	–	–	150
Y	18	28	20	16	22	23	16	15	26	16	31	26	25	26	23
Zr	121	111	130	97	158	131	74	159	128	74	93	84	103	103	107
Hf	2.5	2.4	–	–	3.3	–	–	3.3	–	1.7	–	–	–	–	2.2
Ta	0.66	0.45	–	–	1.12	–	–	1.06	–	0.27	–	–	–	–	0.43
U	0.06	0.26	–	–	0.64	–	–	0.58	–	0.24	–	–	–	–	0.37
Th	0.98	1.57	–	–	2.04	–	–	2.02	–	0.85	–	–	–	–	1.50
K/Rb	>581	442			443			478		370					389
K/Ba	73	44			23			33		41					41
Zr/Hf	48	46			48			48		44					49
Th/U	16.3	6.0			3.2			3.5		3.5					4.0

Analyst, Ni, Cr, Sr, Rb, Y, Zr: Jostein Sandvik (XRF)
Sc, Ba, Hf, Ta, U, Th: Eiliv Steinnes (Instrumental neutron activation analysis, INAA)
– = not determined.

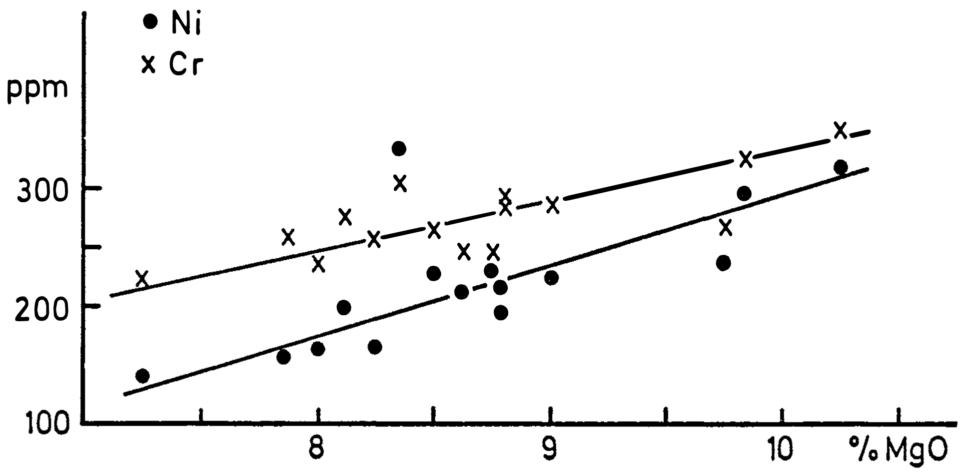


Fig. 4. *Variation diagram of Ni and Cr against MgO.*

Discussion

Regional features

Based on the geological and geophysical data available at that time, Harland (1973b) discussed the geotectonic evolution of Svalbard and the surrounding areas. The Mesozoic activity was thought to be related to opening of the Canada basin (Harland 1973b). It is furthermore obvious that the northern part of Spitsbergen in early Tertiary was rather close to the triple junction between two fracture zones and a spreading ridge in the Arctic basin. Based on new aeromagnetic and bathymetric data Feden et al. (1978) found evidence for a «Yermak hot spot» northwest of Svalbard. These authors proposed that the hot spot activity begun 60 m.y. B.P. and reached a maximum 50—40 m.y. ago. After a decrease in activity around 40—35 m.y. B.P. magnetic data suggest a new activity growth around 10 m.y. B.P. This corresponds well to the new dates presented above. Furthermore they suggest that the influence area of this hot spot may be found far south of Svalbard. This assumption again may be matched by the chemical characteristics for a basalt dredged along the Knipovich ridge (Schilling 1976).

It is surprising, however, that there is no conclusive evidence that the maximum hot spot activity in lower Tertiary (when the hot spot «center» was closer to Spitsbergen) corresponds to volcanic rocks in this area. This stresses the need for further geological work and dating.

The relation between the Quaternary volcanism around Woodfjorden and the plate movements in this area is not well understood. The Spitsbergen fracture zone is supposed to consist of a system of transform faults and ridge segments (Eldholm and Myhre 1977). The fault line along which the recent volcanoes are located, is largely parallel to the «strike» of the fracture zone. One is tempted to suggest that this volcanism may be related in some way to the interaction of deep-seated processes connected to the Spitsbergen fracture zone system and the activity of the «Yermak hot spot».

Chemistry

Since the Spitsbergen plateau lavas have some special chemical features compared to most plateau lavas from other localities around the North Atlantic (Brooks 1973; Brooks and Jakobsson 1974; Noe-Nygaard 1974) it is important to find out whether these rocks represent primary liquids, fractionated liquids, or if they have accumulated minerals or are contaminated.

There is no coveriance between the rather high MgO content and the amount of olivine phenocrysts (Tables 2 and 3). The chemical composition of olivine phenocrysts corresponds well to calculated values for equilibrium olivine crystals (Roeder and Emslie 1970). This indicates that the olivine phenocrysts are not accumulated crystals.

The situation is somewhat different for plagioclase. The *ne*-normative samples which are lowest in CaO, lack plagioclase phenocrysts. This may indicate that plagioclase phenocrysts in the *hy*-normative rocks are of accumulate or xenocrystic origin. On the other hand there is no positive correlation between the highly variable modal plagioclase phenocryst content and CaO or Al_2O_3. Positive Eu-anomalies, as observed in two samples (Fig. 5), are usually interpreted by accumulation of plagioclase. The problem is that sample 248 lack plagioclase phenocrysts, and there is no sign

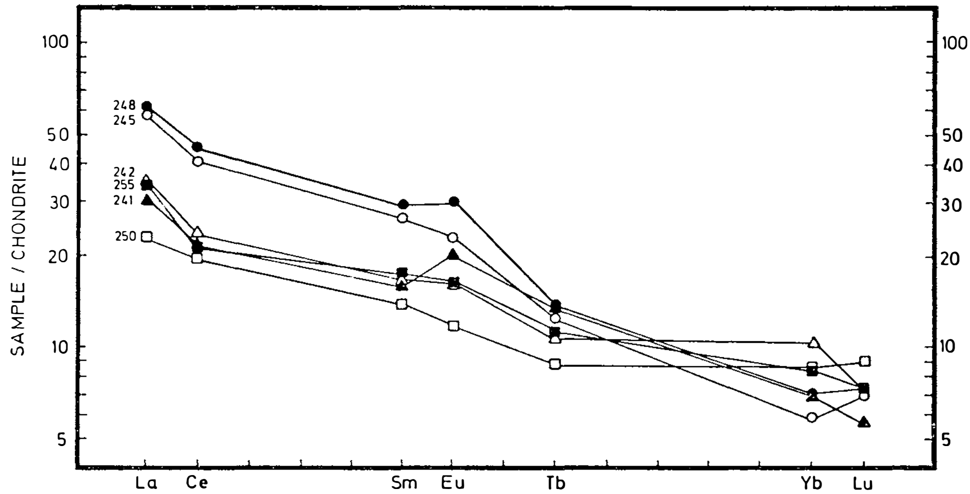


Fig. 5. *Chondrite normalized REE patterns of six plateau lavas.*

of plagioclase resorption in samples containing plagioclase phenocrysts. This indicates that plagioclase accumulation did not take place.

Contamination is difficult to prove, but there is some variance in incompatible element ratios (Table 4) that eventually can be ascribed to contamination. Polve and Vidal (1973) investigated the strontium isotop ratios of some plateau lavas from Stjørdalen south of Sørlifjellet (Fig. 2) and interpreted high $^{87}Sr/^{86}Sr$ ratios of 0.7044—0.7103 as due to contamination. Selective leaching of radiogenic strontium developed by decay of ^{87}Rb in interlayers of mica minerals in the wall rocks or granite xenoliths during magma ascent was proposed as the origin of high $^{87}Sr/^{86}Sr$ ratios of basalt from this area. However, only two of their samples (S9 and W6) correspond chemically to the plateau lavas analysed here. Three of their samples are richer in K_2O and TiO_2 than the plateau lavas and probably transitional to the analysed basanites of the Sverrefjellet volcano (Hoel and Holtedahl 1911; Burov 1965).

Could Eu — selectively — follow Sr into the magma? Sr^{2+} and Eu^{2+} have identical ionic radii (0.113 nm and 0.112 nm) and probably similar electro-negativities. The observed Eu-anomalies require additional supply of about 30% europeum relative to the other REE or 0.35 ppm and 0.5 ppm Eu for samples 241 and 248 respectively. Roaldset (1975) found that phyllosilicates of Precambrian rocks from southern Norway contain 3—8 ppm Eu. EDTA-treatment of these minerals reveals that a relatively high percentage of REE are removed by leaching, and the results furthermore show that Eu may be more easily removed than the other elements. Theoretically it is thus possible to reach at the observed Eu-anomaly by contamination. Calculation shows that this may be obtained if a magma represented by sample 241 or 248 leaches completely three times its own volume of a country rock containing 10% biotite with 5 ppm Eu. It seems unreasonable for this to occur as a general process, but it may have occurred locally. Other «irregularities» such as higher Th/U, K/Rb, and K/Ba ratios than average values for sample 241 also suggest that contamination *may* have occurred. Alternatively these features — including the positive Eu-anomaly — may be inherited from the source region.

Another fundamental question is if there is any simple relationship between the *ne*- and *hy*-normative samples. If, eventually, the *ne*-normative samples were derived by fractional crystallization from *hy*-normative liquids, this fractionation could not occur at low pressure (<8 kb) because of the ol-cpx-plag. thermal divide (O'Hara 1968). The chemical composition of the two types of basalt requires that the fractionate must include phases rich in Na_2O, Al_2O_3 and SiO_2 (plagioclase and pyroxenes). The much higher Sr content of the *ne*-normative samples (Table 4) does not indicate plagioclase fractionation, and calculations show that it is not possible to reach at the *n*e-normative compositions by fractionating high pressure phases like Al-spinel and aluminous pyroxenes either.

There is thus little or no evidence that the *ne*- and *hy*- normative rocks are inter-related by crystal fractionation processes. However, both types of basalt have some common features (low CaO, TiO_2, Sc contents and similar incompatible element ratios), indicating that they were subjected to similar processes or that they represent the same source region. One plausible interpretaion is that the rocks represent different degrees of partial melting of one mantle type. Eventually, these melts were later modified by fractionation.

There are at least two features indicating that all the plateau lavas are somewhat fractionated: Mg/Mg + Fe^{2+} ratios for these lavas are lower than what is expected for basalts in equilibrium with mantle olivine (Fo_{88-90}) (Roeder and Emslie 1970; Green et al. 1974), indicating that they have undergone some 10% olivine (Fo >80) fractionation. (The olivine of lherzolite xenoliths in basanite from the area has «normal» mantle composition, Fo_{91}). There is no positive correlation between Sc and Cr (Table 4) indicating that the Cr-variation is not due to clinopyroxene fractionation. The covariation of Cr and Ni with MgO (Fg. 4) indicates that a chromium phase (spinel) accompanied the olivine fractionation. The observed Cr-variation may be explained by <0.5% spinel fractionation according to the high distribution coefficients ($D_{Cr}{}^{\text{spinel-liquid}} = 600$) given by Allegre et al. (1977). Furthermore the low Sc-values are best explained by slight clinopyroxene fractionation for the *hy*-normative samples and more extensive fractionation for the *ne*-normative samples. According to distribution cofficients for REE reported by Helmke and Haskin (1973) clinopyroxene fractionation may also explain the REE patterns. Fractionation of garnet would also give light REE enriched patterns, but as $D_{Sc}{}^{\text{garnet/liquid}}$ is not known to the author, the effect of eventual garnet fractionation on scandium is not easily determined.

However, clinopyroxene is not present as a phenocryst phase in any sample. This is a fact that points against clinopyroxene fractionation, but such fractionation *may* have occurred at great depth because clinopyroxene is a liquidus phase of alkali-olivine basalts and transitional basalts at high pressures (Thompson 1974). The observed features may also be explained by other processes. The spinel-lherzolite inclusions of the young basanites of the area have clinopyroxene as an abundant phase, 10—15% according to Burov (1965). The Sc-content of mantle lherzolite is proportional to the clinopyroxene content (Frey and Green 1974). The Sc concentration in partial melts derived from lherzolite depends on the bulk distribution coefficient for Sc (which again depends on the clinopyroxene content of the lherzolite) and the nature of the partial melting: equilibrium melting of fractional melting (Shaw 1970). However, calculation shows that under the most probable conditions partial melts of lherzolite will be richer in Sc the higher the degree of partial melting they represent. The observed pattern then may be explained by postulating that the *ne*-normative rocks represent a lower degree of partial melting than the *hy*-normative samples.

Bulk $D^{solid/liquid}$ for heavy REE (HREE) in lherzolite is of the order 0.1—0.2. The concentration of HREE in melts derived from lherzolite will be little affected by actual different degrees of fractional partial melting provided clinopyroxene remains as a residual phase (Shaw 1970). Thus the REE patterns for the two groups of basalts are consistent with what would result from different degrees of partial melting.

Conclusions

1. Volcanic activity has taken place in the Svalbard area more or less periodically at least during the last 150 m.y. The plateau lavas around Woodfjorden are of upper Miocene age and are most probably related to a reactivation of the postulated «Yermak hot spot» 10 m.y.B.P. (Feden et al. 1978). The recent basanite volcanism shows that the area must still be characterized as active.

2. Chemically the plateau lavas are transitional to alkaline olivine basalts. Both *ne*- and *hy*-normative types occur. Most of the characteristic features of these rocks may be explained by postulating that the different rock types represent different degrees of partial melting of a mantle source with residual clinopyroxene. The magmas formed in this way were subsequently modified by slight olivine fractionation. Trace element data suggest that some of the basalt magmas were contaminated by crustal material.

Acknowledgements

Mineralogisk-Geologisk Museum and Norsk Polarinstitutt (Thore S. Winsnes) in Oslo provided the samples analysed in this study. Financial support for some of the analytical work was provided by Norsk Polarinstitutt and The Norwegian Research Council for Science and the Humanities (NAVF), grant D. 42.31—11. Professor Chr. Oftedahl critically discussed the manuscript. Dr. Peter Vogt kindly gave me a copy of an unpublished manuscript (Feden et al. 1978). All this is gratefully acknowledged.

References

ALLEGRE, C. J., M. TREVIL, J.-F. MINSTER, B. MINSTER, and F. ALBAREDE, 1977: Systematic use of trace element in igneous process. Part I: Fractional crystallization processes in volcanic suites. *Contr. Mineral. and Petrol.* 60: 57—75.

BACKLUND, H., 1911: Über einige Olivinknollen aus der Lava von Wood-Bay, Spitsbergen. *Vid. Selsk. Skr. I. Mat. Nat. Kl.* No. 16. Kristiania.

BARBERI, H., H. BIZOUARD, and J. VARET, 1971: Nature of the Clinopyroxene and iron enrichment in alkalic and transitional basaltic magmas. *Contr. Mineral. and Petrol.* 33: 93—107.

BROOKS, C. K., 1973: Tertiary of Greenland — A volcanic and plutonic record of continental break-up. In: Pitcher (ed.): *Arctic Geology. Memoir No. 19:* 150—160. The American Association of Petroleum Geologists.

BROOKS, C. K. and S. P. JAKOBSSON, 1974: Petrochemistry of the volcanic rocks of the North Atlantic ridge system. In: Kristjansson (ed.): *Geodynamics of Iceland and the North Atlantic Area:* 139—154. Reidel Publishing Company, Holland.

BUROV, Yu. P., 1965: Peridotite inclusions and bombs in the trachy-basalts of Sverre volcano in Vestspitsbergen. (Translated from Russian). In: Sokolov (ed.): *Materiali po geologii Spicbergena:* 267—279. Institute for Geology of Arctic, Leningrad.

BUROV, Yu. P. and Yu. Ya. LIVSIC, 1965: Poorly differentiated dolerite intrusions in Spitsbergen. (Translated from Russian). In: Sokolov (ed.): *Materiali po geologii Spicbergena:* 255—266. Institute for Geology of Arctic, Leningrad.

BUROV, Yu. P. and I. A. ZAGRUZINA, 1976: Results of a determination of the absolute age of Cenozoic basic rocks of the northern part of the island of Spitsbergen (Translated from Russian). *In Geologija Sval'barda:* 139—140. NIIGA, Leningrad.

BUROV, Yu. P., A. A. KRASIL'SCIKOV, L. V. FIRSOV and B. A. KLUBOV, 1977: The age of Spitsbergen dolerites. *Norsk Polarinst. Årbok* 1975: 101—108.

ELDHOLM, O. and A. M. MYHRE, 1977: Hovgard fracture zone. *Norsk Polarinst. Årbok* 1976: 195—208.

FEDEN, R. H., P. R. VOGT and H. S. FLEMING, 1978: Magnetic and bathymetric evidence for the «Yermak hot spot» northwest of Svalbard in the Arctic Basin. (Submitted to *Earth and Planetary Science Letters*).

FREY, F. A. and D. H. GREEN, 1974: The mineralogy, geochemistry and origin of lherzolite inclusions in Victorian basanites. *Geochim. et Cosmochim. Acta* 38: 1023—1059.

GAYER, R. A., D. C. GEE, W. B. HARLAND, J. A. MILLER, H. R. SPALL, R. H. WALLIS and T. S. WINSNES, 1966: Radiometric age determinations on rocks from Spitsbergen. *Norsk Polarinst. Skrifter* Nr. 137.

GJELSVIK, T., 1963: Remarks on the structure and composition of the Sverrefjellet volcano, Bockfjorden, Vestspitsbergen. *Norsk Polarinst. Årbok* 1962: 50—54.

GOLDSCHMIDT, W. M., 1911: Petrographische Untersuchung einiger Eruptivgesteine von Nordwestspitzbergen. *Vid. Selsk. Skr. I. Mat. Nat. Kl.* No. 9. Kristiania.

GREEN, D. H., A. D. EDGAR, P. BEASLEY, E. KISS and N. G. WARE, 1974: Upper mantle source for some hawaiites, mugearites and benmoreites *Contr. Mineral. and Petrol.* 48: 33—43.

HALVORSEN, E., 1972: A palaeomagnetic study of two volcanic formations from northern Spitsbergen. *Norsk Polarinst. Årbok* 1970: 70—75.

HARLAND, W. B., 1973 a: Mesozoic geology of Svalbard. In: Pitcher (ed.): *Arctic Geology, Memoir, No. 19:* 135—148. The American Association of Petroleum Geologists.

HARLAND, W. B., 1973 b: Tectonic evolution of the Barents Shelf and related plates. In: Pitcher (ed.): *Arctic Geology, Memoir No. 19:* 599—608. The American Association of Petroleum Geologists.

HELMKE, P. A. and L. A. HASKIN, 1973: Rare-earth elements, Co, Sc and Hf in Steens Mountain basalts. *Geochim. Cosmochim. Acta* 37: 1513—1529.

HOEL, A., 1914: Nouvelles observations sur le district volcanique du Spitsberg du nord. *Vid. Selsk. Skr. I. Mat. Nat. Kl.* No. 9. Kristiania.

HOEL, A. and O. HOLTEDAHL, 1911: Les nappes de lave, les volcans et les sources thermales dans les environs de la Baie Wood au Spitsberg. *Vid. Selsk. Skr. I. Mat Nat. Kl.* No. 8. Kristiania.

MACDONALD, G. A., 1968: Composition and origin of Hawaiian lavas. *Geol. Soc. Am. Mem.* 116: 477—522.

MANSON, V., 1967: Geochemistry of basaltic rocks: Major elements. In: Hess, H. H. and A. Poldervaart (eds.): *Basalts. The Poldervaart Treatise on Rocks of Basaltic Composition* 1: 215—269.

NOE-NYGAARD, A., 1974: Cenozoic to recent volcanism in and around the North Atlantic Basin. In: Nairn, A. E. M. and F. G. Stehli (eds.) *The Ocean Basins and Margins* 2: 391—443.

O'HARA, M. J., 1968: The bearing of phase equilibria studies in synthetic and natural systems on the origin and evolution of basic and ultrabasic rocks. *Earth-Sci. Rev.* 4: 69—133.

ORVIN, A. K., 1940: Outline of the geological history of Spitsbergen. *Skr. Svalbard og Ishavet.* Nr. 78.

POLVE, L. B. and P. VIDAL, 1973: Initial strontium isotopic composition of volcanic rocks from Jan Mayen and Spitsbergen. *Earth Planet. Sci. Letters* 18: 333—338.

ROALDSET, E., 1975: Rare earth element distribution in some Precambrian rocks and their phyllosilicates, Numedal, Norway. *Geochim. Cosmochim. Acta* 39: 455—469.

ROEDER, P. L. and R. F. EMSLIE, 1970: Olivine-liquid equilibrium. *Contr. Mineral. and Petrol.* 29: 275—289.

SCHILLING, J.-G., 1976: Rare-earth, Sc, Cr, Fe, Co and Na abundances in DSDP LEG 38 basement basalts: Some additional evidences on the evolution of the Thulean volcanic province. *Initial Reports of the Deep Sea Drilling Project* 38: 741—750.

SEMEVSKIJ, D. V., 1965: Age of the Sverrefjellet volcano. (Translated from Russian). In: Sokolov (ed.) *Materiali po geologii Spicbergena:* 280—283. Institute for Geology of Arctic, Leningrad.

SHAW, D. M., 1970: Trace element fractionation during anatexis. *Geochim. Cosmochim. Acta* 34: 237—243.

SOKOLOV, V. N., A. A. KRASIL'SCHIKOV, and Yu. Ya. LIVSIC, 1968: The main features of the tectonic structure of Spitsbergen. *Geol. Mag.* 105: 95—115.

THOMPSON, R. N., 1974: Primary basalts and magma genesis. I. Skye, North-West Scotland. *Contr. Mineral. and Petrol.* 45: 317—341.

TYRRELL, G. W. and K. S. SANDFORD, 1933: Geology and petrology of the dolerites of Spitsbergen. *Proc. Roy. Soc. Edinburgh* 53: 284—321.

Sandstone diagenesis– Mesozoic rocks from southern Spitsbergen

By ANDERS ELVERHØI and KNUT BJØRLYKKE[1]

Abstract

A sedimentary section of Upper Jurassic and Lower Cretaceous rocks from Southern Spitsbergen previously described by Edwards (1975) has been studied with respect to sandstone diagenesis. Marine Upper Jurassic coarsening upwards sequences pass upwards into Cretaceous fining upwards cycles of fluvial facies.

Well sorted sandstones which had a high primary porosity are almost completely cemented by pressure solution and quartz overgrowth. Illitisation — illite replacing chert, quartz and feldspar — postdates quartz overgrowth and represents a later stage of diagenesis when potassium concentration and pH were higher in the pore water. Carbonate cement often developed, as euhedral dolomite rhombs displace illite, and represents a later stage possibly associated with tectonic activities. Only the silty and muddy sandstones which were not already fully cemented by pressure solution and quartz overgrowth were influenced.

Well developed pseudomorph of dolomite shows that carbonate cement has been partly replaced by porous iron oxides of a very late stage probably due to weathering by exposure or oxygen rich ground water.

The lower porosities of the Mesozoic sandstones of Spitsbergen as compared to those of the North Sea may be conditioned mainly by the absence of a seal in the overlying Cretaceous and Tertiary sequence. Updip migration of excess pore water during compaction was allowed, maintaining low pore pressures and an effective pressure solution at grain contacts — unlike in the North Sea.

Introduction

Mesozoic and Tertiary sandstones in Spitsbergen are generally well cemented, having low porosity and permeability, and making a striking contrast to some of the North Sea sandstones.

The high degree of diagenetic alteration and cementation could be due to greater burial depth, higher geothermal gradients, or factors relating to the primary mineralogy and the circulation of pore water. Diagenetic tem-

[1] Department of Geology, University of Bergen, Norway

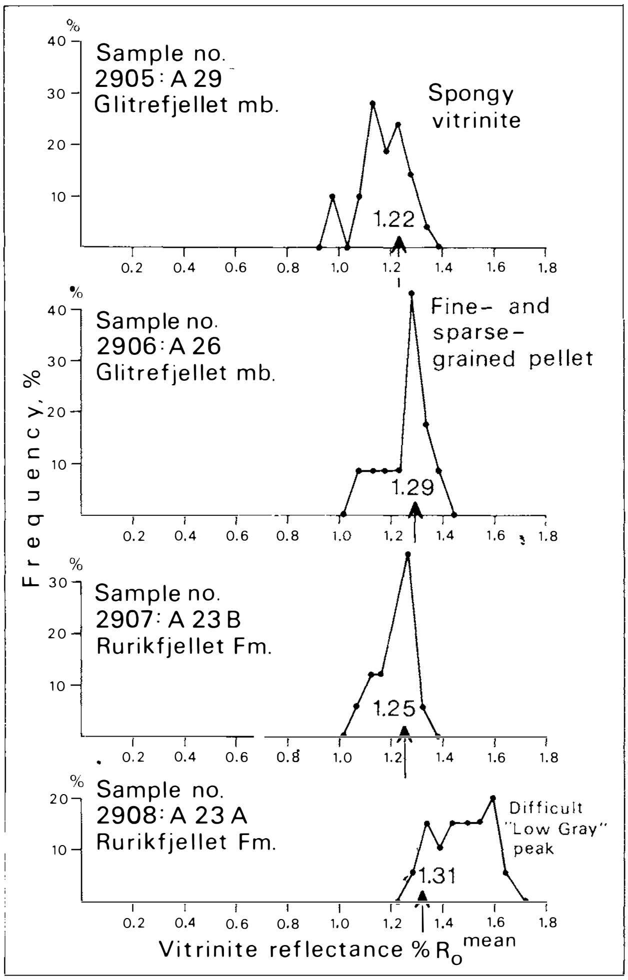


Fig. 1. *Frequency distribution of reflectance of vitrinite grains in kerogen. The representative reflectance value is indicated on each plot by an arrow. The representative rank value indicates a temperature of about 120° C, and a 3.5—4.5 km overburden is suggested. (Analysed by T. Throndesen, Geological institute, University of Oslo).*

peratures can be estimated with some degree of accuracy using palynomorph colouration and vitrinite reflection index. Vitrinite reflectance measurements on dispersed organic matter (Fig. 1), indicate a previous overburden of about 3.5—4.5 km. Clay minerals particularly the presence of expandable smectites, can also give some information about burial depth and temperature.

The purpose of the present paper is to discuss diagenesis in a section of Mesozoic sediments from southern Spitsbergen which has earlier been described and interpreted with respect to depositional environments (Edwards 1975).

Description of the Section

The section investigated (Table 1) is located near Sørkapp, southern part of Spitsbergen, and is some 220 m thick. Its lower part consists of three coarsening upwards units of Jurassic and Lower Cretaceous age (Rurikfjellet Formation) which are interpreted as having been deposited in a marginal marine environment, while the upper 70—80 m (Helvetiafjellet Formation) consists of fining upwards cycles of probable fluvial origin (Edwards 1975) (Fig. 2). The well sorted parts of the cycles consist of relatively pure orthoquartzites which pass upwards into micaceous sandstones and siltstones. The lower part of the section also contains some carbonate cement and iron oxides which produce a reddish or brown colour in this part of the section.

The Upper Cretaceous is missing in Spitsbergen and Paleocene sandstones (Firkanten Formation) rest unconformably on Lower Cretaceous beds (Nagy 1970; Kellogg 1975; Nagy 1978). The basal Tertiary sequence in the Sørkapp region consists of siltstones and up to 10—15 m thick sandstones (Winsnes pers. comm. 1978). A low angle unconformity can be observed between Mesozoic and Tertiary strata reflecting Upper Cretaceous uplifts and erosion.

Laboratory Analyses

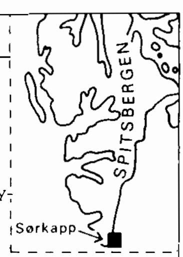
19 samples from the section (Fig. 2) have been analysed petrographically by 1) x-ray diffraction, 2) petrographic microscope, and 3) scanning electron microscopy.

XRD analyses were carried out using unoriented samples mounted on

Table 1.

Schematic geological section from Spitsbergen (Harland et al. 1974; Nagy 1978) and location map.

PERIOD	FORMATION (Fm) MEMBER (Mb)	LITHOLOGY
TERTIARY	Aspelintoppen Fm Battfjellet Fm Gilsonryggen Fm Sarkofagen Fm Basilika Fm Firkanten Fm	Alternating sandstones, shale and siltstones, interlayering coal seams.
		HIATUS/UNCONFORMITY
	Carolinefjellet Fm	Mainly shale and siltstones
CRETACEOUS	Helvetiafjellet Fm: Glitrefjellet Mb, Festningen-sandstone Mb (Studied section)	Sandstones with interlayering mudstones
	Janusfjellet Fm: Rurikfjellet Mb (Studied section)	Sand and mudstones
JURASSIC	Janusfjellet Fm: Agardhfjellet Mb	Shale



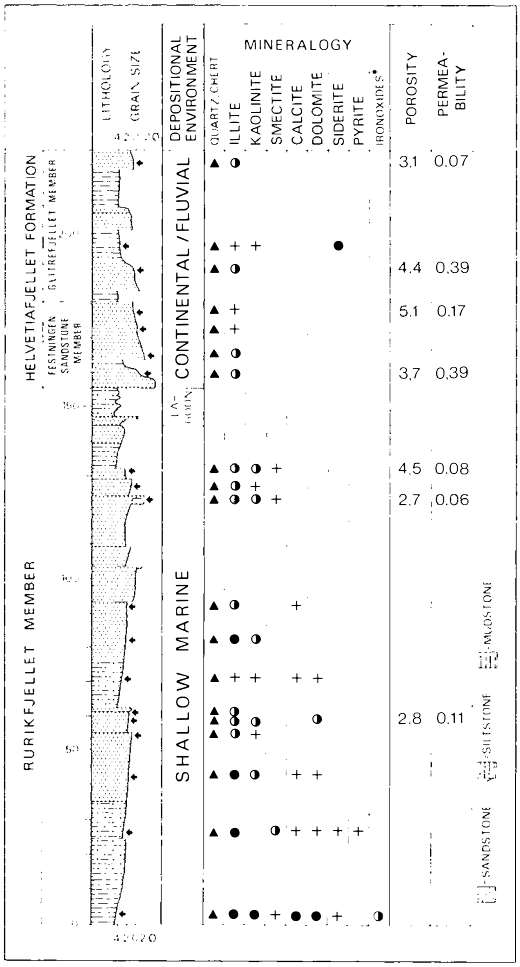


Fig. 2. *Compiled column of the studied section. Lithology and depositional environment is based on Edwards (1975). Samples for mineralogical and petrophysical studies are marked with an arrow. Legend for semi-quantitative mineralogy:*
▲ *major component*
● *abundant*
◑ *minor component*
+ *trace*
* *from thin section*
Porosity in %/o and permeability in millidarcy

vaseline coated glass (Gibbs 1965) and oriented vacuum filtered samples of the less than 63 μm (Stokke and Carson 1973; Wilson and Pittman 1977). Semiquantitative clay mineral analyses are presented as peak intensities following Norish and Taylor (1962). SEM analyses were carried out using gold-palladium coating after treatment in an ultra-sonic tank to remove dust.

Effective porosity was measured using helium gas while nitrogen gas was used for the permeability measurements which were carried out at the Geco Lab., Stavanger.

Mineralogy

XRD analyses and thin section studies show that illite and clastic mica are the most common clay minerals. In the lower part of the section kaolinite and minor amounts of smectite are present. The XRD analyses also confirm the presence of calcite and dolomite which in this section appear as cement, often in the form of euhedral rhombs. Siderite has also been detected. Thin section analyses show that in addition to quartz, chert clasts (about

10 %) are common. Feldspar is rare (<5%) which is also confirmed by XRD analyses.

The sandstones and siltstones exposed in the sequence are tightly cemented and the measured porosities range typically between 3—5% (Fig. 2). Some of this porosity may be due to secondary fractioning and surface leaching. Measurements of seismic velocities in the field (Grønlie 1978) gave a mean value of about 4.5 km/s which is typical for well cemented sandstones.

Pressure solution and quartz overgrowth are extensive in the well sorted sandstones resulting in the very low porosity in the sediments (Fig. 3a). In the Festningen sandstone, however, quartz overgrowth has been less extensive, and euhedral quartz crystals can be seen facing into the pores (Fig. 3b).

Minor amounts of pyrite are common, often as framboidal pyrite similar to that described by Elverhøi (1977).

Diagenesis

Early diagenesis

Little evidence of early diagenetic effects has been observed in these sandstones, although this may be due to the overprinting of the late diagenetic effects. It is likely, however, that feldspar was partly or wholly kaolinitized, but at shallow burial depth by circulation of acid ground water (Sims 1970). Because feldspar content is low, this has not been a very important process.

Pressure solution and quartz overgrowth

Secondary overgrowth of quartz and pressure solution at grain contacts probably took place after considerable burial. This led to a total cementation of the well-sorted, coarse-grained sandstones, resulting in a destruction of the high primary porosity.

The micaceous silty sandstones and mudstones show less overgrowth development and were probably not fully cemented at this stage. This may have been due to the influence of the clastic mica which would have mechanically inhibited compaction and reduced the stress at grain contacts (Siever 1959). Mica would also have produced a different chemical environment with slightly higher pH due to expulsion of potassium ions.

In the mature quartz sandstones there is very little that could have buffered acid pore water while in the siltstones and mudstones with lower primary permeability a slightly increased concentration of K^+ may have been allowed to build up from the expulsion of K^+ from mica and feldspar. We would, in these lithologies, expect to have a chemical gradient of decreasing K^+ and pH from the micaceous siltstones and mudstones into the well sorted quartzites. This may explain the preferred precipitation of silica overgrowth in the well sorted sandstones.

After burial and diagenesis it is therefore probable that the distribution of porosity and permeability was reversed as compared to the primary distribution, the beds with lowest primary porosity having eventually the highest porosity.

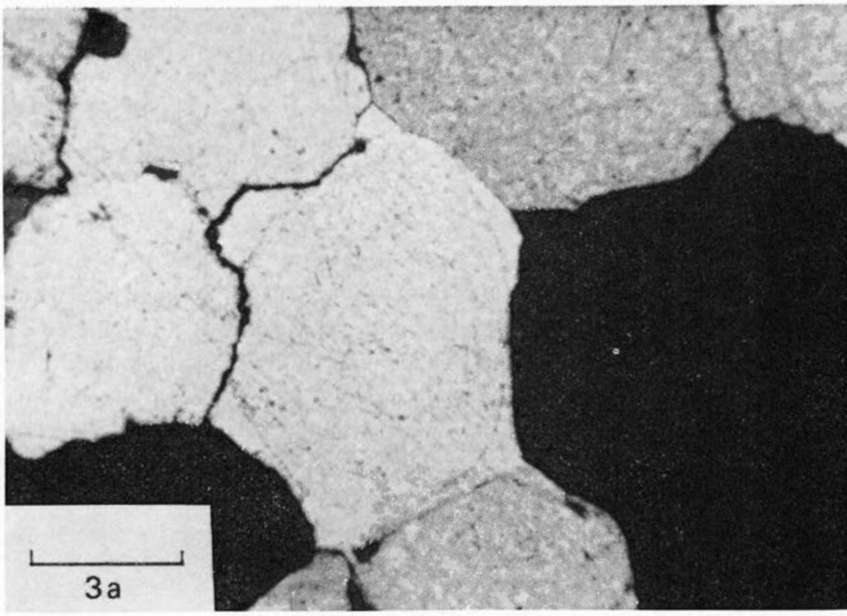


Fig. 3a. *Quartz sandstone with secondary quartz overgrowth. Note later development of microstylolites cutting across both quartz grain and overgrowth. 94 m above base in the section, Fig. 2. (Scale bar: 200 μm, thin section.)*

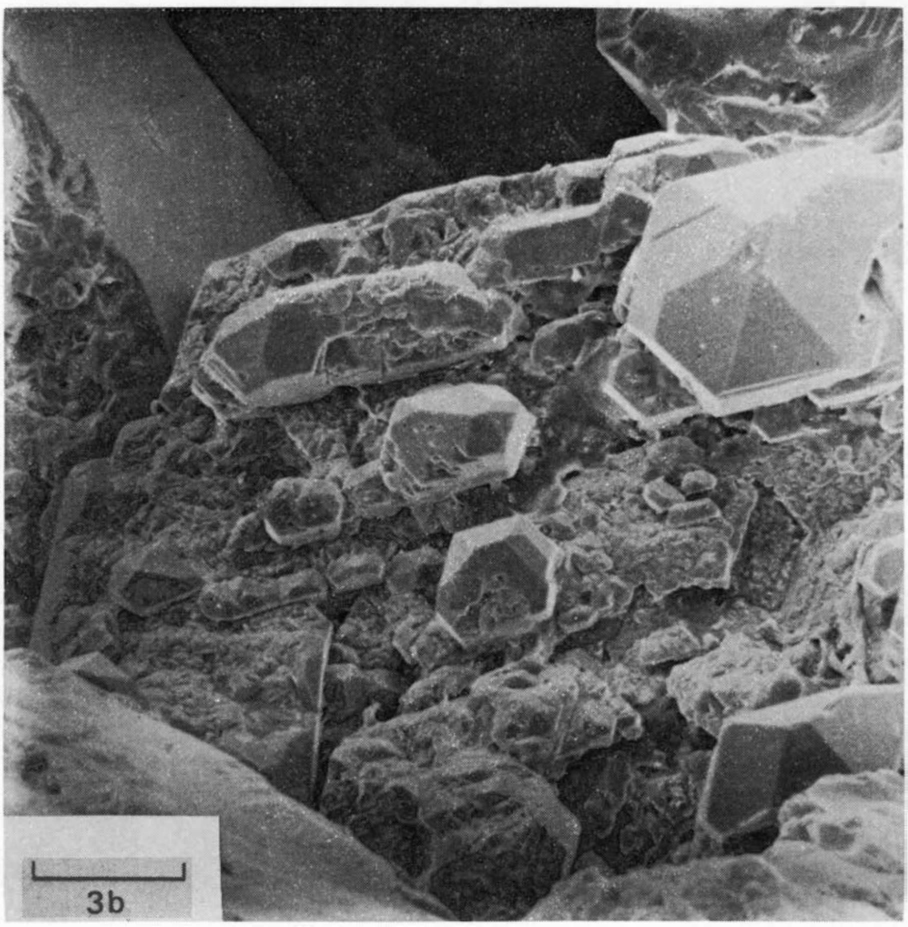


Fig. 3b. *SEM picture of Festningen sandstone where some porosity is preserved and with development of euhedral quartz. 165 m above base in the section, Fig. 2. (Scale bar: 40 μm.)*

Illitisation

Illite can, in both thin section and by scanning electron microscopy, be shown to have replaced clastic mica, chert, quartz, and feldspar grains (Fig. 4a, 4b). Secondary illite tends to follow the structures of the host mineral with respect to size and orientation (Fig. 4a). This is often observed at grain contacts and as incipient corrosion at the contact between grains. Chert and feldspar grains can, however, be observed in all stages of replacement by illite. In grain supported sandstones we frequently find areas of illitic matrix of the same size as the framework grains, suggesting total replacement of probably chert and feldspar grains by matrix. Quartz grains may also, to some extent, have been replaced by illite but they are more stable than chert and feldspar.

Illite is never found between primary quartz grains and quartz overgrowths, but is often observed partly replacing secondary quartz overgrowths (Fig. 4c, 4d). It is thus clear that illitisation postdates the quartz overgrowth.

The growth of illite shows that the chemistry of the pore water has changed towards a more potassium-rich basic composition (Garrels and Christ 1965; Harder 1974). It is difficult to assess what were the sources of potassium and alumina necessary for the formation of illite. As the sandstone beds were already cemented, the flow of water through the whole sequence must have been strongly reduced. The most likely source of Al^{3+} and K^{+} may have been clastic mica derived from within the sequence or from the underlying shale sequence (Janusfjellet Formation Table 1).

Electron scanning photographs show that illite has grown on a micro-styolitic grain contact. It is possible that the growth of illite is associated with tectonic stress.

Carbonate cementation and replacement

Carbonate crystals, mainly dolomite, occur mostly in the fine-grained parts of the lower marine sequence (Fig. 2), probably because the coarser grained, well sorted sandstones were already cemented.

The carbonate cement occurring between grains usually consists of single crystals or an aggregate of rhombs filling the pore space. Dolomite rhombs can be commonly observed displacing and reorienting illite matrix as a result of crystal growth. XRD analyses confirm that dolomite is the dominant carbonate mineral. There is also evidence of dissolution of quartz and replacement by carbonate. All carbonate observed is typically late diagenetic cement and no example of drusy cement has been identified. The introduction of carbonate appears to have occurred very late. Because carbonate was not mobilized earlier during burial diagenesis when quartz pressure solution and cementation took place, it is likely that carbonate cementation resulted from dissolution of carbonate in other parts of the sequence, e.g. during the Tertiary (Miocene?) folding. Carbonate solution would then have produced cementation in the available pore space.

Maturation of the underlying black shales of the Janusfjellet Formation

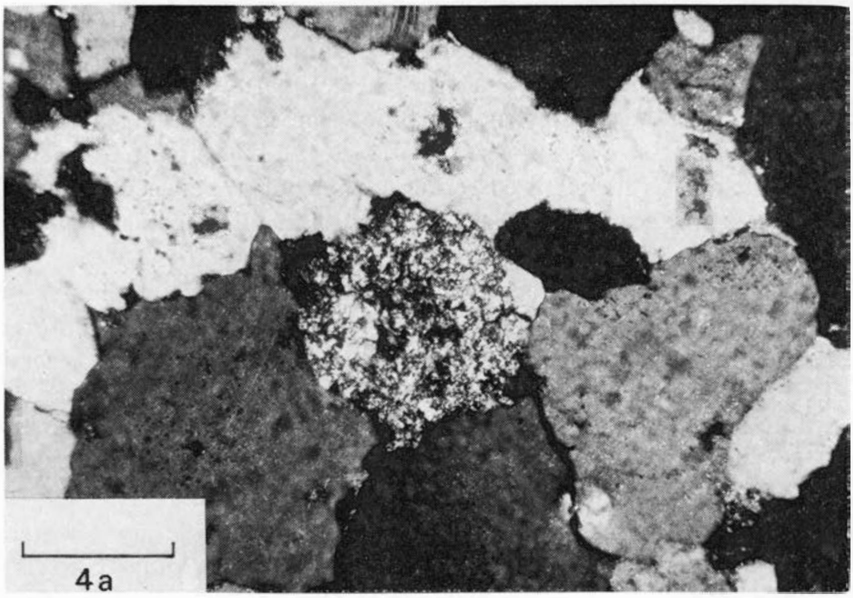


Fig. 4a. *Clastic chert grain showing incipient replacement by illite. 62 m above base in the section, Fig. 2. (Scale bar: 200 μm, thin section.)*

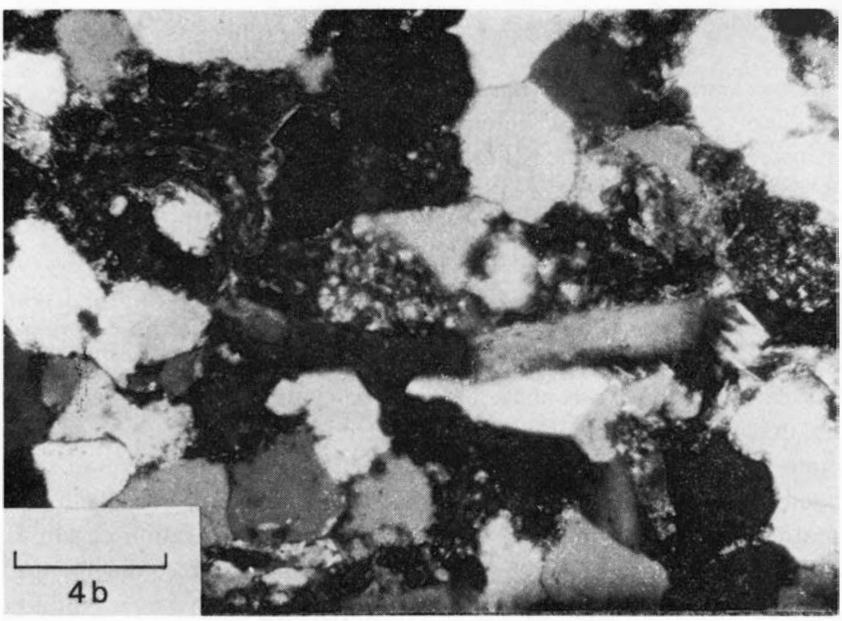


Fig. 4b. *Clastic mica showing authigenic growth of fans of illite at the edges. 162 m above base in the section, Fig. 2. (Scale bar: 200 μm, thin section.)*

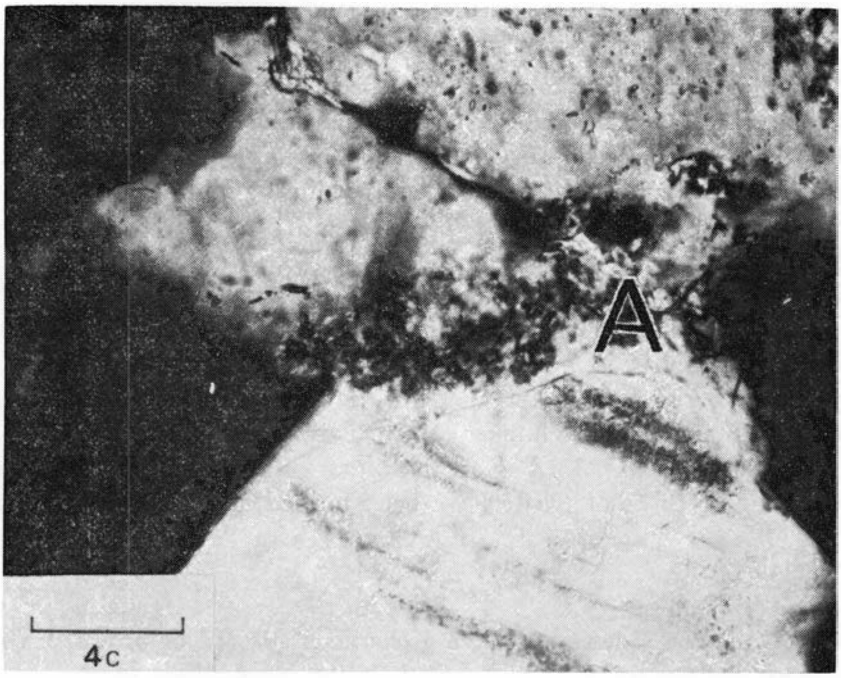


Fig. 4c. *Illite replacement of quartz overgrowth zone (A). 158 m above base in the section, Fig. 2. (Scale bar: 500 μm, thin section.)*

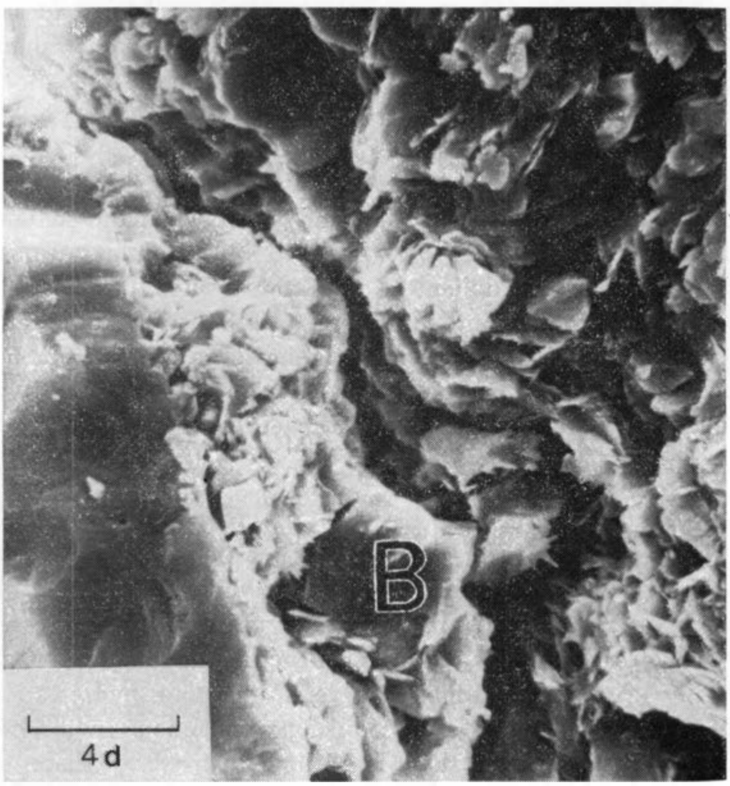


Fig. 4d. *SEM picture of quartz grain contacts with replacement of illite. Some porosity is left and tiny quartz grains (B) not yet dissolved are observed between the illite flakes. 158 m above base in the section, Fig. 2. (Scale bar: 10 μm.)*

may also have produced carbonate by decomposition of kerogen (Curtis 1978). The fact that carbonate cement occurs only in the marine sequence suggests that the source of carbonate was more local, probably from carbonate fossils or clastic carbonate grains dissolved during folding.

Sulphides

Sulphides are common, but occur in relatively small amounts. Pyrite crystals, very often euhedral, both predate and postdate quartz overgrowth and also occur in carbonate cement. It seems, therefore, that the formation of sulphides has occurred in several stages during the diagenesis as has also been observed by Blanche and Whitaker (1978). Framboidal pyrite similar to that described by Elverhøi (1977), is an indication of early sulphide diagenesis, while the larger cubes of pyrite have been formed at a later stage (Sharma 1969).

Iron oxide cement

Many of the rocks described have a characteristic red or brownish colour. This is due to iron oxide cement which is the latest phase of cementation. Brown semi-opaque iron oxides have replaced carbonate and we find good examples of pseudomorphs after dolomite rhombs replaced by hematite (Fig. 5 a). Also illite is partly strained by iron oxides. Iron oxides are semi-transparent, and they clearly form a porous aggregate rather than massive hematite. This is confirmed by scanning electron microscopy of these iron oxides (Fig. 5 b.).

Ferric iron oxides require oxidizing conditions and are not likely to have formed during late diagenesis at great depth. The formation of iron oxides has probably taken place after erosion and uplift when the sediments were exposed to oxidizing ground water (Siever 1959). Iron has probably been derived from iron-bearing dolomites and from pyrite. It is not known how deep this oxidation reaches into the subsurface. This kind of weathering by acid ground water of carbonate cement is, however, very common in Spitsbergen. Because of the porous nature of the iron oxide, samples with significant amounts of such cement will give misleadingly high porosity values.

Stratigraphic and facies control on diagenesis

Diagenetic processes are strongly dependent upon the degree of circulation of pore water and pore pressure in a sandstone. Pore pressure corresponding to hydrostatic pressure will give the maximum stress at grain contact resulting in pressure solution. In order to maintain hydrostatic pressure, excess water must be able to escape during compaction. In the case of the Mesozoic rocks in Spitsbergen there is no tight seal, e.g. of shale, to prevent updip migration of porewater. The Lower Cretaceous sandstones are deposited as an offlapping sequence and have probably served as migration chan-

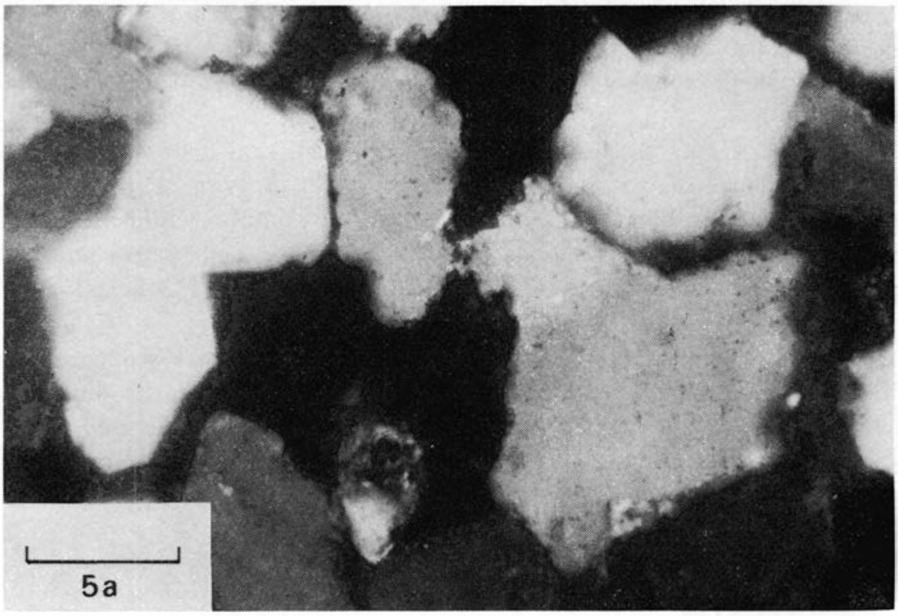


Fig. 5a. *Semi-opaque iron-oxides with pseudomorphose of dolomite (A). 1 m above base in the section, Fig. 2. (Scale bar 100 μ m, thin section.)*

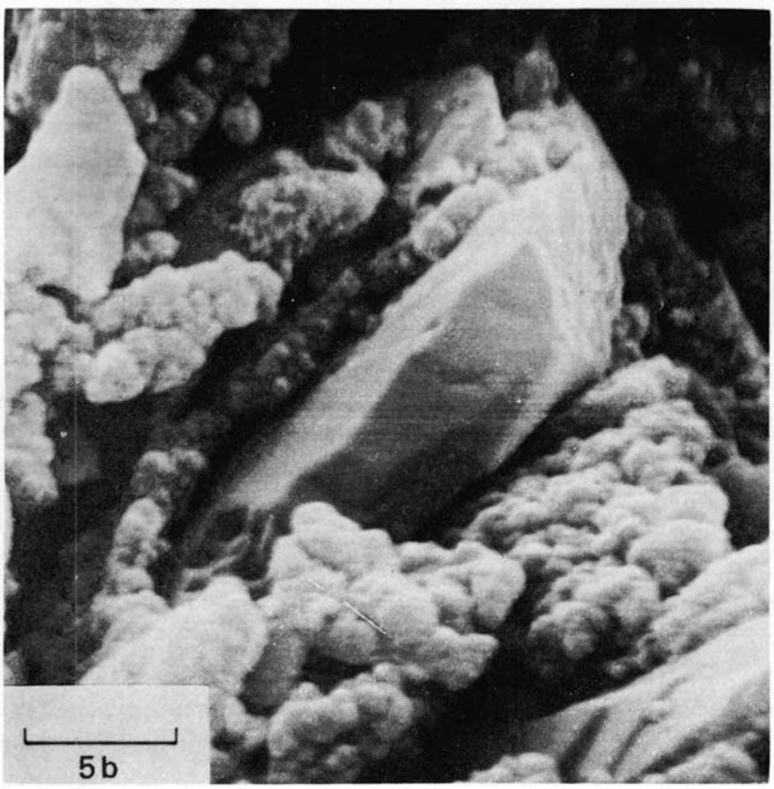


Fig. 5b. *SEM picture of porous iron-oxides. 1 m above base in the section. (Scale bar: 2 μm.)*

nels for water up to the Tertiary/Cretaceous angular unconformity. The Lower Tertiary sandstones also consist of prograding (offlapping) deltaic sediments which probably would allow updip migration of water (Dalland pers. comm.).

During the Upper Cretaceous break and possibly also in Tertiary time, fresh water lenses may have penetrated into the underlying sequences. Fresh water conditions would favour the formation of kaolinite while the late development of illite and carbonate suggests a more closed system where the concentration of metallic ions like K^{+} Ca^{++} and Mg^{++} was allowed to build up.

In the North Sea, in contrast, Upper Mesozoic sedimentary sequences often form onlapping strata where each shaly bed seals off the underlying sequences. The thick Tertiary shale sequences here also contributed to the preservation of the pore pressure and reducing circulation of pore fluid.

Conclusion

The Cretaceous sandstones from south Spitsbergen described in this paper are well cemented and have very little porosity or permeability.

Recent weathering or ground water dissolution of carbonate cement and sulphides, and replacement with red porous iron oxide cement have produced a secondary porosity which may be misleading in an evaluation of possible reservoir rocks.

After burial the well sorted marine sandstones with a high primary porosity were almost completely cemented while the silty impure sandstones preserved some porosity. Since these beds were part of an offlapping sequence which were overstepped by the overlying Tertiary sandstones, the water expelled during compaction could easily have migrated updip, so that a high pore pressure did not develop. The absence of a seal to prevent updip escape of pore water was probably the main reason for the effective pressure solution and quartz overgrowth of the Cretaceous sandstones. Later illite and carbonate cement development in most of the remaining available porosity, indicates a more closed system with higher pH.

Vitrinite reflectance studies suggest that burial depth was probably not more than about 3.5—4.5 km. Expandable smectite found in these sediments also suggests that the burial depth was not excessive.

The contrast in diagenetic alteration between the sequences of Spitsbergen and those of the North Sea may be due mainly to the presence of onlapping shaly sequences serving as seals in the North Sea and causing the build-up of over-pressures. The presence or absence of such a seal may be as important as temperature and overburden for the preservation of porosity during diagenesis.

Acknowledgement

In 1973, M. Edwards logged the section and he is kindly thanked for making data, samples and thin sections available. Fieldwork 1977 was carried out together with G. Grønlie, O. Møller, S. Dahlgren, and S. Solheim, and we are grateful for their helpful assistance and discussion.

T. Throndsen kindly supported the investigation with vitrinite reflectivity measurements. R. J. Steel is thanked for correcting the English langue.

References

BLANCHE, J. B. and J. H. Mc D. WHITAKER, 1978: Diagenesis of part of the Brent Sand Formation (Middle Jurassic) of the northern North Sea Basin. *Jour. Geol. Soc. Lond.* 135: 73—82.

CURTIS, C. D., 1978: Possible links between sandstone diagenesis and depth-related geochemical reactions occurring in enclosing mudstones. *Jour. Geol. Soc. Lond.* 135: 107—117.

EDWARDS, M. B., 1975: Depositional environments in Lower Cretaceous regressive sediments, Kikutodden, Sørkapp Land, Svalbard. *Norsk Polarinstitutt Årbok 1974*: 35—50.

ELVERHØI, A., 1977: Origin of framboidal pyrite in clayey sediments and in Jurassic black shale in the north-western part of the Barents Sea. *Sedimentology* 24: 591—595.

CARRELS, R. M. and C. L. CHRIST, 1965: *Solutions, Minerals and Equilibria.* Harper & Row, New Yourk. 450 p.p.

GIBBS, R. J., 1965: Error due to segregation in quantitative clay mineral x-ray diffraction mounting technique. *Am, Mineral.* 50. 741—751.

GRØNLIE, G., 1978: Preliminary results of seismic velocity measurements on Spitsbergen in 1977. *Norsk Polarinstitutt Årbok* 1977: 229—236.

HARDER, H., 1974: Illite mineral synthesis at surface temperatures. *Chemical Geology* 14: 241—253.

HARLAND, W. B., J. L. CUTBILL, P. E. FRIEND, D. J. GOBBET, D. W. HOLLIDAY, P. I. MATON, R. J. PARKER and R. H. WALLIS, 1974: The Billefjorden Fault Zone, Spitsbergen, the long history of a major tectonic lineament. *Norsk Polarinstitutt Skrifter* Nr. 161.

KELLOGG, H. E., 1975: Tertiary stratigraphy and tectonism in Svalbard and continental drift. *Bull. Amer. Assoc. Petrol. Geol.* 59(3): 465—485.

NAGY, J., 1970: Ammonite faunas and stratigraphy of Lower Cretaceous (Albian) rocks in southern Spitsbergen. *Norsk Polarinstitutt Skrifter* Nr. 152.

— 1978: Oversikt over Svalbards Mesozoicum. *Compendium, Geol. Institute, Univ. of Oslo.* 32 p.p.

NORISH, K. and R. M. TAYLOR, 1962: Quantitative analysis by X-ray diffraction. *Clay Min. Bull.* 5: 98—104.

SHARMA, G. D., 1969: Paragenetic evolution in Peejay Field, British Columbia, Canada. *Miner. Deposita* 4: 346—354.

SIEVER, R., 1959: Petrology and geochemistry of silica cementation in some Pennsylvanian sandstones. Pp. 55—59 in: IRELAND, H.A. (ed.) *Silica in sediments.* Spec. Publs. Soc. Econ. Paleont. Miner., Tulsa 7.

SIMS, J. D., 1970: Authigenic Kaolinite in sand of the Wilcox Formation, Jackson Purchase region, Kentucky. *Prof. Pap. U. S. Geol. Surv.* 700 B, B27-B32.

STOKKE, P. R. and B. Carson, 1973: Variation in clay mineral X-ray diffraction results with the quantity of samples mounted. *Jour. Sed. Petrol.* 43: 957—964.

WILSON, M. D. and E. D. PITTMAN, 1977: Authigenic clays in sandstones: Recognition and influence on reservoir properties and paleoenvironmental analysis. *Jour. Sed.* Petrol. 47: 3—31.

Rank of coal and dispersed organic matter and its geological bearing in the Spitsbergen Tertiary

By SVEIN B. MANUM[1] and TORBJØRN THRONDSEN[1]

Abstract

Vitrinite reflectance measurements on coals and dispersed organic matter in the Spitsbergen Tertiary are reported. A rank profile through the Tertiary sequence (900 m) at Nordenskiöldfjellet shows gradual rank increase ranging from 'sub-bituminous' (R_0 = 0.40) at the top to 'high volatile bituminous B' (R_0 = 0.68) at the base. This profile is used to establish a maturation gradient for the Spitsbergen Tertiary on the basis of which the total depth of burial for the base of the Tertiary at Nordenskiöldfjellet is estimated at 2700 m, implying that roughly 1700 m of sediments have been eroded.

Rank in the economically important coal horizon at the base of the Tertiary sequence shows regional variation but is generally within the «high volatile bituminous B» range. Rank is highest in the central and southern parts of the Tertiary depression and decreases towards the western and eastern flanks.

Isoranks are interpreted in terms of isopachs, and the implications of rank studies for the understanding of the Tertiary basin are discussed in relation to previous knowledge of its history. The main conclusion is that the area of greatest subsidence migrated eastwards probably starting in late Paleocene times.

Introduction

In this study, vitrinite reflectance measurements have been used to determine the rank of Tertiary coals and dispersed organic matter in sediments on Spitsbergen. In spite of the economic interest involved in the Spitsbergen coals for more than 75 years, surprisingly little published information on their rank is available. The data presented here on the rank of the coals in the lowermost Tertiary formation (Firkanten Fm.) should be of direct interest in the exploration and utilisation of this important resource in Spitsbergen.

In recent years, studies of the ocean floor spreading between Greenland and northern Europe (Talwani & Eldholm 1977) have led to renewed interest in the Tertiary deposits on Spitsbergen. The history of the Tertiary basin is now considered to be intimately associated with plate tectonic events in the

[1] Institutt for geologi, Universitetet i Oslo, P.O. Box 1047, Blindern, Oslo 3, Norway.

Norwegian-Greenland Sea area in the Palaeogene (Kellogg 1975; Lowell 1972). We have used coal rank as an indicator of total depth of burial in order to estimate total Tertiary sediment accumulation and subsequent erosion.

Solid organic matter in sediments, and thermal alteration

Solid organic matter is present in most sediments as finely dispersed particles which can be extracted by dissolving the mineral components with hydrochloric and hydrofluoric acids. The relative quantity of organic particles is usually low; Bostick (1974) reported 0.1—0.4 weight percent after acid treatment. Organic content is highest in shales and siltstones, and much lower in sandstones.

Many of the organic particles in sediments can be identified as positively being derived from plants, and the remainder also appear for the greater part to be of plant origin. Bostick (1971) introduced the term 'phytoclasts' for organic particles of clay, silt and sand size which occur in clastic sediments.

Phytoclasts may be studied by transmitted light in ordinary palynological preparations, or they may be sectioned and polished after resin embedding and then studied in a reflected light microscope. The latter method permits comparison with coal constituents, or macerals, which in coal petrology are identified on morphological and physical characteristics as observed on polished surfaces.

In their structure, morphology and colour, phytoclasts may be compared with the basic coal maceral groups, namely vitrinite, liptinite and inertinite. Vitrinite is predominantly derived from humified wood remains. Liptinite comprises the relatively hydrogen-rich plant materials such as spores, cuticles, resins, waxes and material of algal origin. The third maceral group, inertinite, is derived from the same kind of plant materials as vitrinite and liptinite, but appears to have been oxidized or otherwise altered prior to incorporation into the sediment. Phytoclasts are analogous to coal in their chemical composition, carbon, hydrogen and oxygen being the main components, with minor amounts of nitrogen and sulphur (McIver 1967).

'Coalification' is the term applied in coal science for chemical and physical alterations which take place in accumulated plant material from the 'peat' stage through 'lignite' and 'bituminous' coals to highly altered 'anthracite' (ASTM rank classification, Fig. 1). The coalification process and its causes have been discussed for more than a century. It is now generally accepted that temperature is the factor controlling the chemical alterations. In addition, time becomes a controlling factor where the temperature is high enough to permit reaction. The effect of pressure, on the other hand, appears to be mainly physical, that is, causing destruction by compression (Teichmüller & Teichmüller 1975). Therefore, the degree of coalification, or coal rank, is basically determined by the geothermal history of the sediment.

For some time it has been observed that phytoclasts are altered much in the same way as their counterparts in coal. It has been demonstrated that the degree of coalification of phytoclasts is a function of the geothermal history of the sediment in which they are incorporated, and the observations have been substantiated by laboratory experiments (Gutjahr 1966; Staplin 1969; Bostick 1971, 1973). Since temperature is the principal factor controlling the alteration of organic matter, the degree of coalification may be used as an indicator of thermal influence. For temperatures below 300°C, coalification is a sensitive measure of thermal influence and is independent of pore solution and pressure, unlike alterations in minerals.

Vitrinite is the coal maceral commonly used in rank determinations, because its properties alter uniformly during coalification and it has the advantage over other macerals of being ubiquitous. Reflectance of polished vitrinite surfaces increases progressively with increasing coal rank (Fig. 1), and quantitative reflectance measurements have for a few decades been a well established tool in coal petrology. The method and its theoretical basis have been described by McCartney & Ergun (1958, 1967), Kötter (1960), Murchison (1964), de Vries & Bokhoven (1968) and others.

The method of vitrinite reflectance measurements has been extended to vitrinitic phytoclasts by Bostick (1971), and it has in recent years become a useful tool in oil exploration for the assessment of hydrocarbon maturation potential of a sediment.

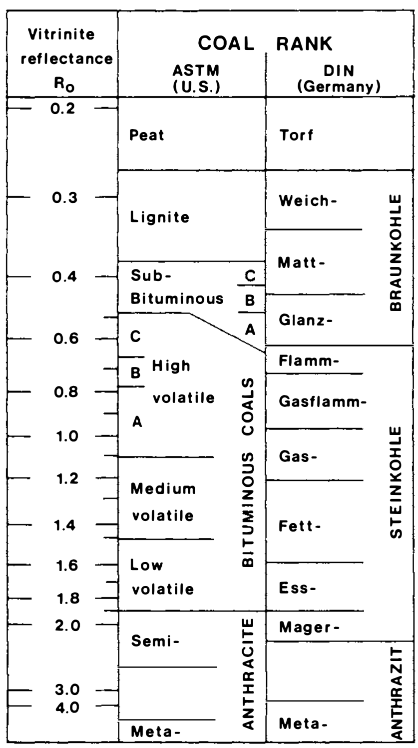


Fig. 1. *Coal ranks in the German (DIN) and U.S. (ASTM) rank classifications and vitrinite reflectance values (after Teichmüller and Teichmüller 1975).*

Geological background

In the entire Svalbard archipelago, Tertiary sediments exist only on Spitsbergen and Prins Karls Forland. The Tertiary geology of Spitsbergen has been the subject of several publications during the last two decades (Atkinson 1963; Livšic 1965, 1974; Vonderbank 1970; Major & Nagy 1972; Kellogg 1975; Croxton & Pickton 1976). Here we shall give only a brief review, pertinent to the present study.

The main Tertiary deposits occur in the central part of Spitsbergen in a large depression with a NNW-trending axis; its length exceeds 200 kilometres with width of 50—70 kilometres (Fig. 2). Four other, small areas occur to the north-west, west and south-west. Their history appears to be separate from that of the main deposits.

To the east, the depression is bounded by almost flat-lying Mesozoic deposits. The most prominent structure in the eastern area is the Billefjorden Fault Zone running north-south across Spitsbergen and known to have been active during Palaeozoic, Mesozoic and Tertiary times (Harland et al. 1974). To the west, the depression is bounded by a Tertiary fold belt active during and after deposition of the Tertiary sediments. The depression attained its present assymmetric form during the Tertiary orogeny.

Tertiary sediments in the central part of the depression exceed 2300 metres in thickness (Harland et al. 1976). They consist of alternating shales, siltstones and sandstones deposited in both marine and continental environments. The sequence has been divided into six lithological formations (Fig. 3). Coal layers occur mostly near the base (Firkanten Fm.) and in the top part of the succession (Aspelintoppen Fm.).

The age of the Firkanten Formation is generally held to be Paleocene, while dating of the upper part of the sequence varies from Eocene (Ravn 1922) to Oligocene (Livšic 1974. This uncertainty reflects the scarcity of reliable index fossils throughout. The abundant plant megafossils in the Firkanten and Aspelintoppen Formations cannot so far be used for a more precise age determination. Recent palynological studies indicate that the Firkanten Formation is no younger than early Paleocene, and dinocysts indicate a late Paleocene age for the base of the Gilsonryggen Formation (Manum & Throndsen, unpubl.).

Our results indicate a total Tertiary deposition of considerably greater thickness than is at present preserved

Thermal alteration studies

Previous publications on the rank of the Tertiary coals in Spitsbergen are few and not very detailed. The most comprehensive study to date is by Horn (1928), who used KOH tests and bulk elemental analysis for rank determina-

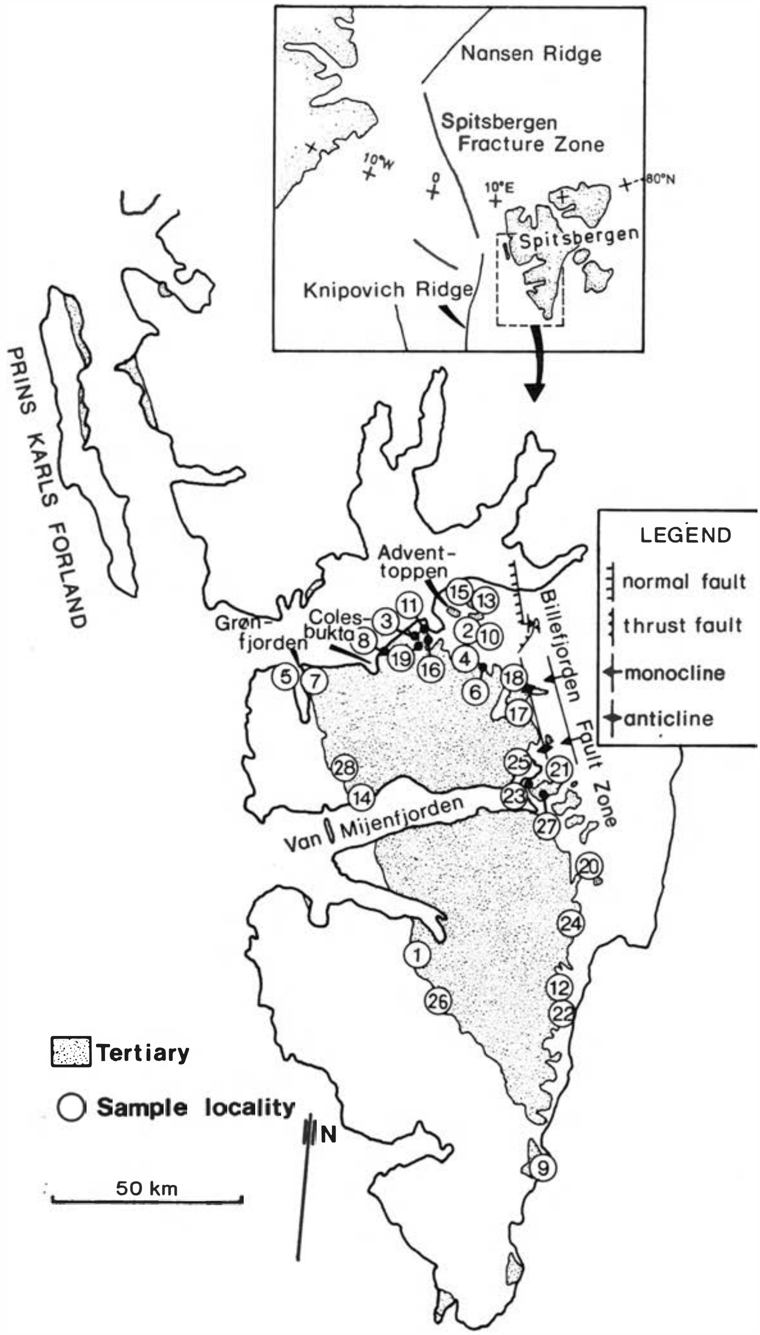


Fig. 2. *Map of southern Spitsbergen with sample localities indicated by numbers.*

Locality names:

(1) Basilika
(2) Bassen
(3) Bjørndalen
(4) Bolterdalen
(5) Festningen
(6) Foxdalen
(7) Grønfjorden
(8) Grumantbyen
(9) Hedgehogfjellet
(10) Helvetiafjellet
(11) Hotellneset
(12) Jemelianovbreen
(13) Knorringfjellet
(14) Kolfjellet
(15) Konusen
(16) Longyearbyen
(17) Lunckefjellet
(18) Møysalen
(19) Nordenskiöldfjellet
(20) NE Paulabreen
(21) Røysklumpen
(22) Schönrockfjellet
(23) Snøvola
(24) Strongbreen
(25) Sveagruva
(26) Valy Hetmanskyfjella
(27) Vallåkerbreen
(28) Ørjankampen

AGE				CLASSIFICATION	DESCRIPTION
Ravn 1922	Vonder-bank 1970	Livsic 1974	Manum & Throndsen unpubl.	Major & Nagy 1972	
Eocene	?	Oligocene?		Aspelin-toppen Fm.	LIGHT GREY SANDSTONES WITH SHALES AND THIN COAL SEAMS. DEPOSITED UNDER CONTINENTAL CONDITIONS.
Eocene	?	? Eocene		Battfjellet Fm.	ALTERNATING BEDS OF DARK SHALE AND GREY SILTY SAND-STONE. MARINE CONDITIONS.
Eocene	?	Eocene	late Paleoc. →	Gilsonryggen Fm.	BLACK SHALE. DEPOSITED UNDER MARINE CONDITIONS.
? Paleocene	? Danian – Montian	Eocene		Sarkofagen Fm.	MEDIUM-GRAINED GREENISH SANDSTONE. DEPOSITED UNDER MARINE AND ESTUARINE COND.
Paleocene	Danian – Montian	Paleocene		Basilika Fm.	DARK GREY SHALES, SILTY SHALES AND SOME THIN BEDS OF CLAY. MARINE CONDITIONS.
Paleocene	Danian – Montian	Paleocene	early Paleoc. →	Firkanten Fm.	LIGHT GREY SANDSTONE WITH SHALES, SILTSTONES AND COAL SEAMS. MARINE AND PALUDAL CONDITIONS.

Fig. 3. *Lithostratigraphic nomenclature and age of the Tertiary sequence in the central Spitsbergen depression.*

tions, following the German rank classification (Fig. 1). Horn (1928) determined coals from Adventtoppen to be 'Glanzbraunkohle', while coals from Longyearbyen (Fig. 2, locality 16), Coles Bay and the east side of Grønfjorden he classified as 'Gasflammkohle'. Coals from Svea (Fig. 2, locality 25) were ranked somewhat higher without the rank being specified. The highest rank recorded by Horn was 'Fettkohle' from Hedgehogfjellet (Fig. 2, locality 9). Harland et al. (1976) concluded that all known Svalbard coals have gone beyond any stage of 'lignite' (ASTM rank classification). The stratigraphically highest coals examined by Harland et al. (1976) came from the top part of the Tertiary succession, the Aspelintoppen Formation.

Our study falls in two parts. The first describes the vertical rank variation through a 900 metres thick sequence at Nordenskiöldfjellet (Fig. 4). In the second part, the regional variation in rank at the base of the Tertiary deposits is described. Sample localities are indicated in Figure 2, while further sample details together with vitrinite reflectance data are given in Appendix I. Preparation methods, measurement equipment and procedures are described in Appendix II.

Vertical rank profile through the Tertiary at Nordenskiöldfjellet

A vertical rank profile through a 900 metres thick sequence at Nordenskiöldfjellet is presented in Figure 4. The profile is based on reflectance values measured on dispersed vitrinitic particles in 14 samples through the sequence plus 7 coal samples from the base and the top (Appendix I).

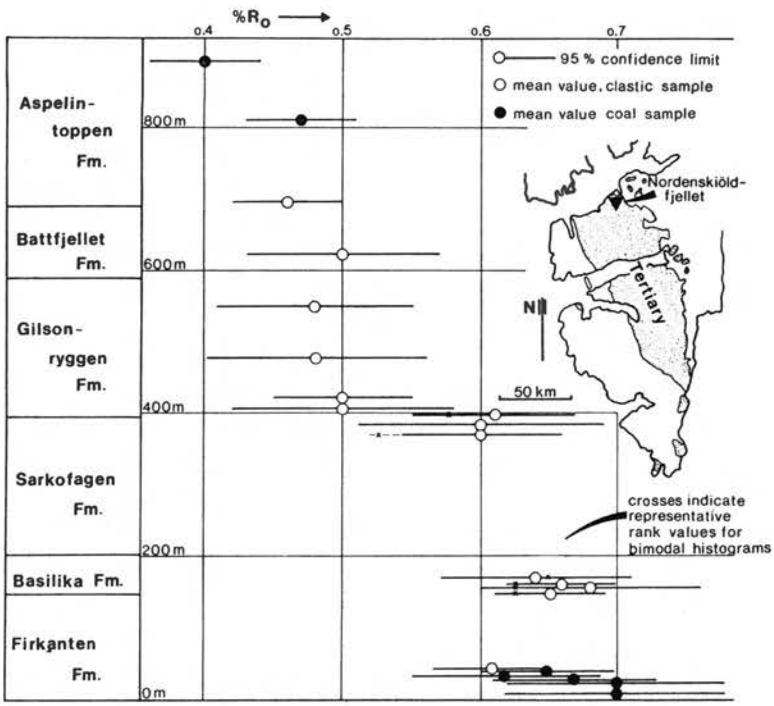


Fig. 4. *Vitrinite reflectance profile through the Tertiary sequence at Nordenskiöldfjellet.*

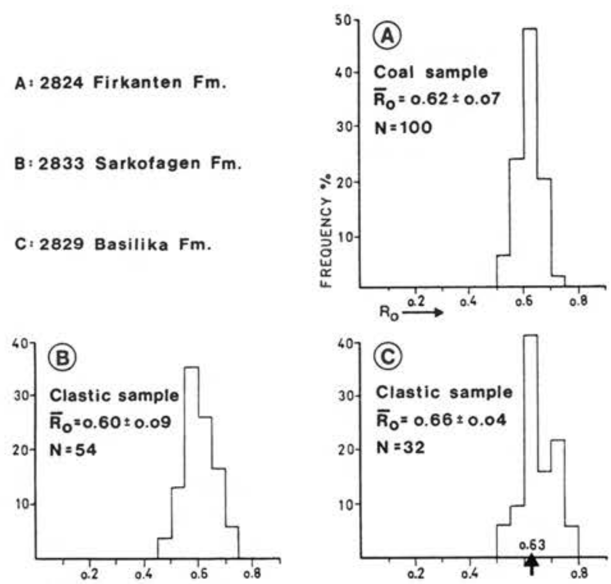


Fig. 5. *Examples of vitrinite reflectance histograms; A: coal sample, B and C: clastic samples. Measurements are grouped at intervals of 0.05 R_o (= percent reflectance in oil). $\overline{R}_o$ is the arithmetic mean of the total number of measurements on one sample, indicated by N. The ± value is the standard deviation. In histogram C, which is bimodal, the arrow indicates the representative rank value (the lower maximum).*

Here a short note is required to explain our procedure for determining the representative reflectance value (R_0) from a reflectance histogram. When the distribution of measurements is unimodal, as in the example shown in Figure 5B, the calculated mean value of the measurements is simply taken as the representative value. However, for some samples the measurements produce bimodal histograms, as the example in Figure 5C. This type of distribution is typical of samples from the Basilika Formation (cf. Appendix I, histograms for samples 2829—2832). For such bimodal histograms, the lower reflectance maximum, indicated by an arrow in the figure, is considered to indicate the rank value of the sediment. The higher maximum, on the other hand, is considered to represent vitrinitic particles reworked from higher rank host rocks, or else particles altered (oxidized) prior to incorporation in the sediment so that they have attained a higher than normal reflectance. Reworked or altered particles with reflectance considerably higher than the indigenous material are readily identified under the microscope and thus excluded from measurements. The bimodal pattern is produced by the readings from particles with reflectance only slightly higher than the indigenous ones and which therefore are difficult to exclude by microscopic observation. Coal sample measurements produce unimodal patterns (cf. the example in Fig. 5A). The problem of reworking found in clastic sediments does not exist in most coals. In the rank profile from Nordenskiöldfjellet, reflectance values are plotted against depths on a linear scale (Fig. 4). Reflectance increases from R_0 = 0.40 at the top to R_0 = 0.68 at the base, corresponding to the rank interval 'sub-bituminous' to 'high volatile bituminous B' in the ASTM rank classification (Fig. 1). The increase is gradual except for a jump at the transition Gilsonryggen Formation — Sarkofagen Formation, from R_0 = 0.50 to R_0 = 0.60 within a 50 metre interval. The jump in recorded reflectance values is considered to be an effect of the change in lithology at this transition. Samples from the Sarkofagen Formation are rather coarse silt-stones which yield large vitrinite particles that are well suited for reflectance measurements, while samples from the Gilsonryggen Formation are claystones yielding only small particles which produce unsatisfactory reflectance surfaces and hence low reflectance values, particularly since maximum and not random reflectance values were measured.

Rank variation at the base of the Tertiary deposits

Vitrinite reflectance measurements were carried out on coal samples from the coal-bearing part of the Firkanten Formation. This horizon which lies close to the base of the sequence offers excellent stratigraphical control everywhere in the Tertiary depression. Twenty-eight localities with a wide regional distribution were sampled (Fig. 2). The reflectance histograms are unimodal (example in Fig. 5A) and the calculated mean values are taken as representative rank values (listed in Appendix I).

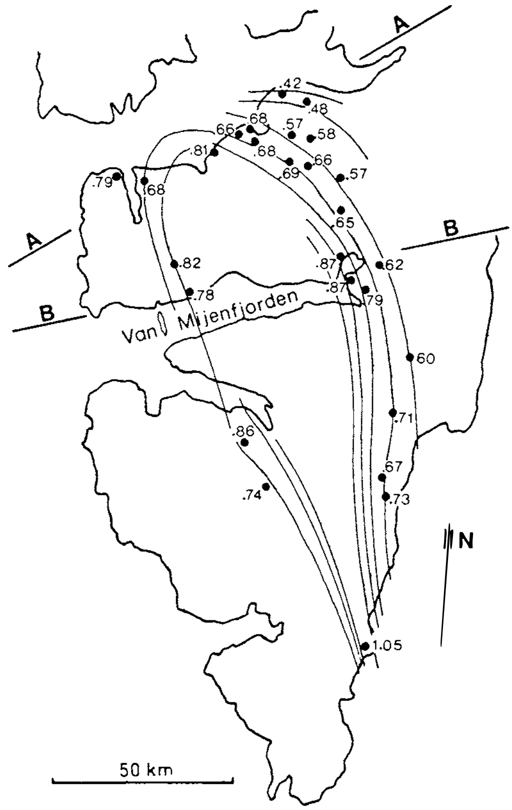


Fig. 6. *Isorank map of the coal-bearing part of Firkanten Formation. Isoranks are contoured at 0.1 R_0 intervals. The spot values indicate averages of all samples from any one locality. A-A and B-B indicate cross sections shown in Figure 9.*

The reflectance data are presented in Figure 6 in the form of an isoreflectance or isorank map of the coalbearing part of the Firkanten Formation, where isoranks are contoured at 0.1 Ro intervals. Data coverage is best north of Van Mijenfjorden, especially in the north-eastern area, and here the isoranks are considered quite reliable. In the southern parts of the map area, however, poorer data coverage provides weaker basis for interpolations.

The map exhibits three distinctive trends: (1) the isoranks mainly run parallel to the outline of the Tertiary deposits, (2) rank is higher in the central and southern parts of the depression than on its flanks, and (3) rank change is steep near the eastern margin of the existing deposits, which is well documented in the northeastern part of the map area (Fig. 9).

Our data show that the economically important coals of the Firkanten Formation are chiefly of 'high volatile bituminous' rank. Coals from Longyearbyen (Fig. 2, locality 16) are of 'high volatile bituminous B' rank (Ro = 0.7); coals from Grønfjorden (Fig. 2, locality 7) are also 'high volatile bituminous B' coals (Ro = 0.7); coals from Sveagruva (Fig. 2, locality 25) are somewhat higher, ('high volatile bituminous A' Ro = 0.9). The highest rank recorded in our study — as well as in that by Horn (1928) — is from Hegdehogfjellet (Fig. 2, locality 9), being in the higher range of 'high volatile bituminous A' interval (Ro = 1.1).

Geological implications of rank studies

Since temperature is the principal factor in coalification, the rank is a measure of depth of burial. A method of estimating total depth of burial from a vitrinite reflectance profile has been presented by Dow (1977). He showed, on theoretical grounds as well as by empirical tests, that a semi-logarithmic plot of vitrinite reflectance values versus depth in a continuously subsiding basin will assume a straight line, the «maturation gradient». A reflectance value of R_0 = 0.18—0.20 is considered to be the minimum reflectance close to the surface (within a few hundred metres). By projecting the straight line obtained from reflectance measurements to this «zero» value, an estimate may be obtained of the total depth of burial.

We have applied Dow's (1977) method to the profile from Nordenskiöldfjellet (Fig. 4) assuming a continuously subsiding basin. The reflectance values from that sequence are plotted on a logarithmic scale in Figure 7. The points show some scatter which we attribute to variability in sample quality. A straight line, or maturation gradient, has been drawn through the points, weighted towards the good quality samples. A projection of this line to the R_0 = 0.2 point gives a total burial for the base of the Tertiary of about 2700 metres. This means that approximately 1700 metres have been eroded.

Given a constant maturation gradient within a basin, sampling points with equal ranks have had approximately equal overburden. We may now combine the isorank map (Fig. 6) and the established maturation profile (Fig. 7) to construct an isopach map for total overburden above the base of the Spitsbergen Tertiary, assuming a constant maturation gradient. (The reflectance

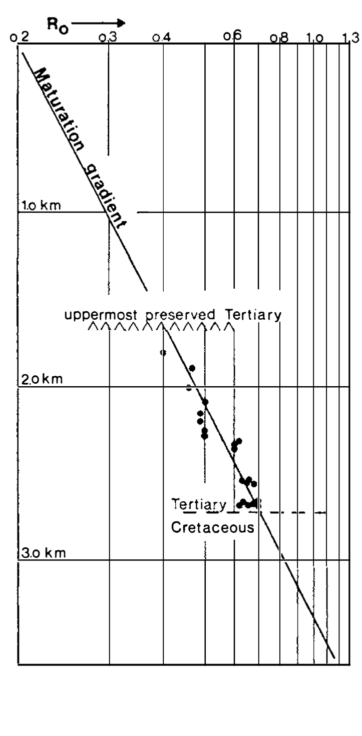


Fig. 7. *Maturation profile, Nordenskiöldfjellet. Same profile as Figure 4, but R_o values are plotted on a semilogarithmic scale against depth to establish the maturation gradient. Total depth of burial is obtained by extrapolating the gradient line to the R_o = 0.2.*

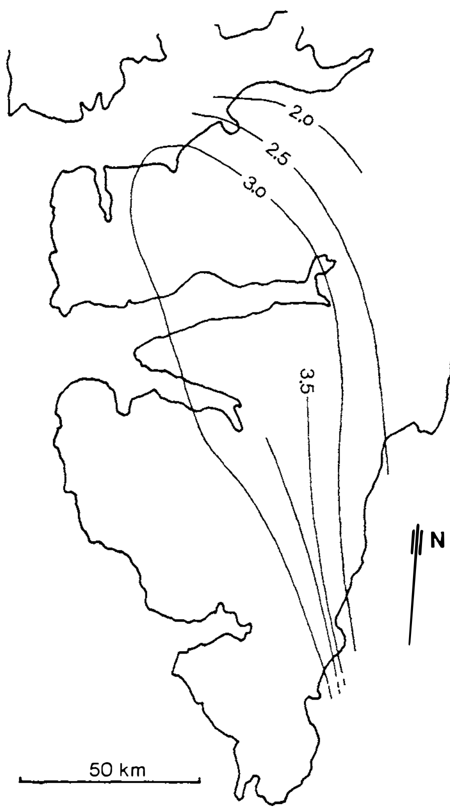


Fig. 8. *Isopach map of total depth of burial of the coal-bearing part of the Firkanten Formation, based on vitrinite reflectance data. Isopachs countoured at 0.5 kilometres.*

values from three coal samples from Festningen (Fig. 2, locality 5; R_0 = 0.79, Fig. 6) have been excluded from this discussion of total overburden in the main depression, because they come from the heavily tectonized fold belt west of the depression.)

The resulting isopach-map is contoured at 500 metres intervals (Fig. 8). The map indicates that greatest thickness of sediment was reached in the south central part of the depression. The rapid thinning towards the eastern margin is noteworthy and particularly well documented. Here the total thickness drops something in the range of 700—1000 metres within less than 15 kilometres in a northeastwards direction. An estimated overburden of 1500—2000 metres at the eastern margin suggests that the Tertiary deposits probably continued for considerable distance eastwards. Studies now in progress of the underlying Mesozoic sequence should throw some light on this question.

It is of interest to compare the total sediment thickness as estimated from rank with known thicknesses of existing Tertiary formations. Of these, only the three lowermost have sufficient extent to provide useful data. If the sediments were deposited in an undisturbed basin, actual thicknesses of stratigraphical units should be directly proportional to total depths of burial (as indicated by rank). However, for the three lowermost formations this is not

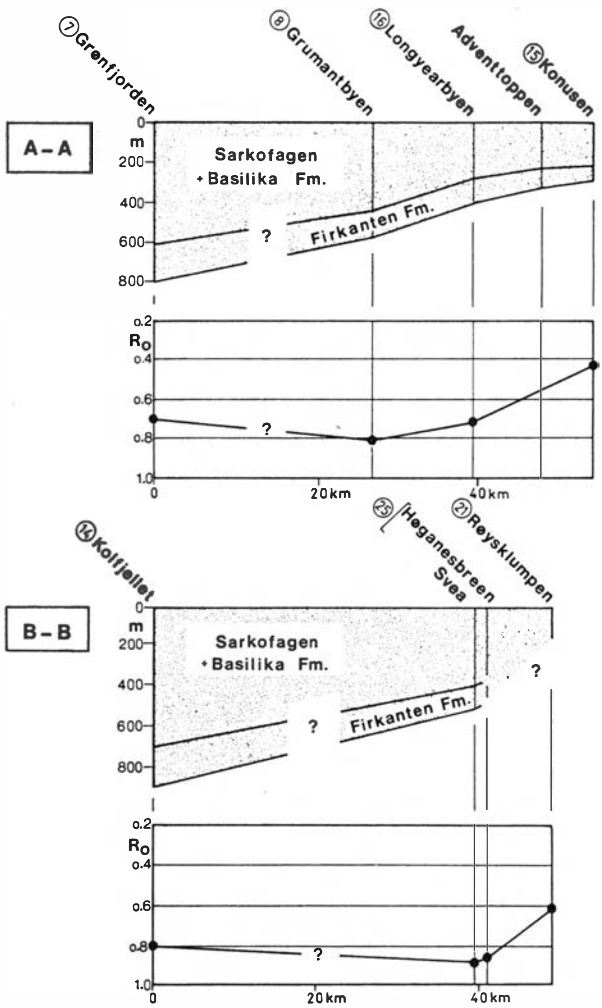


Fig. 9. *Cross sections comparing thicknesses of the three lowermost Tertiary formations and rank of the coal-bearing part of the Firkanten Formation. Locations of sections A-A and B-B are indicated in Figure 6. Thickness data from Vonderbank (1970) and Kellogg (1975).*

everywhere the case. This is demonstrated by east-west cross sections (Fig. 9) comparing measured thicknesses of the three lowermost formations to trends in total burial as indicated by rank.

At the eastern end, the sections show good correlation between thicknesses of the three formations and rank of the basal formation. In the central and western parts of the sections, however, rank is fairly constant or decreasing slightly westwards, while the actual thicknesses show an overall westward increase. This indicates that the subsidence pattern of the basin has changed at some point during its history: the area of greatest subsidence was lying outside the present depression to the west during deposition of the three lowermost formations, while at some later point it migrated eastwards towards the center of the present depression.

This change in the subsidence pattern was observed also by Kellogg (1975) who arrived at this conclusion from a regional study of the sediments. Kellogg concluded that the three lowermost formations were deposited in a large subsiding basin with greatest subsidence west of the existing depression during a pre-deformational phase, and that the area of greatest subsidence migrated eastwards, probably due to tectonic activity along the west coast of Spitsbergen associated with plate tectonic events in the Norwegian-Greenland Sea area. The deformation along western Spitsbergen was related by Lowell (1972) to a compressional strike-slip mechanism along the Spitsbergen Fracture Zone (cp. Fig 2).

Lowell (l. c.) also indicated that the deformation caused uplift which ended marine sedimentation in Spitsbergen (Battfjellet Fm.). Other observations indicate that this started even earlier. Steel (1977) concluded from sedimentological studies that the Battfjellet Formation is part of a large regressive sequence which can be traced far down into the Gilsonryggen Formation; probably down to near its base as indicated by recent kerogen studies (Manum & Throndsen, this vol.). Thus there are indications that the change in subsidence pattern of the basin had already started by the time of deposition of the lower part of the Gilsonryggen Formation. Since the base of Gilsonryggen Formation is now dated as late Paleocene (Manum & Throndsen unpubl.), there is circumstantial evidence that tectonic activity along the west coast of Spitsbergen started in the late Paleocene. The activity continued throughout the time of deposition of the existing Tertiary, since the Aspelintoppen Formation is also folded (Livšic 1974; Croxton & Pickton 1976).

The original basin was deformed during the Tertiary orogenic phase to produce the present synclinal shape. Deformation was greatest in the western and central parts of the basin, and consequently the change in accumulation pattern was greatest here. The effect of the orogeny is also observed further east as minor folds and faults, especially along the Billefjorden Fault Zone (Harland et al. 1974). The steep thickness gradient observed near the eastern margin of the depression is possibly related to differential subsidence along this fault zone.

The regional rank pattern of the coals of the Firkanten Formation is concluded to be related mainly to syn- and possibly post-orogenic changes in subsidence pattern of the Spitsbergen Tertiary basin.

Acknowledgements

This paper is based on a degree thesis in geology submitted to the University of Oslo by the junior author (T.T.).

We were able to benefit from the practical advice and shared experience of the following individuals upon visiting their laboratories: Dr. Neely Bostick, U.S. Geological Survey, Denver, Colorado; Dr. Enzo Lanzoni, AGIP, Milano, Italy; and Dr. Marlies Teichmüller, Landesamt für Bodenforschung, Krefeld, Germany. Their help was instrumental in establishing the technique of measuring vitrinite reflectance in our department.

To Mr. Harald Major of Norsk Polarinstitutt, Oslo, and Mr. Tor Bjærke, this department, we are thankful for fruitful discussions on problems related to Spitsbergen geology and coal rank studies. Mr. Major also provided many of the coal samples.

Samples have also been provided by Mr. Jenø Nagy, this department, Mr. Thore S. Winsnes, Norsk Polarinstitutt, and by Store Norske Spitsbergen Kulkompani A/S.

This study forms part of a palynological research project financed by The Norwegian Research Council for Science and Technology; assistance towards field work in Spitsbergen was also received from Norsk Polarinstitutt.

References

ATKINSON, D. J., 1963: Tertiary rocks of Spitsbergen. *Amer. Ass. Petr. Geol. Bull.* 59 (3): 465—485.

BOSTICK, N. H., 1971: Thermal alteration of clastic organic particles as an indicator of contact and burial metamorphism in sedimentary rocks. *Geosc. Man* III (1971): 83—92.

— 1973: Time as factor in thermal metamorphism of phytoclasts (coaly particles). — *Comptes Rendus. 7. Congr. Internat. Strat. Geol. Carbonifère, Krefeld* 2; 183—193.

— 1974: Phytoclasts as Indicators of Thermal Metamorphism, Franciscan Assemblage and Great Valley Sequence (Upper Mesozoic), California. *Geol. Soc. Amer. Spec. Paper* 153: 1—17.

CROXTON, C. A. and C. A. G. PICKTON, 1976: The Van Mijenfjorden Group (Tertiary) of South-West Nordenskiöld Land Spitsbergen. *Norsk Polarinstitutt Skrifter* Nr. 164: 29—46.

DOW, W. G., 1977: Kerogen studies and geological interpretations. — *J. Geochem. Explor.* 7 (1977): 79—99.

GUTJAHR, C. C. M., 1966: Carbonization measurements of pollen grains and spores and their application. — *Leidse Geol. Meded.* 38: 1—30.

HARLAND, W. B., J. L. CUTBILL, P. F. FRIEND, D. J. GOBBETT, D. W. HOLLIDAY, P. I. MATON, J. R. PARKER and R. H. WALLIS, 1974: The Billefjorden Fault Zone, Spitsbergen. *Norsk Polarinstitutt Skrifter* Nr. 161. 72 pp.

HARLAND, W. B., C. A. G. PICKTON, and N. J. R. WRIGHT, 1976: Some coalbearing strata in Svalbard. *Norsk Polarinstitutt Skrifter* Nr. 164: 7—28.

HORN, G. 1928: Beiträge zur Kenntnis der Kohle von Svalbard (Spitzbergen und der Båreninsel). *Skr. om Svalbard og Ishavet* Nr. 17. 60 pp.

KELLOGG, H. E., 1975: Tertiary Stratigraphy and Tectonism in Svalbard and Continental Drift. *Amer. Ass. Petr. Geol. Bull.* 59 (3): 465—485.

KÖTTER, K., 1960: Die mikroskopische Reflexionmessung mit dem Photomultiplier und ihre Anwendung auf die Kohlenuntersuchung. *Brennst.-Chem.* 41: 263—272.

LIVŠIC, J. J., 1965: Palaeogene deposits of Nordenskiöld Land (Vestspitsbergen) (in Russian). In Sokolov, V. N., (ed.): *Mat.-ly po geologii Spičbergena. Nauk.-issl. Int. Geol. Arktiki:* 185—208

— 1974: Palaeogene deposits and the platform structure of Svalbard. *Norsk Polarinstitutt Skrifter* Nr. 159. 51 pp.

LOWELL, J. D., 1972: Spitsbergen Tertiary orogenic belt and the Spitsbergen Fracture Zone. — *Geol. Soc. Amer. Bull.* 83: 3091—3102.

McCARTNEY, J. T. and S. ERGUN, 1958: Optical Properties of Graphite and coal. *Fuel* 37: 272—282.

— 1967: Optical Properties of Coals and Graphite. *Bur. Mines Bull.* 641: 1—47.

McIVER, R. D., 1967: Composition of kerogen — clue to its role in the origin of petroleum. *7. World Petroleum Congr. Mexico 1967* 2: 25—36.

MAJOR, H. and NAGY, J., 1972: Geology of the Adventdalen map area. *Norsk Polarinstitutt Skrifter* Nr. 138: 58 pp.

MURCHISON, D. G., 1964: Reflectance Techniques in Coal Petrology and their Possible Application in Ore Mineralogy. *Bull. Inst. Min. & Met.* 689: 479—502.

RAVN, J. P. J., 1922: On the Mollusca of the Tertiary of Spitsbergen, collected by Norwegian and Swedish Expeditions. *Result. Norsk. Spitsb. Eksped.* Nr. 2. 28 pp.

STAPLIN, F. L., 1969: Sedimentary organic matter, organic metamorphism, and oil and gas occurence. *Bull. Can. Petr. Geol.* 17 (1): 47—66.

STEEL, R. J., 1977: Observations on some Cretaceous and Tertiary sandstone bodies in Nordenskiöld Land, Svalbard. *Norsk Polarinstitutt Årbok* 1976: 43—67.

TALWANI, M. and O. ELDHOLM, 1977: Evolution of the Norwegian-Greenland Sea. *Geol. Soc. Amer. Bull.* 88: 969—999.

TEICHMÜLLER, M. and R. TEICHMÜLLER, 1975: The geological basis of coal formation. In: Stach, E. et al. (eds.): *Stach's Textbook of Coal Petrology:* 5—53. Gebrüder Borntraeger, Berlin, Stuttgart, 1975.

VONDERBANK, K., 1970: Geologie und Fauna der Tertiären Ablagerungen Zentral-Spitsbergens. *Norsk Polarinstitutt Skrifter.* Nr. 153: 155 pp.

VRIES, H. A. W. De and C. BOKHOVEN, 1968: Reflectance measurements on coal. *Geologie en Mijnbouw.* 47 (6): 423—434.

Appendices

Appendix I

Vitrinite reflectance data listed by formations and localities

Formation and locality (nos. refer to Fig. 2)	Sample no	Stratigraphic position	Lithology	Mean vitrinite reflectance (in oil) ± standard deviation	Number of readings
Firkanten Formation (coal-bearing part)					
(1) Basilika	2668		coal	0.89 ± 0.04	50
	2669		coal	0.83 ± 0.03	50
(2) Bassen	2682		coal	0.57 ± 0.02	50
	2683		coal	0.57 ± 0.03	50
(3) Bjørndalen	2821	Askeladden seam	coal	0.65 ± 0.05	50
	2822		shale	0.61 ± 0.04	9
	2823	Longyear seam	coal	0.67 ± 0.06	50
	2824	Longyear seam	coal	0.62 ± 0.08	100
	2825	Longyear seam	coal	0.70 ± 0.08	100
	2826	Svea seam	coal	0.70 ± 0.08	100
(4) Bolterdalen	2811	Longyear seam	coal	0.68 ± 0.04	50
	2820	Longyear seam	coal	0.69 ± 0.07	100
(5) Festningen	2702		coal	0.79 ± 0.04	50
	2703		coal	0.81 ± 0.05	50
	2704		coal	0.76 ± 0.03	50

Formation and locality (nos. refer to Fig. 2)	Sample no	Stratigraphic position	Lithology	Mean vitrinite reflectance (in oil) ± standard deviation	Number of readings
Firkanten Formation (cont.)					
(6) Foxdalen	2660		coal	0.66 ± 0.03	50
(7) Grønfjorden	2666		coal	0.67 ± 0.03	50
	2667		coal	0.69 ± 0.06	46
(8) Grumantbyen	2673		coal	0.81 ± 0.04	50
(9) Hedgehogfjellet	2804		coal	1.05 ± 0.10	100
(10) Helvetiafjellet	2676		coal	0.62 ± 0.04	50
	2677		coal	0.53 ± 0.04	50
(11) Hotellneset	2815	Svea seam	coal	0.70 ± 0.06	50
	2816	Todal seam	coal	0.66 ± 0.04	50
	2817	Longyear seam	coal	0.67 ± 0.04	50
(12) Jemelianovbreen	2670		coal	0.71 ± 0.03	50
	2671		coal	0.62 ± 0.04	50
(13) Knorringfjellet	2813		coal	0.48 ± 0.06	100
(14) Kolfjellet	2805		coal	0.76 ± 0.05	50
	2808		coal	0.86 ± 0.03	50
	2809		coal	0.72 ± 0.06	50
(15) Konusen	2812		coal	0.42 ± 0.06	100
	2847		coal	0.41 ± 0.04	50
(16) Longyearbyen	2649		coal	0.71 ± 0.04	50
	2650		coal	0.71 ± 0.04	50
	2651		coal	0.67 ± 0.03	50
	2652		coal	0.71 ± 0.03	50
	2653		coal	0.66 ± 0.04	50
	2654		coal	0.67 ± 0.03	50
	2655		coal	0.68 ± 0.04	50
	2814	Longyear seam	coal	0.68 ± 0.06	100
(17) Lunckefjellet	2681		coal	0.68 ± 0.04	50
	2685		coal	0.61 ± 0.03	50
(18) Møysalen	2661		coal	0.60 ± 0.03	50
	2662		coal	0.54 ± 0.04	50
(20) NE Paulabreen	2806		coal	0.60 ± 0.02	50
(21) Røysklumpen	2678		coal	0.61 ± 0.03	50
	2679		coal	0.62 ± 0.03	50
(22) Schønrockfjellet	2803		coal	0.73 ± 0.05	50
(23) Snøvolla	2664		coal	0.87 ± 0,03	50
(24) Strongbreen	2807		coal	0.71 ± 0.04	50
(25) Svea					
Høganesbreen	2657		coal	0.83 ± 0.04	50
Svea, Østgruva	2818		coal	0.91 ± 0.08	100
Ortbreen	2827		coal	0.87 ± 0.06	50
Ortbreen	2828		coal	0.85 ± 0.05	50
(26) Valy Hetmansky fjella	2800		coal	0.75 ± 0.04	50
	2801		coal	0.67 ± 0.03	50
	2802		coal	0.78 ± 0.04	50
(27) Vallåkerbreen	2674		coal	0.79 ± 0.03	50
(28) Ørjankampen	2810		coal	0.82 ± 0.03	50

Formation and locality (nos. refer to Fig. 2)	Sample no	Stratigraphic position	Lithology	Mean vitrinite reflectance (in oil) ± standard deviation	Number of readings
Basilika Formation					
(5) Bjørndalen	2831	8 m above base	shale	0.68 ± 0.08	41
	2832	3 m above base	shale	0.65 ± 0.04	39
(16) Longyearbyen	2829	10 m above base	shale	0.66 ± 0.04	32
	2830	40 m above base	shale	0.64 ± 0.07	16
Sarkofagen Formation					
(19) Nordenskiøldfjellet	2833	18 m below top	shale	0.60 ± 0.09	54
	2842	1 m below top	shale	0.61 ± 0.06	32
	2843	20 m below top	shale	0.60 ± 0.06	17
Gilsonryggen Formation					
(19) Nordenskiøldfjellet	2834	21 m above base	shale	0.50 ± 0.05	32
	2835	4 m above base	shale	0.50 ± 0.05	36
	2836	87 m above base	shale	0.48 ± 0.08	32
	2837	160 m above base	shale	0.48 ± 0.07	15
Battfjellet Formation					
(19) Nordenskiøldfjellet	2838	38 m above base	shale	0.50 ± 0.07	110
Aspelintoppen Formation					
(19) Nordenskiøldfjellet	2839	180 m above base	coal	0.40 ± 0.04	100
	2840	121 m above base	coal	0.47 ± 0.04	100
	2841	1 m above base	shale	0.46 ± 0.04	100

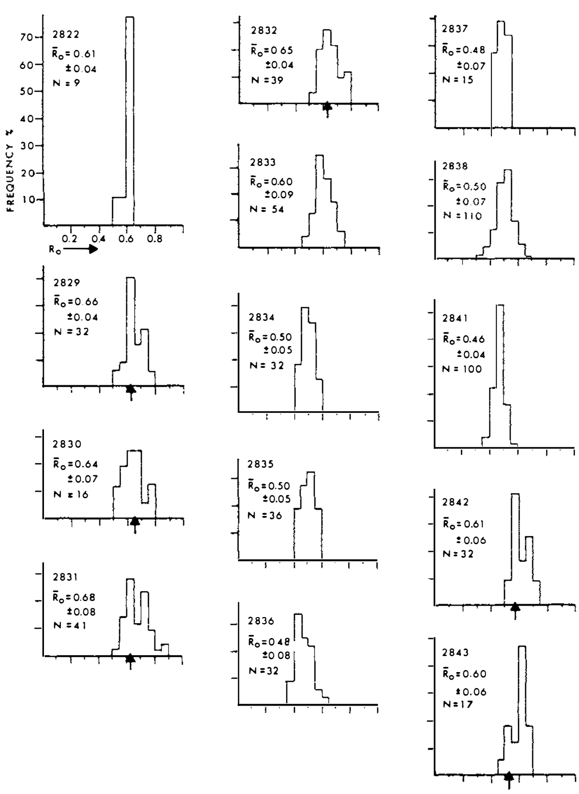


Fig. 1, Appendix I.
Vitrinite reflectance histograms for all the clastic samples included in the list above. Sample numbers refer to the numbers in the list. For further explanations, compare Fig. 5.

Appendix II

Preparation methods, measurement equipment and procedures

Preparation methods

Normal palynological preparation techniques are used to obtain phytoclasts from sediments. Crushed samples are dissolved in hydrofluoric acid after any carbonates have been removed with hydrochloric acid and washing. Any remaining minerals are subsequently removed by heavy liquid separation ($ZnBr_2$, density 2.0) after a brief liquid sonification. Samples for reflectance measurements are never heated during processing, nor are oxidizing agents applied. Coal samples are not subjected to chemical treatment before embedding in resin and polishing. Coal samples and dried phytoclast residues are embedded in a cold setting epoxy resin to make briquettes, which are subsequently ground flat and polished according to the following scheme:

Grinding:
(1) Carborundum paper, with water
(2) Silicon carbide powder no 800 on a steel plate, with water.

Polishing:
The samples are polished for two minutes in each of the following steps. Subsequent to each step the samples are rinsed with alcohol.
(1) 8 μm diamond paste on STRUERS DP cloth DUR, with alcohol
(2) 1 μm diamond paste on STRUERS DP cloth MOL, with alcohol
(3) 0.25 μm diamond paste on STRUERS DP cloth NAP, with alcohol
(4) MgO on STRUERS DP cloth NAP, with water

Reflectance measurements

Major problems in reflectance measurements on phytoclasts are the identification of vitrinitic particles and selection of the particles to be measured. This problem has been discussed thoroughly by Bostick (1971) and will therefore not be considered here.

Equipment used in this study is a Carl Zeiss Standard Universal microscope with incident illumination from a stabilzed light source. Viewing and measurements are made through a ZEISS Epi 40.0/0.85 Pol oil objective, using an immersion oil with refractive index $n = 1.518$. Illumination is through a green filter with peak transmission at 546 nm, the field illuminated is about 5 μm in diameter, and the ZEISS microscope photometer senses a field about 3 μm in diameter. The photometer scale is calibrated against glass standards of known reflectance as shown in the table below. For photometer calibration, the standard with reflectance closest to the samples to be measured is selected.

Refractive indexes and reflectance percentages in oil (n = 1.518) of the three glass standards by Bausch & Lomb used in this study

Refractive index (n)	Reflectance in oil (R_0)
1.69446	0.302
1.75721	0.533
1.85643	1.006

Readings are made with the polarizer set at 45°. For each individual reading, the microscope stage is rotated 360° in order to locate the position of maximum reflectance, which is then measured. This is standard procedure in coal petrology and we have applied it also for clastic vitrinite. However, the far less time consuming method of random reflectance measurements, using a stationary stage, has now become standard in phytoclast studies. The latter method would not have produced significantly different results on our material, since vitrinite anisotropy remains insignificant in the reflectance range below $R_0 = 1.4$ (de Vries & Bokhoven 1968) and all our measurements are well below this value (highest $R_0 = 1.1$).

The number of readings on one sample is 50 to 100 for coal, while for phytoclasts as many particles as possible are measured, usually between 25 and 50. Readings are grouped at intervals of 0.05 R_0 and frequencies for each group are presented in a histogram. Arithmetic mean and standard deviation are calculated from the measured values.

Dispersed organic matter (kerogen) in the Spitsbergen Tertiary

By SVEIN B. MANUM[1] and TORBJØRN THRONDSEN[1]

Abstract

Dispersed solid organic matter (kerogen) from a sequence of Tertiary sediments in Spitsbergen has been studied semi-quantitatively in palynological preparations. Four morphological categories of kerogen are recognized and their relative frequencies compared with depositional environments. Opaque wood tissue particles (melanogen) show no correlation with depositional environments. Translucent wood tissue particles (hylogen) and identifiable plant remains of non-wood origins (phyrogen) are richly represented in non-marine and marginal marine deposits, the latter type usually being the more common, particularly in marginal marine environments. Fine structureless organic detritus (amorphogen) consistently dominates in distal marine environments, while in more near-shore environments its representation is highly variable.

Introduction

In most sedimentary rocks solid organic matter is present in small amounts, usually with less than 0.5 weight percent. Part of this matter is made up of identifiable microfossils — palynomorphs — which have for a long time received the attention of palynologists. The rest — the palynodebris — is usually ignored by the palynologists, who attempt to remove as much of it as possible in order to concentrate usable fossils and to facilitate microscopic examination. Part of the palynodebris is recognizable as fragments of distinct plant structures, but mostly it is too fragmented or degraded for definite identification. A meaningful classification for the entire range of palynodebris has been slow to emerge, and until recently there has been only slight advance in the study of these clastic particles. In the last few years, however, more attention has been paid to dispersed organic matter since it has been realised that it generates hydrocarbons under favourable maturation conditions in the sediments.

[1] Institutt for geologi, Universitetet i Oslo, P.O.Box 1047, Blindern, Oslo 3, Norway.

'Kerogen' is the term now most widely used for the total range of dispersed organic matter in sedimentary rocks. Originally defined as the solid organic matter which upon destructive distillation yields oil (Crum-Brown 1912), the term has since been extended to include all the insoluble organic matter which may be extracted from clastic sediments using hydrochloric and hydrofluoric acids to dissolve the mineral components (Burgess 1974). Bostick (1971) proposed the term 'phytoclasts' for the same material, which refers to the fact that the clastic organic matter is predominantly of vegetable origin.

Morphological and chemical analogous to kerogen particles are found in coal, and it has been established that dispersed organic matter in sediments is subject to chemical and physical alteration under influence of heat and pressure in much the same way as is the organic matter in coal (Bostick and Foster 1975). This recognition has led to the use of such alterations as a measure of the degree of thermal influence in sediments. Thus, in a previous study we have applied the vitrinite reflectance method to vitrinitic kerogen particles in the Spitsbergen Tertiary in order to study the geothermal history of the basin (Manum and Throndsen this vol. p. 159).

In this study we present semi-quantitative data on the variation in kerogen composition through the Tertiary sequence in Spitsbergen, and we compare the kerogen variation with depositional environments as interpreted from other sources. The very few kerogen studies of this kind that have as yet been published indicate the usefulness of kerogen composition analysis in environmental interpretations (Manum 1976; Bujak et al. 1977). Our study does not, however, aim at a comprehensive interpretation of sedimentary environments in the Spitsbergen Tertiary. It covers only a representative section through the sequence with the object of demonstrating the potential of the method.

This paper is based on results presented in a thesis in geology submitted to the University of Oslo by the junior author (T.T.).

Classification and quantitative analysis of kerogen

The following considerations refer to kerogen as observed by transmitted light in palynological preparations.

Classification

A large proportion of the kerogen, particularly in near-shore and nonmarine sediments clearly represents the decay resistant residues of fragmented land plant litter and other humified plant remains which have entered into the sedimentary cycle. Inferring from general knowledge about plant litter decomposition (Dickinson and Pugh 1974) it is concluded that fragmentation and biodegradation are essentially caused by a great variety of organisms in several cycles; arthropods, annelids, fungi and bacteria being particularly active. Much of the debris, however, is too finely fragmented to be identifiable; its origins in near-shore and non-marine sediments are considered predominantly to be diverse resistant land plant materials. In fine-grained offshore sediments, however, where fine organic particles or fluffy organic masses with no recognizable morphological structures dominate the kerogen assemblages, algae appear to be the main source of kerogen (Combaz 1974; Dow 1977). The degree of fragmentation is obviously desicive for the level of morphological identification to which the organic particles may be taken, and it also affects the distribution of the particles in sediments.

Another factor significantly affecting appearance and hence classification of kerogen particles is the diagenetic degradation in the sediments. The better the preservation, the higher will be the number of classes that may potentially be recognized. However, a classification should not be more detailed than to allow meaningful comparison between kerogen of different degrees of diagenetic degradation. Thermal influence also alters the characteristics of kerogen, particularly if alteration has been strong (i.e. to that of the upper ranges of bituminous coal rank).

Four major classes of kerogen particles are usually distinguished. However, terminology and the criteria used to define them may differ (Staplin 1969; Burgess 1974; Combaz 1975; Bujak et al. 1977). For our material, which is rather highly diagenetically degraded, the classification of Bujak et al. (1977) has proved quite satisfactory and it has in our opinion the additional advantage that the terminology avoids plant morphological connotations.

Below is a short description of the four kerogen classes, amorphogen, phyrogen, hylogen and melanogen, used in this study, slightly modified after Bujak et al. (1977).

Amorphogen. Morphologically structureless organic detritus which is finely disseminated or may cohere to varying degrees into fluffy masses.

Phyrogen. Translucent particles that can be recognized as being derived from plants, wood tissue excluded. Includes plant cuticles and palynomorphs. Even fragments which are broken up, perforated or corroded beyond definite identification to specific plant parts are included.

Hylogen. Translucent plant material of woody origin. Particles with a red-orange colour at the edges or other thin areas only are also regarded as translucent.

Melanogen. Completely opaque organic particles, edges included. Particles are commonly angular, fissured, and sometimes with cellular structures.

Quantitative analysis

The relative amounts of the four classes of kerogen are estimated according to an arbitrary frequency scale: Dominant: more than 50%; abundant: between 20 and 50%; moderately frequent: between 5 and 20%; rare: less than 5%. Ordinary strew mounts and 40x objective are used in the analysis.

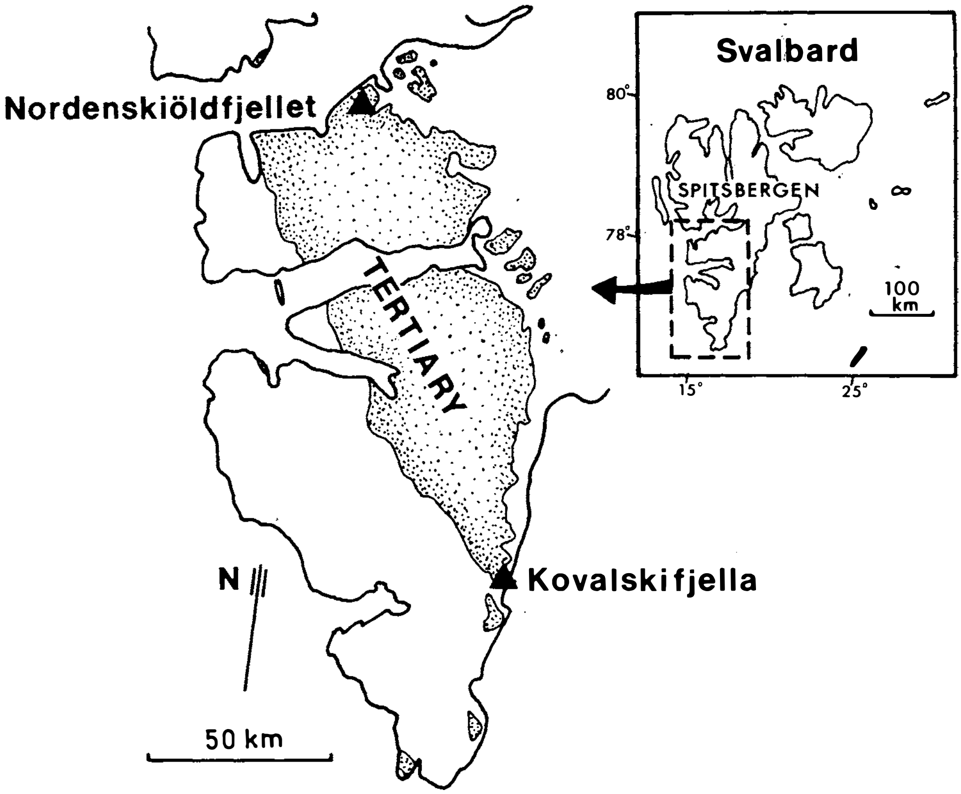


Fig. 1. *Map of southern Spitsbergen showing sample localities and areas of Tertiary deposits.*

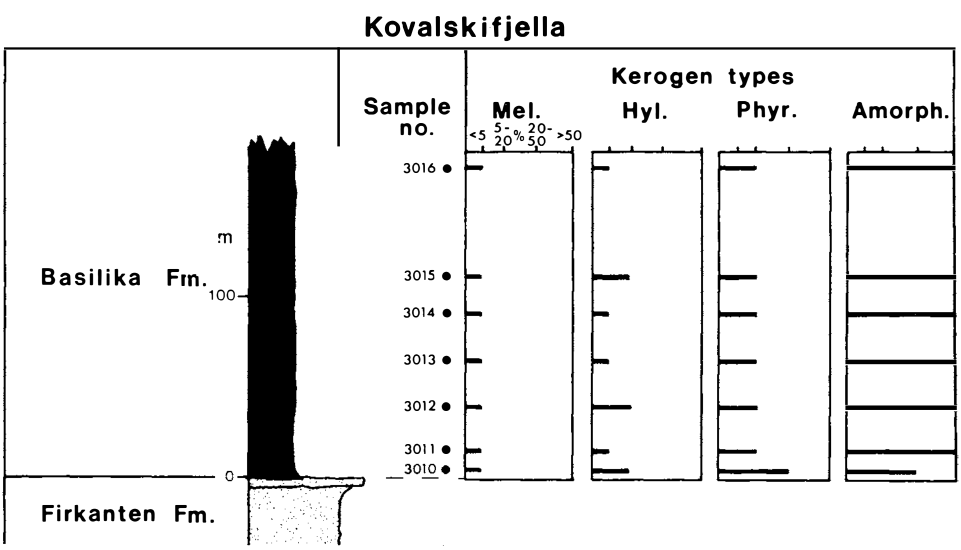


Fig. 2. *Profile showing kerogen composition in the Basilika Formation at Kovalskifjella.*

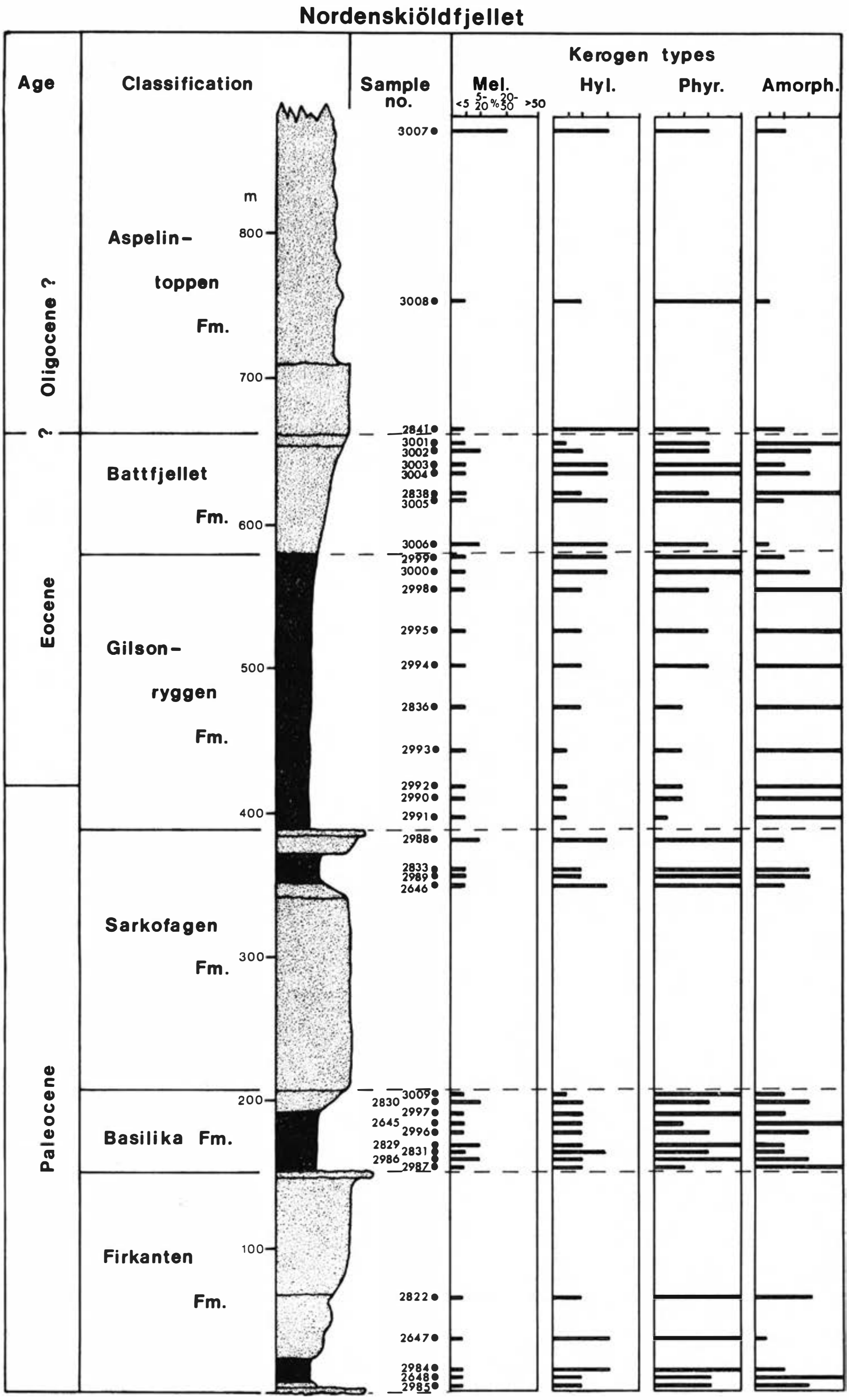


Fig. 3. *Profile showing kerogen composition through the Tertiary sequence at Nordenskiöldfjellet.*

Material. Processing method

Altogether 45 samples from a complete section through the Tertiary sequence at Nordenskiöldfjellet and a part of the section at Kovalskifjella have been analysed (compare map, Fig. 1). Sample positions in the sequences are shown in figures 2 and 3. Formations composed of shales and siltstones have been sampled at fairly close and regular vertical intervals in order to study the variation in kerogen composition through an apparently monotonous sequence. Formations dominated by sandstones, however, have been sampled from siltstone and shale bands in order to study the kerogen assemblages in fine-grained marginal marine and non-marine sediments. Sandstones are omitted because of their extremely low kerogen contents.

Sample processing was the same as for ordinary palynological preparations, using hydrochloric and hydrofluoric acids to extract the organic residues from the rock samples. However, the usual steps to remove the finer fractions of organic detritus were omitted, as were oxidation and heating.

Geology

In the central Spitsbergen depression more than 2300 metres of Tertiary sediments are preserved. They have been studies more comprehensively in recent years by Vonderbank (1970), Livsic (1974), and Kellogg (1975) (compare also Manum and Throndsen this vol. p. 159).

The depositional environment has been interpreted as alternating nonmarine and marine, with coals occurring at the base and top of the sequence. Six lithological units have been recognized since the work of Nathorst (1910); they have subsequently been renamed and ranked as formations. Lithostratigraphical terminology used in this paper follows Major and Nagy (1972). The age of the sequence is generally held to be Paleocene at the base, but opinions vary from Eocene to Oligocene for the top. A recent palynological study indicates uppermost Paleocene for the middle part (base of Gilsonryggen Fm., Manum and Throndsen, unpublished).

The Tertiary formations and their kerogen composition

As is seen from Figs. 2 and 3, sampling density varies through the sequences. Only apparently monotonous fine-grained sequences have been sampled continously i.e. the Basilika and Gilsonryggen Formations. The remaining formations, composed mainly of sandstones were sampled only from their finer grained lithologies.

The coal-bearing part of the Firkanten Formation is composed of shales, siltstones, sandstones and coals deposited in shallow marine, littoral and paludal environments (Kellogg 1975). In these environments phyrogen is generally the dominant kerogen type, and hylogen and amorphogen are also well represented, however, the latter is more variable. Melanogen is rare.

The Basilika Formation consists mainly of shales and siltstones with a few beds of sandstones. The unit shows stratigraphical thinning and facies change in a north-eastward direction (Kellogg 1975). At Nordenskiöldfjellet, the lithology indicates marginal marine deposition, while at Kovalskifjella the depositional environment is considered to be more offshore. This difference in depositional environments between the two localities is clearly reflected in the kerogen composition. At Nordenskiöldfjellet phyrogen and amorphogen are the dominating types with mutual variation. Hylogen is moderately frequent and melanogen is in general rare. At Kovalskifjella, however, amorphogen dominates, while phyrogen is only moderately frequent, and hylogen and melanogen are rare.

The upper, silt-bearing part of the Sarkofagen Formation is composed mainly of alternating sandstones and siltstones deposited in shallow marine and deltaic environments (Dalland 1977). The kerogen is here dominated by phyrogen. Amorphogen and hylogen are moderately frequent to abundant. Melanogen is rare.

The Gilsonryggen, Battfjellet and Aspelintoppen Formations are closely related. They comprise a regressive sequence grading from offshore facies in the Gilsonryggen Formation through marginal marine conditions in the Battfjellet Formation to non-marine in the Aspelintoppen Formation (Steel 1977).

In the upper half of the Gilsonryggen Formation a gradual increase in very fine-grained sandstones indicates an approaching shore-line (Steel 1977). The kerogen assemblages also reflect this trend, and it can be traced down to near the base of the formation. Amorphogen is dominant through most of the sequence, except near the top where it decreases significantly. Phyrogen and hylogen increase gradually from rare close to the base to abundant and dominant at the top of the formation. Melanogen is rare throughout.

The Battfjellet Formation was deposited in marginal marine environments (Kellogg 1975, Steel 1977). Kerogen assemblages in the shales and siltstones of this formation show great variation. In general phyrogen is the most common type, amorphogen is also common but variable. Hylogen is moderately frequent to abundant, and melanogen is rare. This is a kerogen composition closely similar to that of the Basilika Formation at this locality.

The depositional environment of the Aspelintoppen Formation was non-marine with fluvial, lacustrine, paludal and aeolian deposition (Major and Nagy 1972; Kellogg 1975). Only three horizons were examined for kerogen. Amorphogen is only rare to moderately frequent. Phyrogen and hylogen are the more common types, and melanogen is rare except for one sample, where it is abundant.

Conclusion

Melanogen is poorly represented in all the examined samples. It appears to be somewhat more common in marginal marine than in offshore sediments, but its variation with depositional environments is not consistent. Hylogen shows a better correlation with depositional environments than melanogen. Hylogen is best represented in non-marine deposits, and is also well represented in marginal marine deposits. Phyrogen shows a similar relationship to depositional environments as hylogen, but with higher ratios; thus phyrogen is usually the dominant type in marginal marine deposits. Amorphogen generally occurs with inverse ratio to hylogen and phyrogen. Amorphogen ratios are consistently high in offshore sediments, while in marginal marine deposits the ratios vary greatly.

Kerogen assemblages consistently dominated by amorphogen with traces only of the other types are indicative of offshore deposition. When the depositional environment becomes progressively more near-shore, both phyrogen and hylogen gradually become more abundant, and in marginal marine environments both phyrogen and hylogen are richly represented usually with phyrogen as the dominant type, and amorphogen amounts variable. In non-marine sediments, both phyrogen and hylogen occur with high ratios with amorphogen only poorly represented.

Acknowledgements

This study forms part of a palynological research project financed by The Norwegian Council for Science and Technology; assistance towards field work in Spitsbergen was also received from Norsk Polarinstitutt.

Thanks are due to Mr. Alv Orheim, Store Norske Spitsbergen Kulkompani A/S and Mr. Jenø Nagy, this department for providing us with some of the samples used in this study.

References

BOSTICK, N. H., 1971: Thermal alteration of clastic organic particles as an indicator of contact and burial metamorphism in sedimentary rocks. *Geosc. and Man* III (1971): 83—92.

BOSTICK, N. H. and J. N. FOSTER, 1975: Comparison of vitrinite reflectance in coal seams and in kerogen of sandstones, shales and limestones in the same part of a sedimentary section. — In Alpern, B., (Ed.): *Pétrographie de la matière organique des sédimentes, relations avec la paléotémperature et le potentiel pétrolier:* 13—26. Centre National de la Recherche Scientifique, Paris 1975.

BUJAK, J. P., M. S. BARSS and G. L. WILLIAMS, 1977: Offshore East Canada's organic type and color and hydrocarbon potential. *Oil and Gas Journ.* April 4. (1977): 198—202; April 11. (1977): 96—100.

BURGESS, J. D., 1974: Microscopic examination of kerogen (dispersed organic matter) in petroleum exploration. *Geol. Soc. Amer. Spec. Paper* 153: 19—30.

COMBAZ, A., 1974: La matière algaire et l'origine du pétrole. *Advances in Organic Geochemistry 1973*: 423—438, Editions Technip, Paris 1974.

— 1975: Essai de classification des roches carbonées et des constituants organique des roches sédimentaires. In Alpern, B., (ed.): *Pétrographie de la matière organique des sédimentes, relations avec la paléotémperature et potentiel pétrolier:* 93—101. Centre National de la Recherche Scientifique, Paris 1975.

CRUM-BROWN, A., 1912: Oil shales of the Lothians. *Geol. Surv. Great Britain, Man.* 143.

DALLAND, A., 1977: Erratic clasts in the lower Tertiary deposits of Svalbard — evidence of transport by winter ice. *Norsk Polarinstitutt Årbok* 1976: 151—165.

DICKINSON, C. H. and G. J. F. PUGH, 1974: *Biology of plant litter decomposition.* — Vol. 1. 146 pp. Academic Press, London 1974.

DOW, W. G., 1977: Kerogen studies and geological interpretations. *J. Geochem. Explor.* 7 (1977): 79—99.

KELLOGG, H. E., 1975: Tertiary stratigraphy and tectonism in Svalbard and continental drift. *Amer. Ass. Petr. Geol. Bull.* 59 (3): 465—485.

LIVSIC, J. J., 1974: Palaeogene deposits and the platform structure of Svalbard. *Norsk Polarinstitutt Skrifter* Nr. 159. 51 pp.

MAJOR, H., and J. NAGY, 1972: Geology of the Adventdalen map area. *Norsk Polarinstitutt Skrifter* Nr. 138: 58 pp.

MANUM, S. B., 1976: Dinocysts in Tertiary Norwegian-Greenland Sea sediments (Deep Sea Drilling Project Leg 38), with observations on palynomorphs and palynodebris in relation to environment. In Talwani, M., Udintsev, G., et al.: *Initial Reports of the Deep Sea Drilling Project.* Vol. 38: 897—919.

MANUM, S. B., and T. THRONDSEN, 1978: Rank of coal and dispersed organic matter and its geological bearing in the Spitsbergen Tertiary. *Norsk Polarinstitutt Årbok* 1977: 159—177 (this volume).

NATHORST, A. G., 1910: Beiträge zur Geologie der Bären-Insel, Spitzbergens und des König-Karl-Landes. *Geol. Inst. Univ. Uppsala, Bull.* 10: 261—416.

STAPLIN, F. L., 1969: Sedimentary organic matter, organic metamorphism, and oil and gas occurrence. *Bull. Can. Petr. Geol.* 17 (1): 47—66.

STEEL, R. J., 1977: Observatons on some Cretaceous and Tertiary sandstone bodies in Nordenskiöld Land, Svalbard. *Norsk Polarinstitutt Årbok* 1976: 151—165.

VONDERBANK, K., 1970: Geologie und Fauna der tertiären Ablagerungen Zentral-Spitsbergens. *Norsk Polarinstitutt Skrifter.* Nr. 153. 155 pp.

A diapir structure in Bjørnøyrenna

By YNGVE KRISTOFFERSEN and ANDERS ELVERHØI

Abstract

A shallow seismic reflection survey and geological sampling of a bathymetric high (excess elevation 70 m) in Bjørnøyrenna show this feature to be associated with an anticlinal structure and high velocity (5.5 km/s) Permo-Carboniferous rocks outcropping on the sea floor.

Introduction

Bjørnøyrenna is an east-west trending trough with gentle bathymetric gradients and water depths of 400—500 metres in the central part (Fig. 1).

Geological sampling (Emelyanov et al. 1971) and seismic refraction measurements indicate that the trough is floored by unconsolidated sediments of thickness 100 metres or more (Sundvor 1974; Renard and Malod 1974; Eldholm and Talwani 1977; Hinz and Schlüter 1978). A localized bathymetric high in the central part of Bjørnøyrenna associated with deformed consolidated sediments was noted by Sundvor (1974) and later multi-channel seismic surveys by the Norwegian Petroleum Directorate have linked this bathymetric feature with diapirism at depth (Rønnevik and Myhre 1978). In this paper results of a shallow seismic survey of the bathymetric high are presented and the stratigraphy of the outcropping rocks is discussed.

Data

A shallow seismic reflection (1 kJ sparker) and magnetometer survey was carried out in Bjørnøyrenna in the western Barents Sea by Norsk Polarinstitutt in 1977 under the Barents Sea Project (Fig. 1). Navigation was by Decca main chain-Finnmark. Relatively large errors in positioning may arise as the different lane patterns, generally running in a north-south direction, cross at

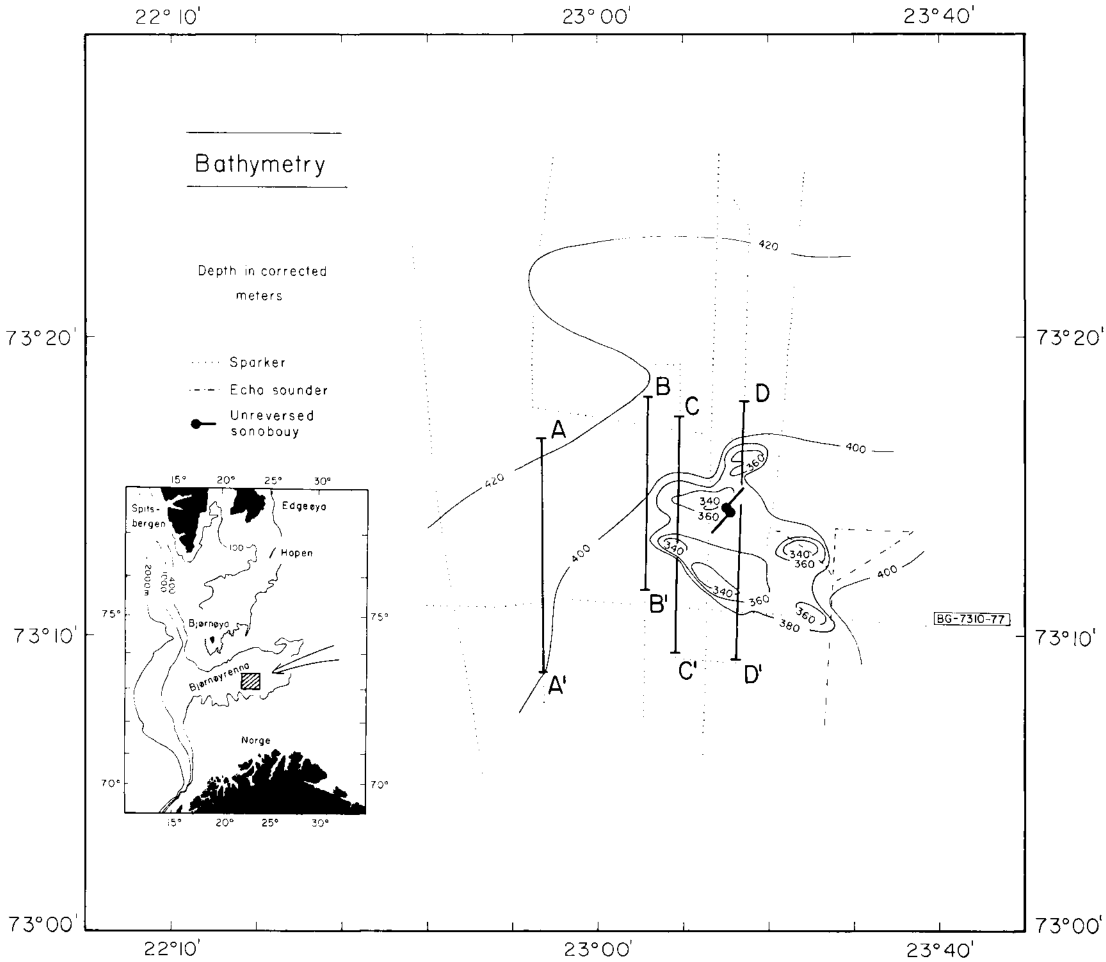


Fig. 1. *Bathymetry and profile locations. Shallow seismic reflection (Sparker) records along line BG-7310-77 were kindly provided by the Norwegian Petroleum Directorate. To obtain consistency in bathymetry and thickness of Quaternary sediments with line BG-7310-77, all Decca navigation fixes have been moved 2.5 km in a direction N15°W from their theoretical positions.*

an acute angle. The time variable errors in the lane pattern are the most serious as they affect the relative positions of the individual profiles. All crossings of the bathymetric high were made within a four-hour period at the same time of the day on different occasions, and the error in the relative position of the profiles is estimated to be less than 0.5 km.

A Decca Hi-Fix station on Kapp Nordenskiöld on the east coast of Bjørnøya was used to calibrate the absolute position of the green lane pattern which was found to be 490 metres west of its theoretical position in the daytime. This indicates that all navigational fixes should be shifted about one kilometre towards NNW assuming that the positions of the crossing violet lanes are correct. However, line BG-7310-77 positioned by satellite, requires all Decca fixes to be moved with as much as 2.5 km towards NNW to obtain consistency in the observed bathymetry and thickness of Quaternary sediments (Figs. 1, 3, 4 and 6). This implies that violet Decca lanes are east of their theoretical position.

Quaternary sediments

Sparker records from Bjørnøyrenna show an acoustically transparent layer of thickness 100–200 milliseconds (two-way traveltime) resting with a distinct angular unconformity on a stratified sequence (Fig. 2). The thickness of this upper layer is increasing towards the south where also internal reflectors appear (Figs. 2 and 3). To the north the sediment thickness above the unconformity decreases to about 20 ms on the south slope of the Spitsbergen Bank.

Seismic velocities of 3 km/s or more are observed for the dipping strata below the unconformity (Eldholm and Talwani 1977; Sundvor 1974, Renard and Malod 1974) and the available evidence suggests a Quaternary age for the sedimentary section above the angular unconformity observed in Bjørnøyrenna.

Pre-Quaternary rocks

The stratified sequence below the unconformity forms a culminating anticline which rises more than 70 metres above the adjacent sea floor (Figs. 1 and 4). Maximum apparent dips along survey lines are 15—18°. A parallel syncline with gentle dips is present to the north (Fig. 4). On the westernmost profile faulting and flexuring are observed (Fig. 2).

Two sonobuoy measurements with 1 kJ sparker as energy source were attempted over the central part of the bathymetric high (Figs. 1 and 5). Only marginal record quality was obtained due to insufficient energy for this water depth, however consistency in the obtained velocities may justify some consideration. In the centre of the anticline a layer with a thickness of about 230 metres and a compressional velocity of 3.5 km/s is overlying a layer with a velocity of 5.5 km/s (Fig. 5).

Silicified limestone with chert, mudstone (marl), and sandstone were the dominant lithologies of the dredged rocks recovered from the bathymetric high (Fig. 6). Measurements of compressional seismic velocity carried out in the laboratory gave values of 5.1 and 5.5 km/s for silicified limestone and mudstone (marl), respectively.

Sonobuoy measurements from adjacent areas i Bjørnøyrenna show seismic velocities less than 5 km/s for the upper 2.5 km of the sedimentary section (Eldholm and Ewing 1971; Sundvor 1974; Renard and Malod 1974; Eldholm and Talwani 1977; Hinz and Schlüter 1978). This suggests localized shallowing of the high velocity rocks associated with the bathymetric high. The


Second
0.5
0.6
0.7
0.8
0.9
North
South
A
A'
B
B'
0.6
0.7
0.8
0.9

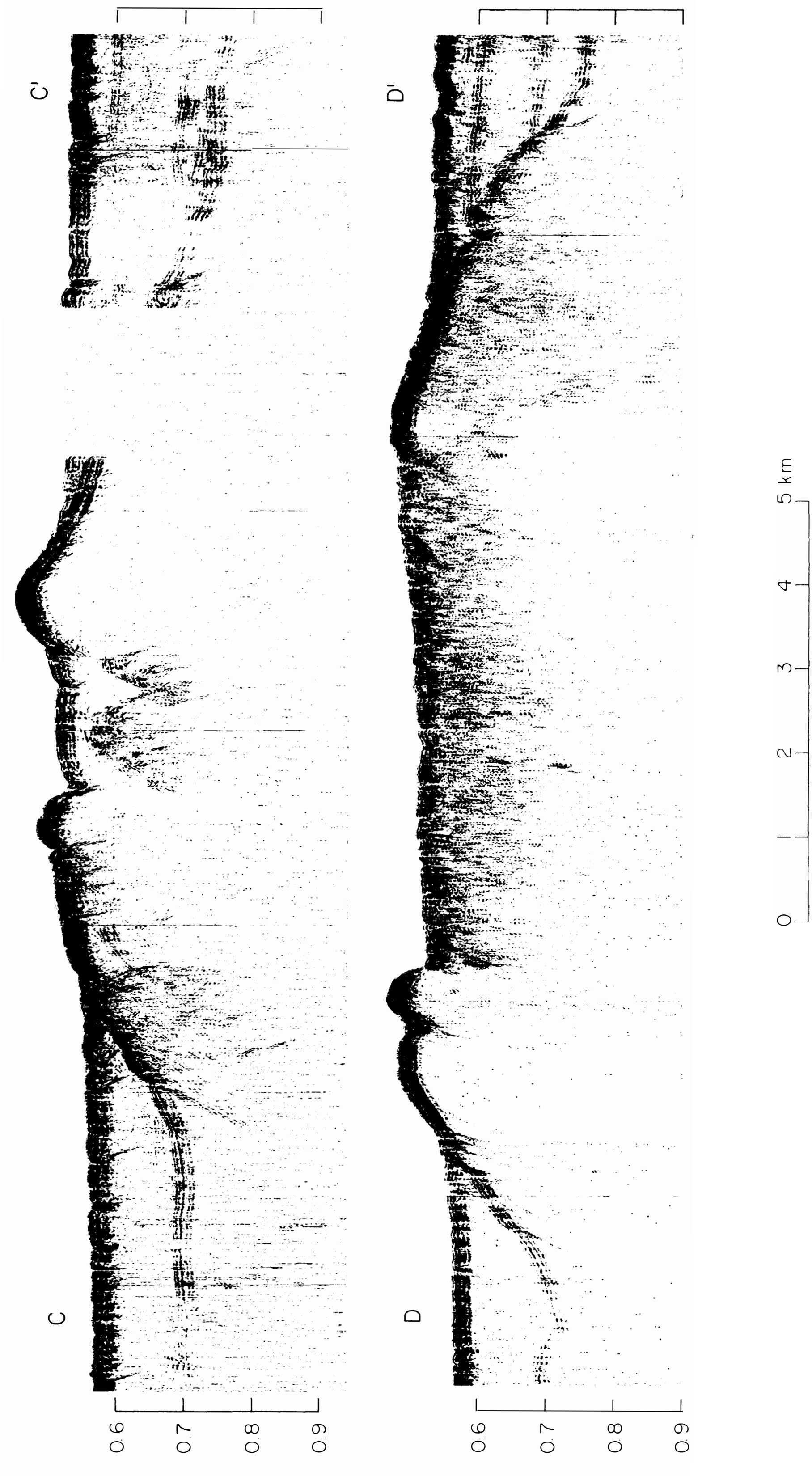


Fig. 2. Shallow seismic reflection records from Bjørnøyrenna. Profile locations in Fig. 1.

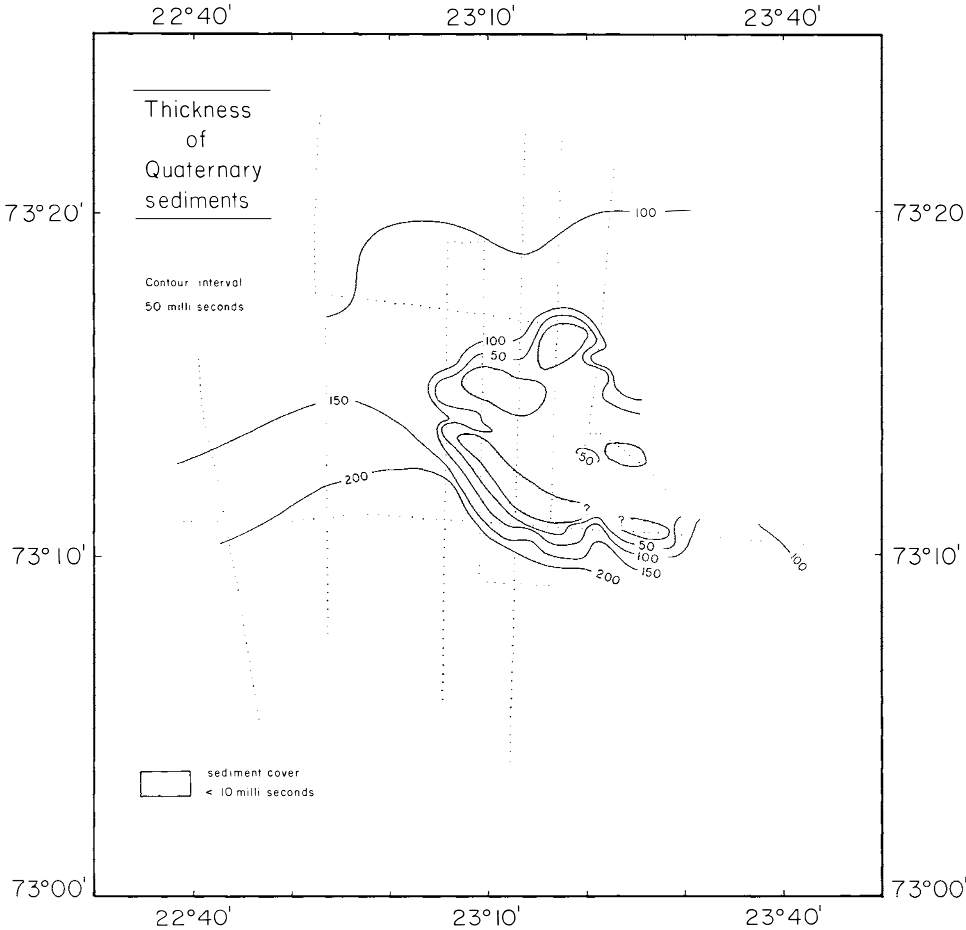


Fig. 3. *Sediment thickness above the angular unconformity measured in milliseconds of two-way travel time. Assuming a seismic velocity of 2 km/s in unconsolidated sediments — 100 milliseconds equals a thickness of 100 metres. For comment on navigation, see Fig. 1.*

observed velocity of 3.5 km/s in the central part of the bathymetric high may in part be due to heavy fracturing of rocks with higher seismic velocity.

Boulders from 20 kg to gravel size with some clay were recovered in dredge hauls from five localities on the bathymetric high and the main lithologies are summarized in Fig. 6. The larger boulders of silicified limestone and marl were angular, whereas boulders of softer lithologies were subangular and showed glacial striations. On the larger boulders, unidirectional glacial striations were observed on one side and an angular opposite side. This suggests in situ erosion by a glacier rather than emplacement of the material by ice rafting. Furthermore the consistency in the seismic velocities obtained by the sonobuoy measurements and by the laboratory measurements on the dredged samples, also favours an in situ origin of the dredged material. The

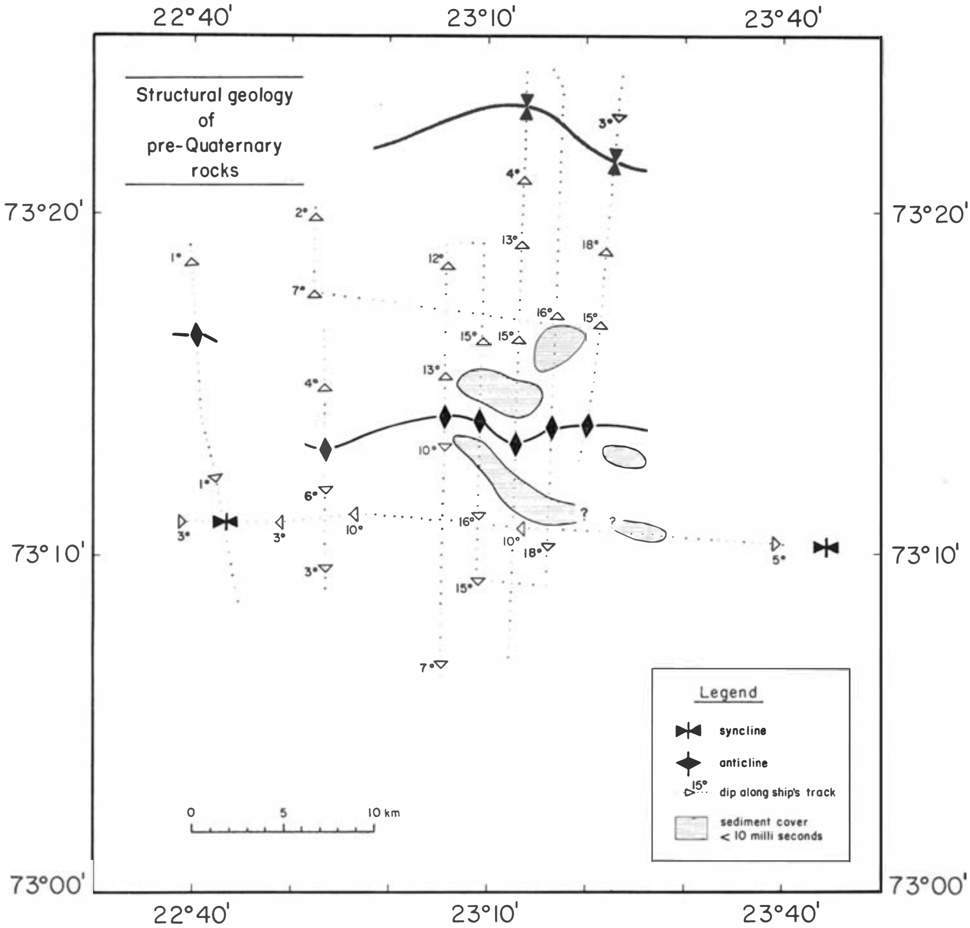


Fig. 4. *Apparent dip measured along pofiles of layers below the angular unconformity. For comment on navigation, see Fig. 1.*

lithology observed in the dredge hauls is therefore considered as representative for the bathymetrich high.

The silicified limestone boulders are characterized by a high content of bioclastic material where the faunal elements are brachiopodes, echinodermes and bryozoans of Permo-Carboniferous age. Work on the Permo-Carboniferous sequence in the Isfjorden area (Ø. Lauritzen pers. comm.) and descriptions of exposures in the Hornsund area of western Spitsbergen (Nysæther 1977), seem to indicate definite lithological similarites between the recovered rocks and the Upper Permian Kapp Starostin Formation. No sulfate minerals were observed in the dredged material.

The faunal and lithological similarities between rocks from Spitsbergen and Bjørnøyrenna therefore indicate a similar upper Paleozoic depositional environment in the two areas.

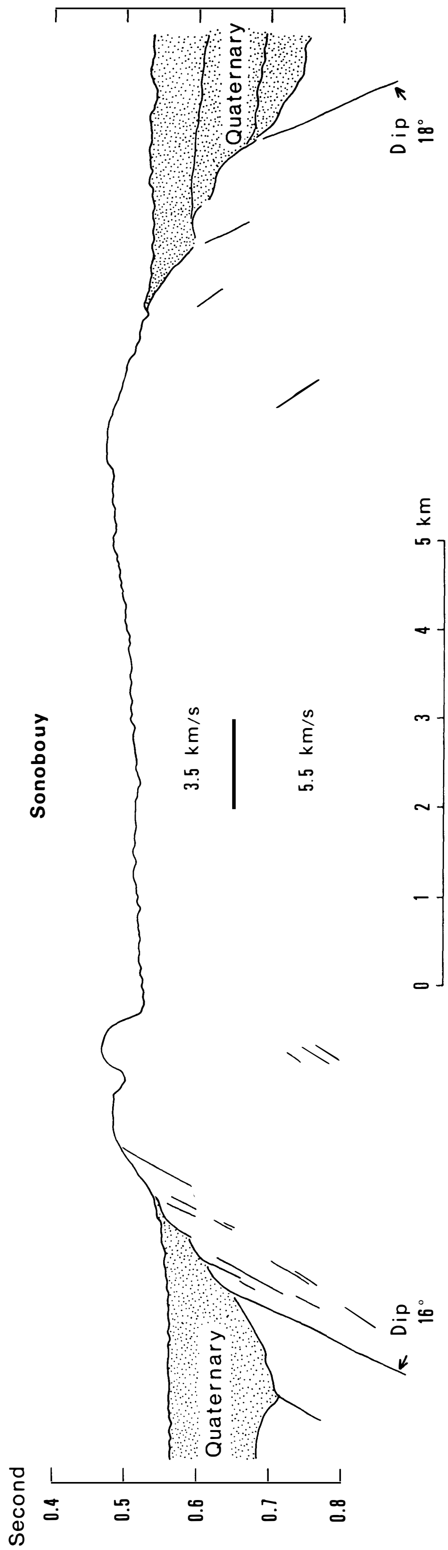


Fig. 5. *Unreversed sonobuoy measurements. Buoy and profile locations in Fig. 1.*

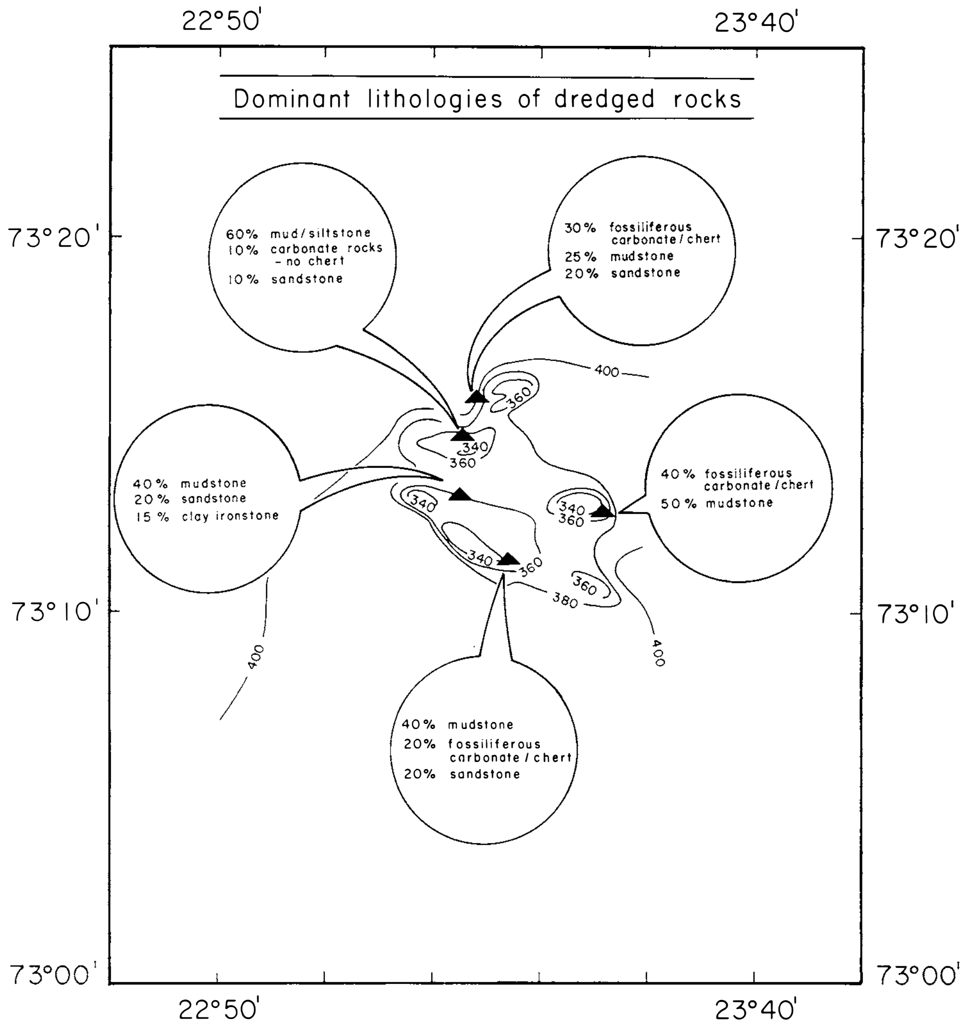


Fig. 6. *Locations of dredge hauls and the dominant lithologies in the recovered rocks. For comment on navigation, see Fig. 1.*

Discussion and conclusion

The anticlinal structure and the high velocity rocks locally present at the sea floor suggest that the bathymetric high in Bjørnøyrenna is related to diapirism at depth. Evaporites are present in Spitsbergen in the Lower to Upper Permian Gipshuken Formation and to a lesser degree in the overlying Kapp Starostin Formation (Flood et al. 1971). The observed total thickness of the two formations is 7—800 m (Cutbill and Challinor 1965) and individual evaporite beds of a thickness less than 10—15 metres alternate with carbonate-rich units. These thicknesses are far below what is necessary for the generation of large scale diapirism, and only minor evaporite structures (few metres), probably tectonically induced, have been observed in Spitsbergen (Lauritzen 1978).

On the other hand, the observed lithological similarities between the Permo-Carboniferous rocks of Spitsbergen and rocks recovered from Bjørnøyrenna open the possibility that evaporites may well be present in strata underlying the bathymetric high.

Extensive diapirism is observed in the seismic data in the Tromsøflaket area and in the Nordkapp Basin (Rønnevik and Myhre 1978). A seismic line in the vicinity of the bathymetric high in Bjørnøyrenna shows a dome-like feature at depth (Rønnevik pers. comm.). Tentative dating of seismic reflectors by the method of Vail et al. (1977), suggests that diapirism has taken place from two stratigraphic levels in the Permian and probably also in the Devonian sequence (Rønnevik and Myhre 1978). This widely observed diapirism in the Barents Sea suggests that evaporite rather than shale is the active agent.

Acknowledgements

We gratefully acknowledge the cooperation of I. Røren and the crew of M/S «Olaf Scheel». O. Møller, University of Oslo, kindly carried out some of the laboratory measurements on dredged samples. Sparker records along line BG-7310-77 were kindly provided by the Norwegian Petroleum Directorate. This research was carried out under the Barents Sea Project at Norsk Polarinstitutt, funded by NTNF and the Norwegian Petroleum Directorate.

References

CUTBILL, J. L. and A. CHALLINOR, 1965: Revision of the Stratigraphical Scheme for the Carboniferous and Permian Rocks of Spitsbergen and Bjørnøya. *Geol. Mag.* 102: 418—439. Hertford.

ELDHOLM, O. and J. EWING, 1971: Marine geophysical survey in the south-eastern Barents Sea. *Jour. Geophys. Research* 76: 3832—3841.

TALWANI, M., 1977: Sediment distribution and structural framework of the Barents Sea. *Geol. Soc. of Am. Bull.* 88: 1015—1029.

EMELYANOV, E. V., V. M. LITVIN, V. A. LEVCHENKO and G. P. MARTYNOVA, 1971: The geology of the Barents Sea. In: *The Geology of the East Atlantic Continental Margin* 2. Europe. Report no. 70/14. Institute of Geological Sciences.

FLOOD, B. J. NAGY and T. WINSNES, 1971: Geological map Svalbard 1:500 000. Sheet 1G Spitsbergen southern part. *Norsk Polarinstitutt Skrifter* Nr. 154A.

HINZ, K. and H. U. SCHLÜTER, 1978: The geological structure of the western Barents Sea. *Marine Geology* 26: 199—230.

LAURITZEN, Ø., 1978: Utviklingsmønstre i gips-/anhydritttavleiringer fra de underpermiske sedimentene på Svalbard, med et foreslått klassifikasjonssystem. *Abstract XIII. Nordiske Geologiske Vintermøte, København: 17.*

NYSÆTHER, E. 1977: Investigations on the Carboniferous and Permian stratigraphy of the Torell Land area, Spitsbergen. *Norsk Polarinstitutt Årbok* 1976: 21—43.

RENARD, V. and J. MALOD, 1974: Structure of the Barents Sea from seismic refraction. *Earth and Planetary Sci. Letters 24: 33—47.*

RØNNEVIK, H. C. and L. MYHRE, 1978: Geologisk kartlegging i vestlige del av Barentshavet. *Abstract XIII Nordiske Geologiske Vintermøte, København: 17.*

SUNDVOR, E., 1974: Seismic refraction and reflection measurements in the southern Barents Sea. *Marine Geology* 16: 255—273.

VAIL, P. R., R. M. MITCHUM jr., S. THOMPSON III, R. G. TODD, J. B. SANGREE, J. M. WIDNIER, J. W. BUBB and W. G. HATTELID, 1977: Seismic Stratigraphy and Global Changes of Sea Level. *Am. Assoc. Petrol. Geol. Memoir* 26, Stratigraphic Interpretation of Seismic Data.

Holocene sedimentation on the shelf around Bjørnøya, northwestern part of the Barents Sea

By ANDERS ELVERHØI and YNGVE KRISTOFFERSEN

Abstract

Detailed sediment sampling and shallow seismic profiling on the once glaciated shelf around Bjørnøya indicate sediment infilling into topographic lows and extensive winnowing down to 150 m water depth.

Glacial sediments cover the sea bottom in water depths between 150 m and 480 m. Fine grained winnowed sediments are deposited locally in overdeepened troughs and below 480 m water depth in Bjørnøyrenna.

In areas with glacial sediments, ferric precipitation due to ferrous diffusion from underlying sediments produces an iron crust where lumps of clay and clasts are incorporated.

Introduction

Shelves with glacially formed topography and till deposits are being reworked in response to the present day conditions (Swift 1970; Slatt 1974). On the Spitsbergen Bank pebbly clay deposited by the Pleistocene ice-sheet is reworked post-glacially to produce a gravel and boulder lag. The lag mixed with Holocene bioclastics are winnowed to produce carbonate rich sediments which are now being deposited in adjacent areas (Bjørlykke et al. 1978). In this paper aspects of the Holocene processes of sedimentation of a previously glaciated area around Bjørnøya are discussed, based on shallow seismic reflection measurements and sediment sampling.

Data acquisition and laboratory procedures

1050 km of continuous sparker profiles were obtained southeast of Bjørnøya in the summer of 1977. Navigation was by a Hi-Fix slave station at Bjørnøya (Fig. 1), combined with the Decca main chain, Finnmark (Northern

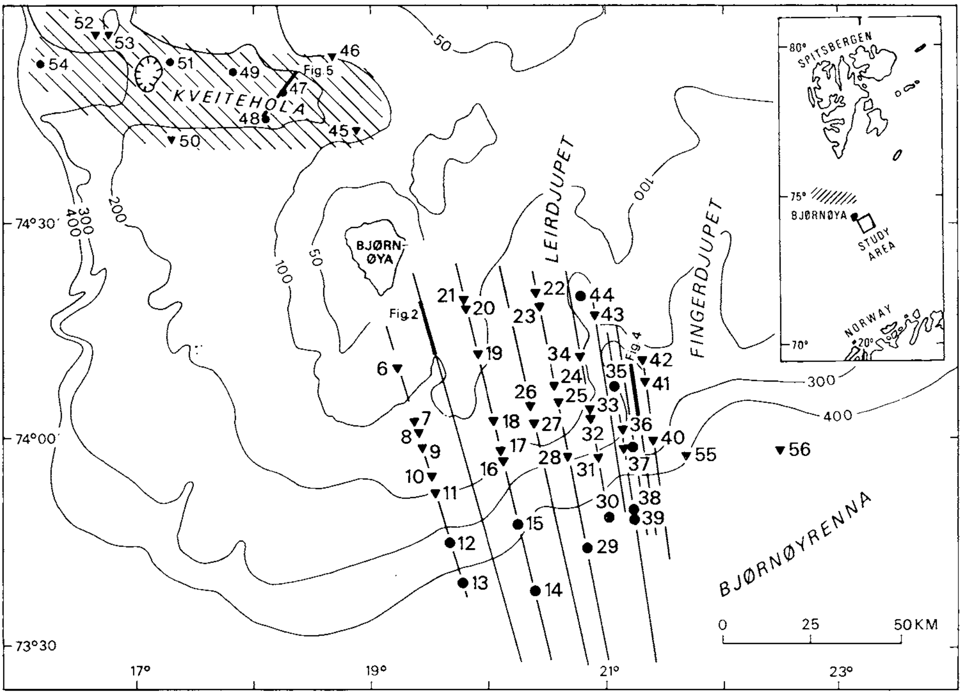


Fig. 1. *Bathymetric map of survey area with locations of sparker profiles (——), dredge hauls (▼), and gravity cores (●). Heavy lines refer to profiles shown in Figs. 2, 4, and 5.*

Norway). A geological sampling program was carried out along the sparker lines, and also in the Kveitehola area. Gravity cores 0.3 to 1.5 m long, were taken of the more fine-grained sediments in the deeper parts of Bjørnøy-renna and dredging was carried out in areas with coarse-grained sediments (Fig. 1).

Complete grain size analyses of the <2 mm grades (whole ϕ-values) were carried out on the cores, based on standard pipette and sieving procedures. Supplementary, mud-, sand- and gravel content was measured on selected samples.

Mineralogical and geochemical data was obtained by XRD records and atomic adsorption.

Bedrock morphology and topographic smoothing by sediment infilling

A very flat bottom is observed (Fig. 2) on the shallow parts of the Spitsbergen Bank down to 90 m water depth. Below this level, a hummocky topography is present at a vertical scale of 5—20 m and a horizontal scale of 2—500 m. This morphology does not appear to be related to variation in the thickness of unconsolidated sediments.

Mesozoic rocks are suggested to underly the area (Edwards 1975), and

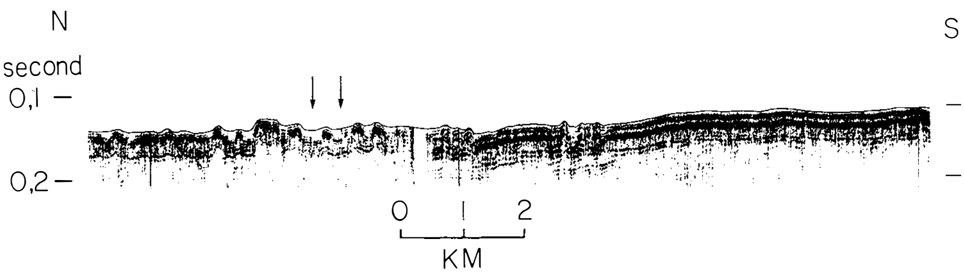


Fig. 2. *Sparker profile from the shallow bank southeast of Bjørnøya. Acoustically transparent sediment infill is observed in topographic lows in water depths greater than 90 m (indicated with arrows). Profile location in Fig. 1.*

strata with an apparent southward dip are observed to the south (Kristoffersen in prep.). The hummocky bottom topograpy may reflect varying resistance to glacial erosion of the different lithological sequences, i.e. shale, sandstone or carbonates and chert and the characteristic flat bottom morphology down to 90 m may be due to more uniformly competent bedrock.

South of Bjørnøya down to 150 m of water depth, the sandy and gravelly substratum is composed of mixed clastics and bioclastics (Fig. 3) with lithological similarities to the sediment cover on the Spitsbergen Bank. Here lag deposits mixed with Holocene produced bioclastics are found and represent an in situ sediment source (Bjørlykke et al. 1978).

Below 90 m of water depth, sediments transparent to the acoustic energy of the sparker system are present as infill in topographic lows (Fig. 2). It seems likely that these deposits represent clastic and bioclastic sediments transported over a short distance from the higher areas on the bank into the «valleys».

Holocene non-depositional areas

Below 150 m water depth down to 480 m, stiff pebbly clay with scattered crushed shells cover the sea-bottom (Fig. 3), and eastward along the slope similar glacial sediments have been shown to be present (Bjørlykke et al. 1978). The exposure of these relict sediments is indicative of Holocene non-depositial areas.

The boundary between areas of winnowing and areas of non-deposition is found in eastern parts of the slope in 60—90 m depth (Bjørlykke et al. 1978), but is observed south of Bjørnøya in 150 m water depth. This reflects a high flow regime far below wave base. No current velocity measurements have been carried out yet. The actual area is, however, just beneath the oceanic polar front (Omdal 1954), where large lateral temperature gradients are present (Trangeled) and strong thermohaline currents are likely to exist. More oceanographic data are needed for a meaningful interpretation of the sedimentary environment in this area.

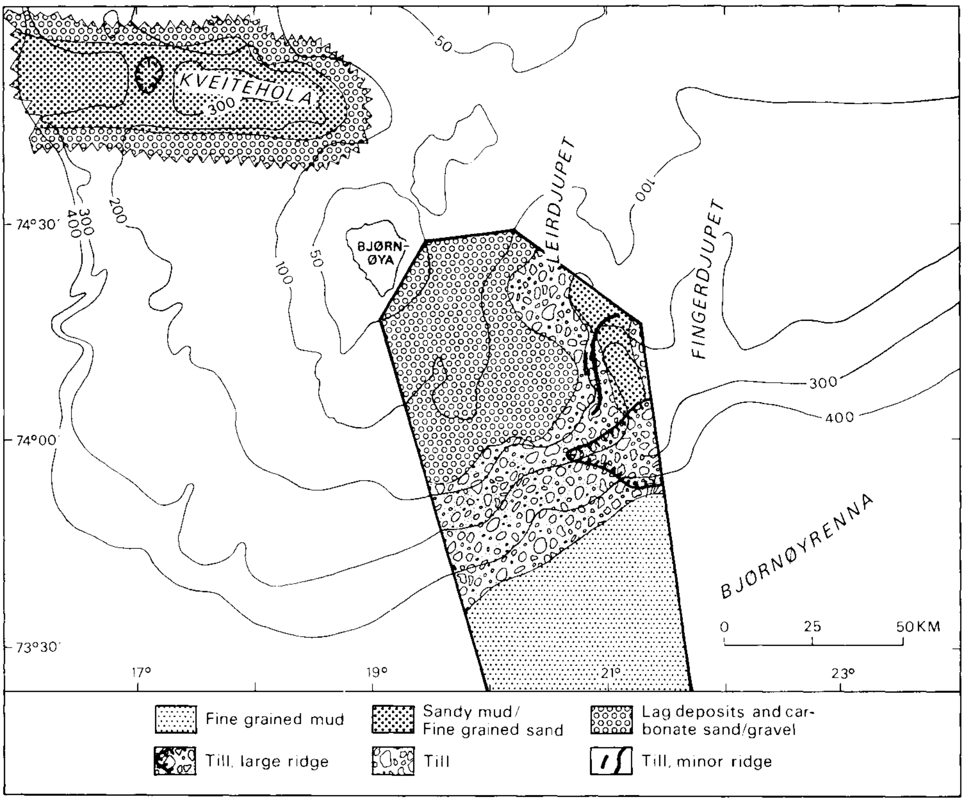


Fig. 3. *Lithology of the bottom sediments.*

Sedimentation within the troughs around Bjørnøya

A 10—20 milli-seconds thick acoustically transparent sedimentary unit covers the deeper, central part of Leirdjupet. (Fig. 4).

Predominantly muddy sediments (80% $< 63\ \mu$, 20% sand) were recovered from this area and the carbonate content is 50% within the fine-sand grades. Below a sill depth of 300 m, Leirdjupet represents a basin, where sediments winnowed from the bordering higher areas are trapped.

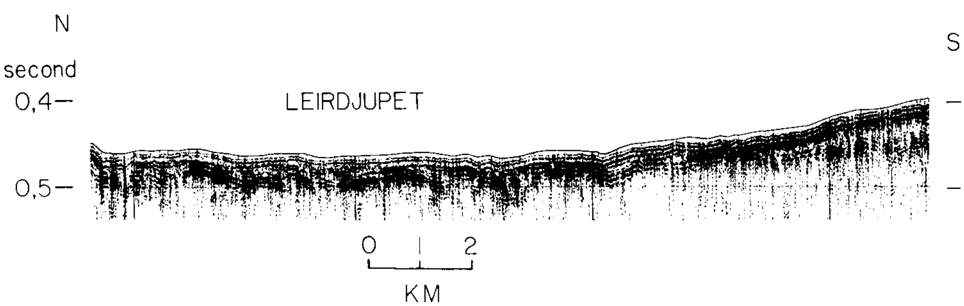


Fig. 4. *Sparker profile from the central trough of Leirdjupet where sediment is presently being trapped. Profile location in Fig. 1.*

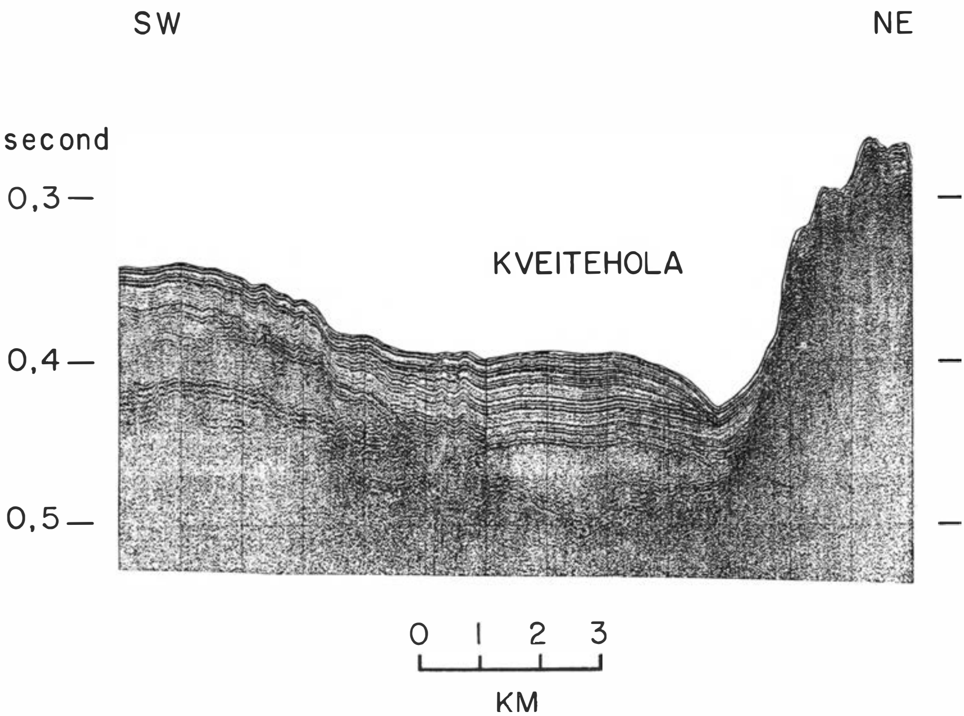


Fig. 5. *Sparker profile along an oblique NE-SW crossing of Kveitehola. (Obtained at a survey in 1971 by the NTNF Shelf Division and Norsk Polarinstitutt). Profile location in Fig. 1.*

Olive-grey carbonate rich (30—50% $CaCO_3$) muddy sand with a well sorted sand population (75%; 63—250 μm, 25% < 63 μm) cover the sea bottom in Kveitehola, the trough northwest of Bjørnøya. These carbonate-rich sediments have probably been winnowed from the Spitsbergen Bank and transported as bed load (e.g. Visher 1969).

A well developed channel follows the northern side of the trough (Fig. 5) and probably owes its origin to bottom currents flowing westward through Kveitehola under the influence of the Coriolis force. The channel probably serve as a conduit for the sediment transport from the Bank to the continental slope in the west.

Recent sedimentation in Bjørnøyrenna

Small-scale hummocky topography is observed within Bjørnøyrenna, and the soft muddy sediments on the sea bottom contain several grained lamina. Bentonic foraminifera are mixed with planctonic species and the latter constitutes 30—40% of the sample. The abundance of foraminifera decrease down-core with no significant change in the relative abundance of individual species (Fig. 6). The present fauna suggests a large component of warm Atlantic water in the watermass. Atlantic water, however, did not reach north

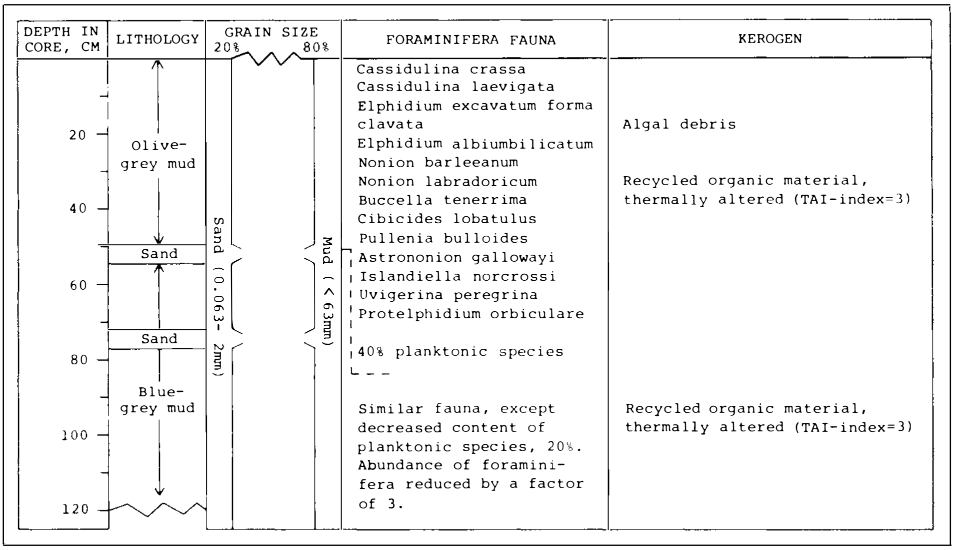


Fig. 6. *Schematic core description of the bottom sediments below 480 m water depth in Bjørnøyrenna, southeast of Bjørnøya.*

of Northern Norway before Preboreal time (conf. Mangerud 1977). Therefore, a Holocene age is suggested for the sediments, i.e. at least for the upper 1.5 m.

The stratigraphy of the sediments in the cores is characterized by an olive-grey top unit (10—40 cm) overlying blue-grey sediments. The olive colour correlates with a relative abundance of green algal debris varying in size from fine silt to sand, and the observed colour is attributed to the organic material. (More detailed work on the stratigraphy is underway).

Recent iron-crust formation

Within areas where the bottom is covered by pebbly mud (150—480 m water depth), fragments of an X-ray amorphous iron-crust containing pebbles and soft sediments were commonly observed (Fig. 7, Table 1). One side of the fragments contained bentonic foraminifera and is interpreted to be the side in contact with water.

Flakes of iron-crust with dimension 0.10 × 0.10 m were brought up by dredging, and the abundance of these samples suggests that far wider areas may be covered with iron-crust. Iron-crust with similar Fe-content is reported from the Frans Josef Land area (Samoilov and Titov 1922). The water depths where the iron-crust was recovered is far below the level that could have been exposed during the Weichselian lowered sea level of 130 m (Milliman and Emery 1969). A subaerial origin, therefore, appears unlikely. The dredge

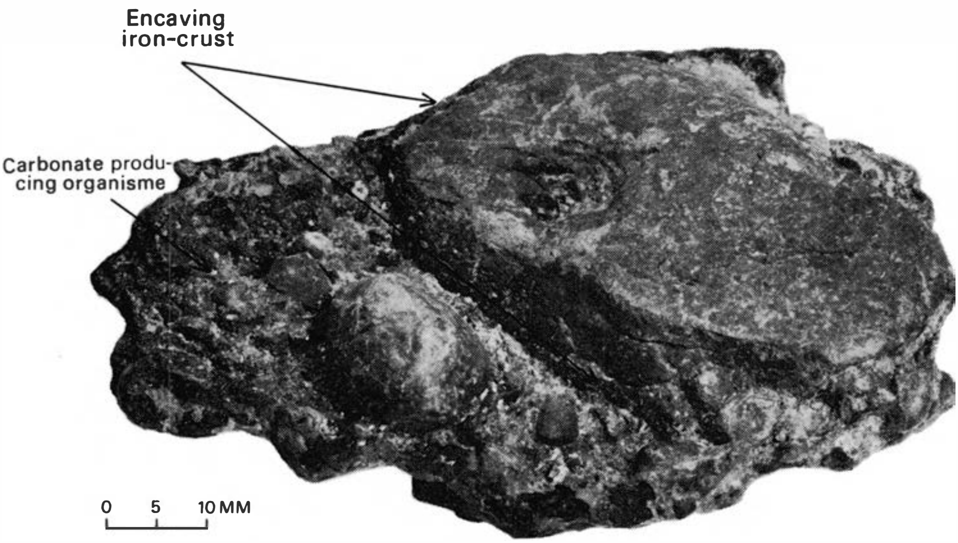


Fig. 7. *Photograph of iron-crust from the sea bottom (200—480 m water depth) southeast of Bjørnøya. White spots are carbonate producing organisms as foraminifera a.s.*

Table 1

Main element geochemistry of iron-crust at the sea-bottom (200—480 m water depth) south east of Bjørnøya. X-ray analyses showed only quartz. Analyses on Fe^{III}/Fe^{II} showed 90⁰/₀Fe^{III}.

Element	Weight percent
SiO_2	62.89
TiO_2	0.39
Al_2O_3	9.24
Fe_2O_3	12.05
MgO	1.63
CaO	1.84
K_2‘	1.64
Na_2O	2.25
MnO	0.12
Loss on ignition	8.70

locations are in the position of the oceanic polar front, where mixing of cold Arctic water and warm Atlantic water takes place.

Precipitation of ferric species from the water-masses is excluded as the incorporated pebbles show a clear upward surface (Fig. 7). The sediments southeast of Bjørnøya show high content of iron and siderite (Bjørlykke et al. 1978), and recent pyrite formation is taking place 1—2 cm below the sediment surface in clayey sediments (Elverhøi 1977). A ferrous source is available, and upwards diffusion of Fe^{II}-ions from the sediment may thus presipitate as ferric species in contact with the water-masses.

Conclusion

Sediments on the shelf around Bjørnøya (northwestern part of the Barents Sea) are now being reworked in response to the present day current regime.

This is expressed in a number of ways:

1) Down to 150 m water depth glacial sediments are reworked and mixed with Holocene produced biogene carbonate clasts to produce a coarse grained sediments cover. Winnowing and redeposition of these sediments smooth the glacially moulded topography.
2) On the slope from 150 m down to 480 m water depth south of Bjørnøya strong bottom currents inhibit sediment deposition and relict glacial sediments cover the sea bottom.
3) Within the Bjørnøyrenna a relatively calm environment favours sediment fallout from suspension.
4) In the submarine overdeepened troughs running down the slope from the Spitsbergen bank, a thick acoustic transparent cover is formed by winnowed sediments deposited out of suspension.
5) Ferrous diffusion from underlying clayey sediments produces a ferric-oxide crust at the sediments surface, where pebbles and lumps of clay are bound together.

Acknowledgements

The cooperation of I. Røren and the crew on M/S «Olaf Scheel» are gratefully acknowledged.

Able assistance in the field was provided by H. Øines, S. Dalgren, A. Solheim, and O. Skarbø during the survey. T. Trondsen and K. Bomstad kindly carried out kerogen and foraminifera analyses.

This research was carried out under the Barents Sea Project at the Norwegian Polar Research Institute, funded by NTNF and the Norwegian Petroleum Directorate.

References

BJØRLYKKE, K., B. BUE and A. ELVERHØI, 1978: Quaternary sediments on the northwestern part of the Barens Sea and their relation to underlying Mesozoic bed rocks. *Sedimentology* 25: 227—246.

EDWARDS, M. B., 1975: Gravel fraction on the Spitsbergen Bank, NW Barents Shelf. *Norges geol. Unders.* 316: 205—217.

ELVERHØI, A., 1977: Origin of framboidal pyrite in clayey sediments and in Jurassic black shale in the northwestern part of the Barents Sea. *Sedimentology* 24: 591—595.

KRISTOFFERSEN, Y., (in prep.): The distribution of Quaternary sediments in the northwestern part of the Barents Shelf.

MANGERUD, J., 1977: Late Weichselian marine sediments containing shells, foraminifera, and pollen, at Ågotnes, Western Norway. *Norsk Geologisk Tidsskrift* 57: 23—54.

MILLIMAN, J. D. and K. O. EMERY, 1969: Sea levels during the past 35 000 years. *Science* 162: 1121—1123.

OMDAL, K., 1953: Drivisen ved Svalbard 1924—1939. *Norsk Polarinstitutt Meddelelse* Nr. 72.

SAMOILOV, Ya. V. and A. G. TITOV, 1922: Iron and manganese concretions on the bottom of the Black, Baltic and Barents Sea. *Trudy Geol. i Min. Muzeya Ross. Akad. Nauk.* III (1917—1918), Petersburg.

SLATT, R. M., 1974: Continental shelf sediments off Eastern Newfoundland: A preliminary investigation. *Can. J. Earth Sci.* 11: 362—368.

SWIFT, D. J. P., 1970: Quaternary shelves and the return to grade. *Mar. Geol* 79: 322—346.

TRANGELED, S.: *Oceanography of the areas of the Barents Sea and the West Spitsbergen Current.* A preliminary typewritten manuscript.

VISHER, G. S., 1969: Grain size distributions and depositional processes. *Jour. Sed. Pet.* 39: 1074—1106.

Glacial deposits southeast of Bjørnøya, northwestern part of the Barents Sea

By ANDERS ELVERHØI and YNGVE KRISTOFFERSEN

Abstract

A detailed shallow seismic reflection survey supported by sediment sampling southeast of Bjørnøya show moraine ridges in: 1) 300—350 m, 2) 200 m, and 3) 150 m water depths outside (1) and upslope, (2 & 3) Leirdjupet — a submarine trough. These glacial stages are probably related to the Late Weichselian ice cover (max. 18—20 000 years B.P.).

Introduction

Recent marine geophysical and geological investigations combined with glacial geological studies confirm Pleistocene glaciaton of the Barents Sea (Hoppe 1970; Grosval'd et al. 1974; Matisov 1977). However, the time and areal extent of the different ice-sheets is still an open question.

In this paper the depostional environment and a relative stratigraphy of glacial deposits southeast of Bjørnøya are discussed — based on shallow seismic reflection measurements and sediment sampling.

Data acquisition and laboratory procedures

In the summer of 1977 continuous sparker profiles were obtained southeast of Bjørnøya followed by a geological sampling programme (Fig. 1).

Mud-, sand- and gravel- (>2 mm) content in these sediment cores were measured at selected levels.

Mineralogical analyses of the < 2 mm grades were carried out on water-milled samples, low vacuum-filtered on Millipore slides, and later run on a Siemens XRD. Kerogen investigations were done on HCl- and HF-treated samples.

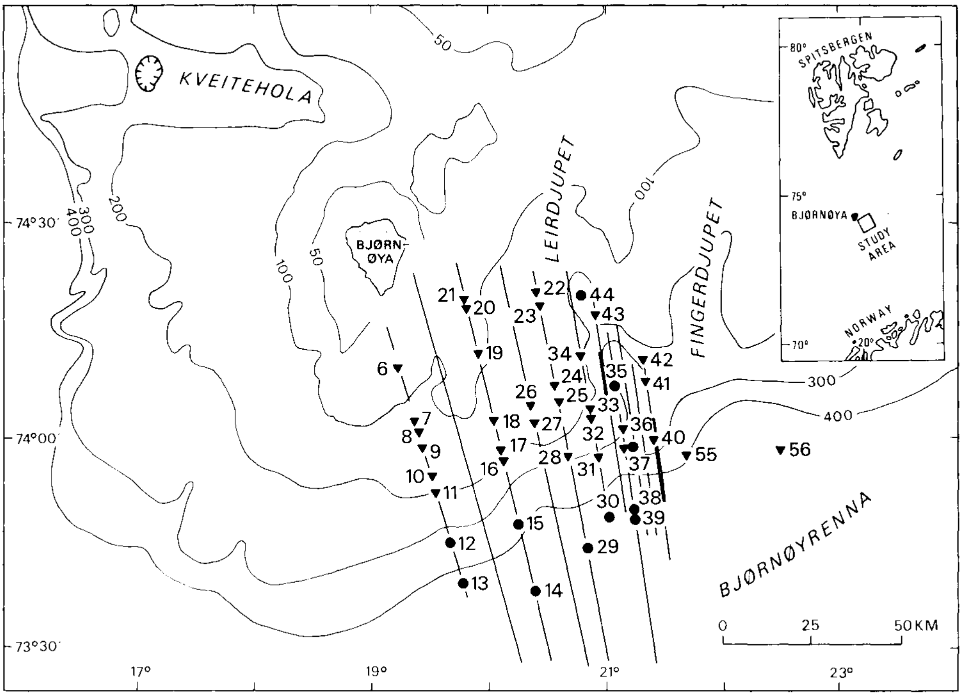


Fig. 1. *Bathymetric map with survey area and position of sparker profiles (——) and geological sampling stations (▼ dredging, ● gravity coring). Heavy lines refer to profiles shown in Fig. 2.*

Distribution of Quaternary sediments

The sea floor on the top and the upper slope of the Spitsbergen Bank is highly reflective and only limited acoustic penetration was obtained with the lkJ sparker array. Southward dipping reflectors, unconformable with the sea floor are overlain by a thin veneer of sediments (20 milli seconds) (Kristoffersen in prep.). On the lower slope, the sedimentary unit above the unconformity increases in thickness (100—200 milli seconds) towards the central part of Bjørnøyrenna.

Firm pebbly clay with scattered crushed shell covers the sea floor from a water depth of 150 m down to 480 m south of Bjørnøya. Similar glacial sediments have been observed farther east, south of Hopen (Bjørlykke et al. 1978). Seismic refraction measurements indicate velocities in the range 3.5 — 4.5 km/s for the sub-bottom layers (Eldholm and Talwani 1977). We therefore interpret the sedimentary unit above the angular unconformity as Quaternary deposits with pre- Quaternary high velocity rocks below.

Moraine ridges southeast of Bjørnøya

Outside Leirdjupet the Quaternary cover forms an east-west striking ridge in a water depth of 300—350 m. The southern slope is slightly steeper

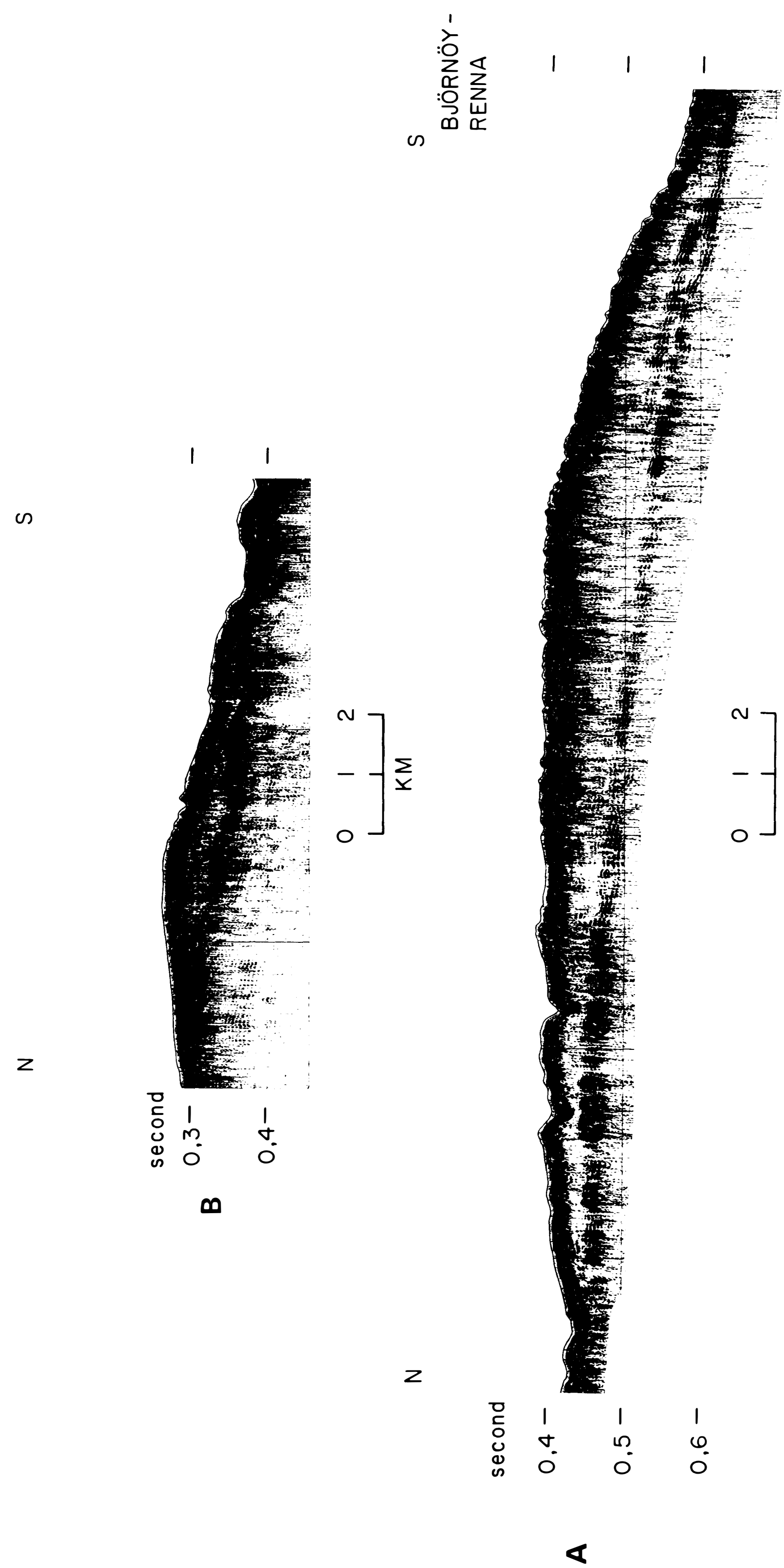


Fig. 2. *Sparker profiles across moraine ridges outside (A) and upslope (B) Leirdjupet. The bathymetry of Kveitehola, a submarine trough northwest of Bjørnøya, indicate a ridge in the same water depth as the ridge outside Leirdjupet. For profile location, see Fig. 1.*

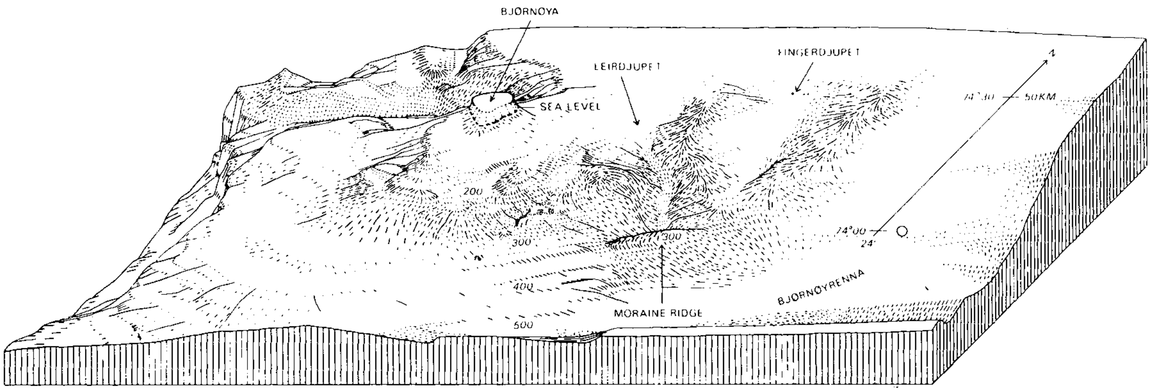


Fig. 3. *Block diagram of the sea floor morphology southeast of Bjørnøya. A moraine ridge occur outside Leirdjupet, and glaciomarine sediments are observed on the sea bottom in the adjacent areas towards the west. (The numbers refer to water depth).*

than the northern slope (Figs. 2 and 3). The top of the ridge has an excess elevation of about 70 m with respect to the inner part of Leirdjupet (Fig. 2). The eastward extension of the ridge was not observed, however a sparker line east of Fingerdjupet shows no indication of a sediment ridge.

Based on: 1) the geometry of the sediment lens, 2) the position outside the trough (Leirdjupet), and 3) boulder- and pebble-rich stiff clay on the top (Elverhøi and Kristoffersen 1978) the sediment lens is interpreted as a till deposited by a glacier that drained through the Leirdjupet. A maximum thickness of 150 m for a distance of 12—15 km of the till ridge (Fig. 2), indicates a major glacial stage with heavy glacial drainage and deposition in this area.

Farther upslope in Leirdjupet in 150 m and 200 m of water depth, minor sediment lenses are observed, and similarly interpreted as till deposits. Wether these till ridges have originated by deposition beneath a floating shelf ice (Carey and Ahmad 1961) or by deposition mainly in front of a glacier, is not clear.

Glacio marine deposits

From the deeper parts of the slope west of the ridge, 0.5 m long cores were obtained of firm pebbly clay. An olive-grey top unit (5—15 cm) is overlying a blue-grey coloured section (Fig. 4). A glacial origin is suggested due to the high content of both pebbles and clay. The well preserved algal debris in the upper unit, however, exclude till formation of older marine sediments, and the top unit is interpreted as a glaciomarine deposit. No essential mineralogical and textural difference or difference in foraminiferal fauna (Fig. 4) or compaction are observed between the two sedimentary

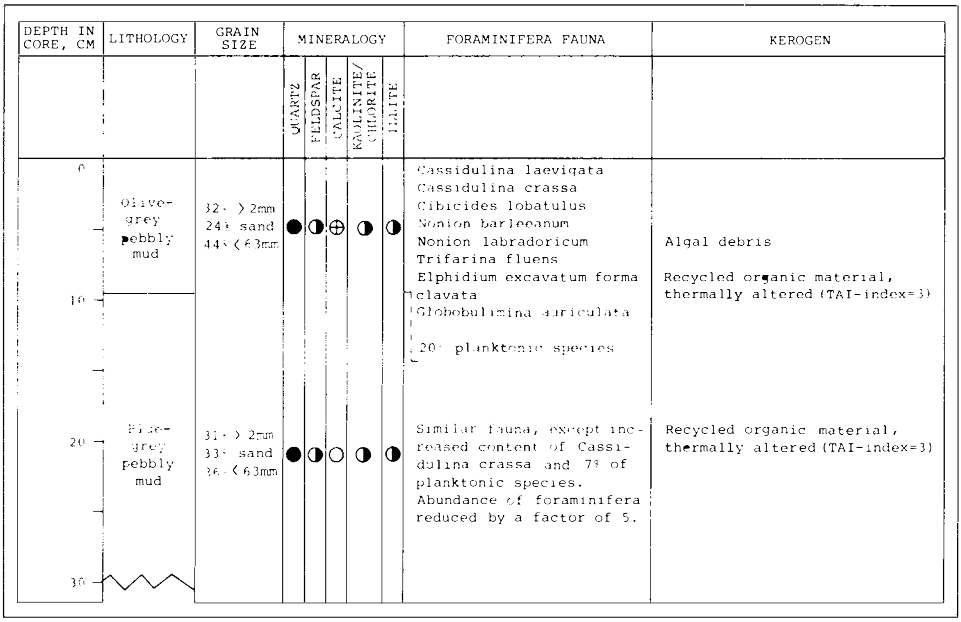


Fig. 4. *Schematic core description of glaciomarine sediments with the main species of the foraminiferal fauna. The mineralogy is based on XRD peak intensity (● — major component, ◑ — minor component, ⊕ — trace, ○ — not detected).*

units. For lack of satisfactory criteria for distinguishing between different glaciomarine environments (e.g. Carey and Ahmad 1961; Syden and John 1976), the lower unit is also interpreted as a glaciomarine deposit.

Pleistocene depositional stratigraphy

The well preserved ridge structure of the moraine outside Leirdjupet suggests that this deposit represent the youngest major glacial stage in the area. Enough material for C^{14} dating was not obtained, however with a Weichselian ice cover on the Bank (Hoppe 1970), the ridge may be related to a major stage of this ice sheet.

The minor ridges farther upslope Leirdjupet in 200 m and 150 m of water depths, respectively, are interpreted as successively younger moraine deposits.

By analogy with continental glaciers where ice streams extend far down through the valleys, a glacial stream may have run down the Leirdjupet, while the ice-sheet itself terminated at some higher level on the slope. Glaciers calve with concurrent distal depositons of glaciomarine sediments. Therefore, the large moraine and adjacent glaciomarine sediments may have well deposited synchronously. The content of planktonic foraminifera and well preserved algal debris in the glaciomarine deposits (Fig. 4), suggests sedimentation in open water or in water intermittently covered with ice.

Pebbly clay is suggested to cover the Spitsbergen Bank in early Holocene time, and, winnowing of these sediments down to 100 m water depth is dated to Holocene (Bjørlykke et al. 1978). Probably recent winnowing also takes place down to 150 m depth south of Bjørnøya (Elverhøi and Kristoffersen 1978), and with a maximum eustatic lowering of 130 m during Late Weichselian time (Milliman and Emery 1969), the preservation of glacial sediments observed in present water depths of 150—480 m seems unlikely. The moraine ridges and the firm pebbly clay may therefore have been deposited during the retreat of the Late Weichselian ice cover (max. 18—20 000 years B.P.).

Conclusion

Glacial drainage through the Leirdjupet deposited a large moraine ridge in 300—350 m water depth in front of this through — during a major glacial stage probably in Late Weichselian time (max. 18—20 000 years B.P.).

In 200 m and 150 m depth of water, minor moraine ridges exist probably related to successively younger glacial stages.

On the southern slope of the Spitsbergen Bank, glaciomarine deposits cover the seabottom, and may possibly have been deposited synchronously with the formation of the large moraine ridge.

The extent of the Pleistocene ice cover of the Barents Sea is still an unsolved question. The present study shows however, that the record of the glacial history is well expressed in submarine troughs, and these key areas should receive special consideration in further pursuit of the problem.

Acknowledgements

We gratefully acknowledge the cooperation of I. Røren, the crew on M/S «Olaf Scheel», and the cheerful spirits of assistants H. Øines, A. Dalgren, A. Solheim, and O. Skarbø during the field work. Kerogen and foraminifera analyses were kindly carried out by T. Throndsen and K. Bomstad.

This research was carried out under the Barents Sea Project at the Norsk Polarinstitutt, funded by NTNF. The marine geophysical survey was supported by the Norwegian Petroleum Directorate.

References

BJØRLYKKE, K., B. BUE and A. ELVERHØI, 1978: Quaternary sediments on the northwestern part of the Barents Sea and their relation to underlying Mesozoic bed rocks. *Sedimentology* 25: 227—246.

CAREY, S. W. and N. AHMAD, 1961: Glacial marine sedimentation. In Raasch, G. O. (ed.): *Geology of the Arctic* 2 Univ. of Toronto Press, Toronto, Ont.: 865—894.

ELDHOLM, O. and M. TALWANI, 1977: The sediment distribution and structural framework of the Barents Sea. *Geol. Soc. of Am. Bull.* 88: 1015—1020.

ELVERHØI, A. and Y. KRISTOFFERSEN, 1978: Holocene sedimentation on the shelf around Bjørnøya, northwestern part of the Barents Sea. *Norsk Polarinstitutt Årbok* 1977: 199—207.

GROSVAL'D, M. G., A. S. LAVROV, and L. M. POTAPENKO, 1974: The glacial stage Marchida-Vel't: a double surge of the Barents Glacier Shield? *Materialy glajacialogiceskich issledovanij. Chronika, obsuzdenija* 24: 173—188. (In Russian).

HOPPE, G., 1970: The Würm ice sheets of northern and Arctic Europe. *Acta Geographica Lodziensia* 24: 205—215.

KRISTOFFERSEN, Y., (in prep.): The distribution of Quaternary sediments in the northwestern part of the Barents Shelf.

MATISOV, G. C., 1977: Bottom gemorphology and the problem of pleistocene glaciation of the Barents Sea shelf (in Russian). *Gemorfologija* 2: 91—98, Moskva.

MILLIMAN, J. D. and K. O. EMERY, 1969: Sea levels during the past 35 000 years. *Science* 162: 1121—1123.

SYDEN, D. E. and B. S. JOHN, 1976: *Glaciers and landscape. A geomorphological approach.* 376 pp. Arnold, London.

Holocene emergence and finds of pumice, whalebones, and driftwood at Svartknausflya, Nordaustlandet

By OTTO SALVIGSEN

Abstract

Marine features are found up to about 120 m above sea level, and levels up to 70 m are dated here. Datings of twenty driftwood samples and three whalebones give an emergence curve starting at 9,500 years B.P. The rate of emergence was high from 9,500 to 7,500 B.P. and low in the period 7,500—5,500 B.P. Uplift has been insignificant during the last 1,500 years. The only pumice level found is dated to about 4,500 B.P. Driftwood logs and whalebones are common up to 50 m above sea level and are also found scattered at higher levels. Embedded logs give reliable rates of the beaches in which they are found, although one well preserved log found 90 m above sea level has given an infinite ^{14}C-age.

Acknowledgements

Tor Jacobsen carried out altitude determinations. Both he and Tore Hansen provided able assistance, often under difficult field conditions. The ^{14}C datings were performed under the direction of Dr. Reidar Nydal and Siv. ing. Steinar Gulliksen, and driftwood samples were identified by Dr. Leif M. Paulsen, University of Oslo. My sincere thanks are extended to the above and to staff members of Norsk Polarinstitutt for their valuable assistance in preparing the manuscript for publication.

Introduction

Relative emergence curves (with varying degrees of accuracy) exist for several localities in Svalbard (Feyling-Hanssen and Olsson 1960; Blake 1961; Schytt et al. 1968; Boulton and Rhodes 1974), and papers by Andrews (1970) and Blake (1975) give a good review of problems relevant to the post-glacial uplift of other areas. The main purpose of this paper is to present a reliable emergence curve for the Svartknausflya area of Nordaustlandet.

Physical setting

Nordaustlandet is the second largest island in the Svalbard archipelago; approximately 80% of the island is covered by ice. Between 1936 and 1938 a

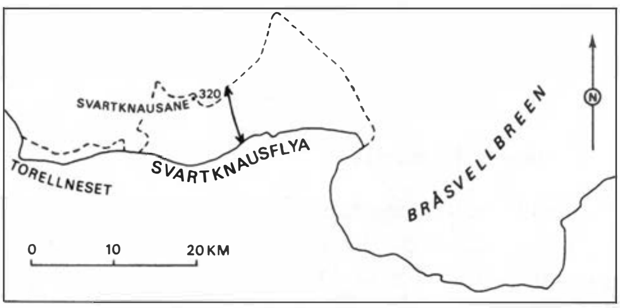
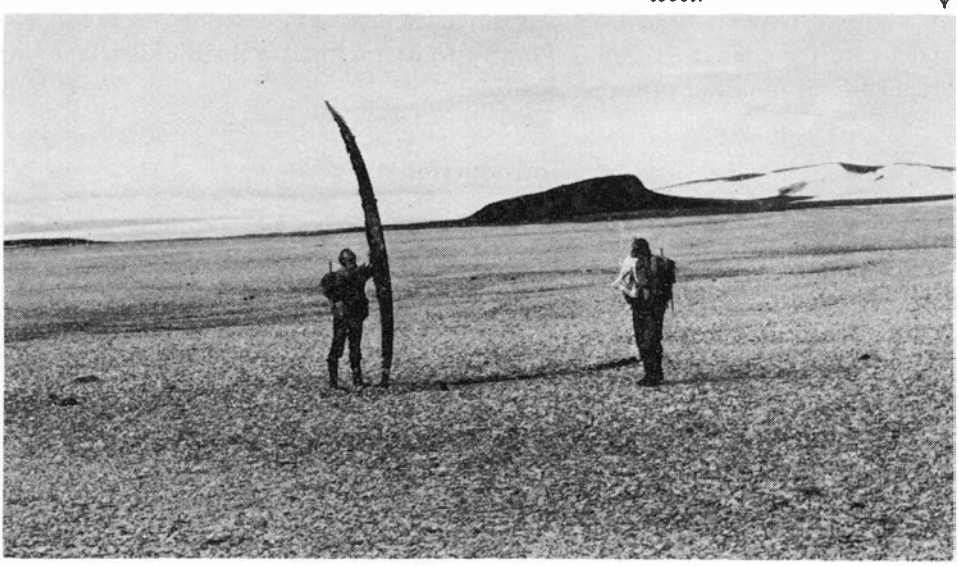


Fig. 1. *Location map. The area investigated in detail on Svartknausflya is marked by a straight line between the shore and the glacier.*

Fig. 2. *Typical raised beaches on Svartknausflya (note the sparse vegetation). The whalebone was found on the surface. In the background Svartknausane, 320 m above sea level.* ↓



large part of the Sørfonna glacier surged, and this was later named Bråsvellbreen. Svartknausflya is the name given to the ice free coastal plain west of this glacier tongue (Fig. 1). The geology of the area was described by Thompson (1953) and Holland (1961). Raised beaches are exceptionally well developed, and most of the sediment in the beaches is derived from Permocarboniferous sediments. The beaches have shingly surfaces and become increasingly sandy with depth. In late August 1976, only the upper 0.3—0.5 m of the beaches had melted and their surfaces supported an extremely sparse vegetation. Pumice, driftwood, and whalebones were therefore easily identified (Fig. 2). The climate here is unfavourable to biological destruction, and both whalebones and driftwood are much better preserved than on the western coast of Spitsbergen (Figs. 3 and 4).

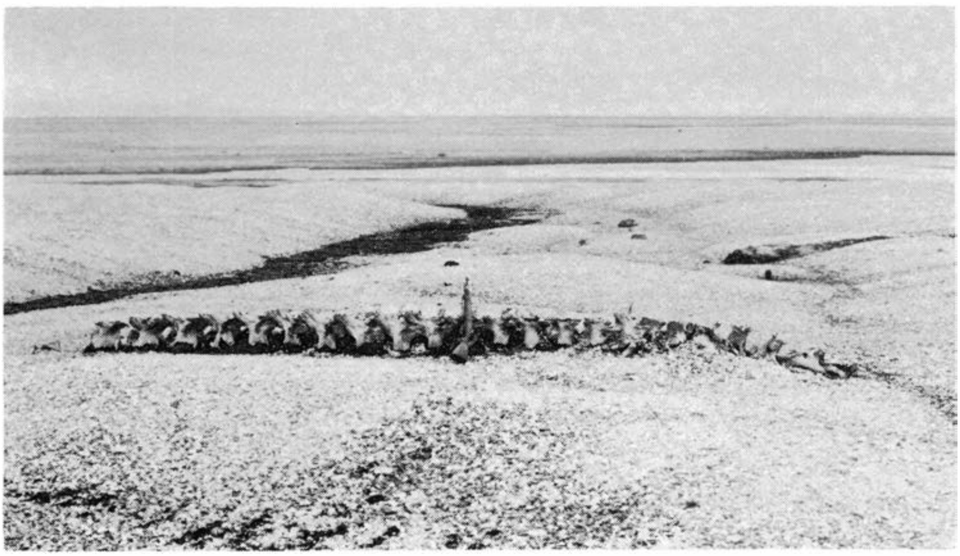


Fig. 3. *Row of whale vertebrate, about 20 m above sea level, corresponding to an age of more than 5,000 years.*

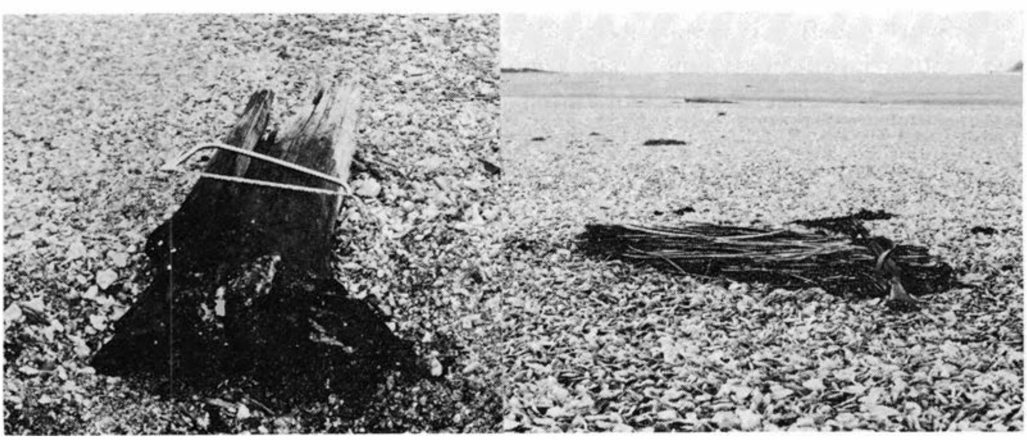


Fig. 4. *Driftwood* (Larix sp.) *found on the surface of old beaches. Left, root about 4,500 years old, and right, log about 9,000 years old.*

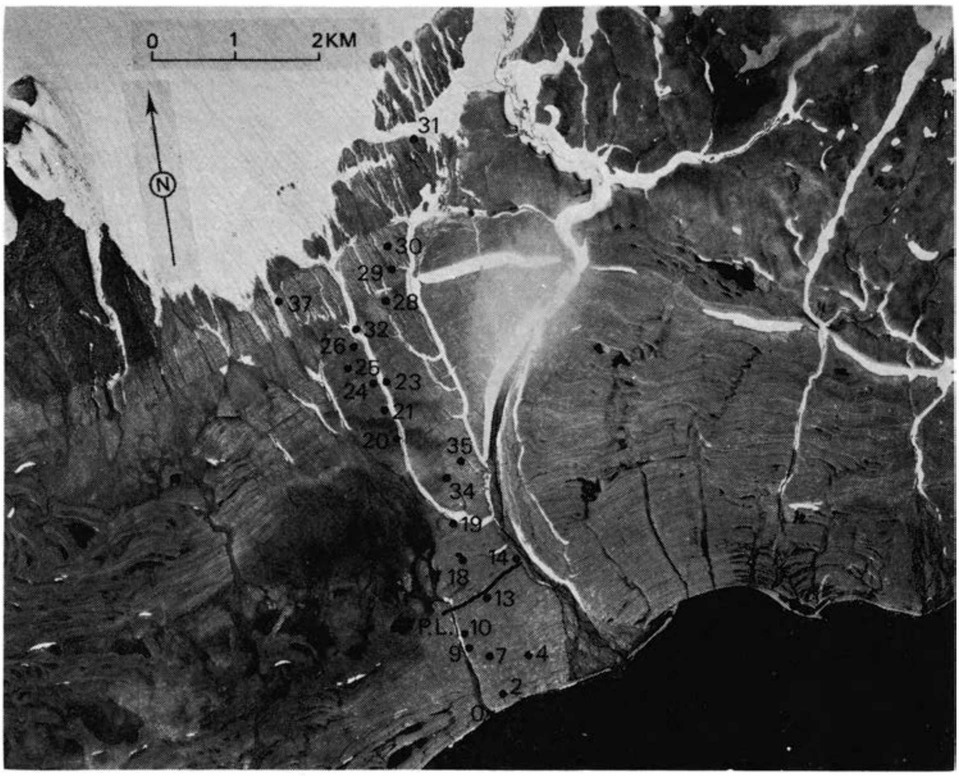


Fig. 5. *Vertical aerial photograph with field sample numbers superimposed. The line marked P.L. shows the pumice level on Svartknausflya (15.5—16 m above sea level).*
Photo: Norsk Polarinstitutt (S 69 3142 — 23 August 1969)

The almost total absence of end moraines along the glacier edge bordering Svartknausflya is remarkable. Other evidence of more extensive glaciation is either lacking or vague, apart from the raised beaches. It is difficult to determine the highest limit of raised beaches with any precision, but observations in the area near Svartknausane, suggest a height in the order of 120 m above sea level. In some places the glaciers rest directly on raised beaches.

Field work

Field work was done in July and August 1976. A traverse of about 8 km from the shore to the glacier was studied in detail in a width of over 1 km (Fig. 5). The remainder of the ice free area was surveyed on foot, but detailed studies were impossible. Therefore the tilt of the strandlines on Svartknausflya could not be established.

The altitudes of the samples collected for ^{14}C datings were determined by precise topographical survey.

Modern and raised beaches

Recent shore forms

Rock outcrops occur only on the eastern part of the present shore line (near Bråsvellbreen). The shoreline elsewhere is composed of sand and gravel, often in ridge forms. The most dominant process governing the distribution of loose material is normal wave-action, but longshore currents also transport material from east to west. Comprehensive and permanent alterations of the shoreline are caused by wave action produced by strong southerly winds combined with tidal changes. Such conditions form new beach ridges, sometimes outside of tidal lagoons. Smaller ridges built up in calmer periods may also be eroded, giving the shoreline a new appearance. Wave action reaches a maximum height of about 3 m above mean tide level. It should be noted that both driftwood and more modern kinds of flotsam and jetsam are extremely rare on the present shoreline.

Pack-ice had very little effect on the configuration of the shore in the summer of 1976, as this ice grounded outside the beach ridges.

The surface of the ice foot was not found anywhere, but remnants of winter ice were often found completely buried in sand and gravel. Melting during the summer, produced hollows on the beach surface (see Fig. 6). Such depressions (produced by ice melt in storm ridges) have been described from Spitsbergen by Jahn (1977).

The levels of both high and low tide were determined as often as possible and these were used to establish mean tide level. All altitudes in the text refer to this level.

Fig. 6. *Modern beach with depressions caused by melting of buried ice.*

Raised shores

In the area chosen for this study, raised beaches extend from the sea to the glacier in an unbroken series, the terrain rising slightly all the way. The beaches are dissected by meltwater streams and gullies, but bedrock outcrops are not found. A few granitic erratics (probably transported by icebergs) were found below the marine limit. The raised ridges are smoothed out and do not have the sharp crests shown by the recent beach ridge.

Each raised ridge represents the mean tide of a sea level about 2.5 m lower than the ridge. Pumice and driftwood have probably been thrown about 2.5 m higher than the mean tide. Skeletons of whales were probably stranded in the low tide zone (Blake 1975).

Relative emergence curve

Construction of the curve

Twentyone driftwood samples from the raised beaches of Svartknausflya have been ^{14}C dated (Table 1, Fig. 7). The ages of three whalebone samples

Table 1.
Radiocarbon dates from Svartknausflya.

Field Sample No	Laboratory dating No	Dated material	^{14}C-years before 1950±1σ	$\delta^{13}C$ °/oo	Sample weight (g)	Sample elevation (m)	Approx. log diam. (cm)
31	T-2393	Picea sp.	>46600 1)		5.8	89.9	20
37	T-2394	Whale vertebra	9630±120	-17.0	125	70 2)	
30	T-2503	Salix sp. 3)	9550±80		4.6	65.5	8
29	T-2502	Whale bone	9640±140	-18.5	95	60.7	
28B	T-2697	Larix sp.	9130±80	-26.4	4.4	52.8	Unknown
32A	T-2504	"	8800±100		5.1	51.8	25
26	T-2505	"	8780±110		5.6	48.7	30
25	T-2696	Picea sp.	8890±130	-26.7	6.3	46.3	20
24	T-2695	Larix sp.	8770±120	-26.0	6.4	43.7	35
23	T-2506	"	8200±110		5.7	41.8	40
21	T-2507	Salix sp.	8150±100		3.7	36.8	15
20	T-2508	Larix sp.	7440±110		4.6	31.4	30
35B	T-2509	"	5850±90		6.0	25.1	45
34B	T-2698	Conifer 4)	6270±90	-24.6	6.5	23.1	10
19	T-2510	Whale bone	5670±90	-17.6	68	19.2	
18	T-2699	Larix sp.	4970±60	-25.9	7.0	16.4	30
14	T-2396	"	4560±80		7.0	16.0	30
13	T-2395	Picea sp.	4650±90		5.5	14.7	30
10	T-2694	Salix sp.	4100±90	-27.1	4.7	12.2	15
9	T-2693	Larix sp.	4020±100	-24.4	5.1	10.5	30
7	T-2511	"	3520±70		5.2	7.7	15
4	T-2692	Pinus sp.	2600±50	-24.4	5.2	4.5	25
2	T-2512	Larix sp.	1570±70		3.7	2.7	50

1) Age based on the 2σ criterion.
2) Elevation determined by Paulin altimetry.
3) On the surface, 1 m long.
4) 0.5 m long piece of wood lying on the surface.

The age determination is based on a ^{14}C half-life of 5570 years. For whalebones, isotopic fractionation is corrected for by normalizing to $\delta^{13}C$ = -25‰ PDB. The wood dates are not corrected for isotopic fractionating.

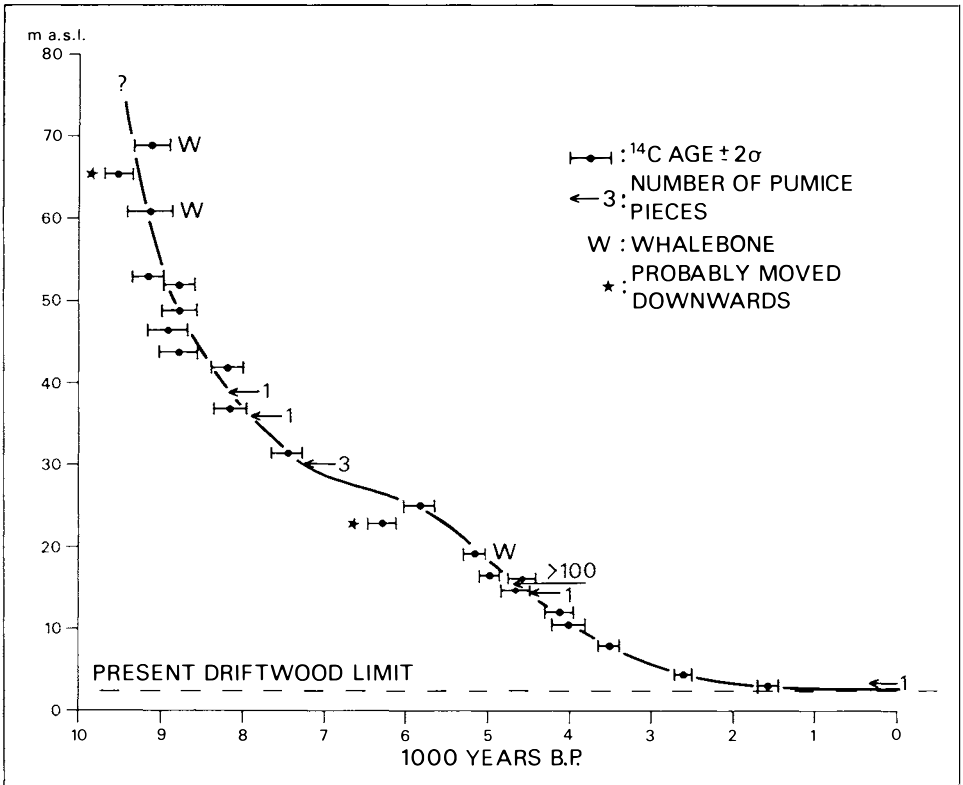


Fig. 7. *Relative emergence curve for Svartknausflya.*

are also plotted in the diagram (Fig. 7) and their ages agree with the driftwood datings. The reported ages of the whalebones have been reduced with 510 years which is thought to be their apparent age (Mangerud and Gulliksen 1975).

One small log (30/T-2503) and one piece of wood (34B/T-2698) found on the surface seem to be somewhat older than the beaches on which they are found. It appears most likely that these pieces of wood have been moved to levels 3—4 m below their contemporaneous shoreline although this assumption could not be ascertained in the field. Such movements may have taken place as a result of exceptional meltwater floods in the spring. If one neglects these two samples, the curve can be drawn as a single line with a form which fits with all ages $\pm 2\sigma$. The curve presented here should, however, be regarded as one of several alternatives although these differ only in minor details.

Compared with other emergence curves from Svalbard this curve is of special importance for two reasons. First, it is constructed on the basis of a great number of accurately leveled and dated driftwood samples. Second, the samples are collected in such a limited area that the tilt of the old beaches can be ignored in the construction and interpretation of the diagram.

Rates of emergence

The relative emergence of Svartknausflya can be dated back to about 9500 years B.P. The average rate of emergence in periods of 2000 years has been determined as follows:

9,500—7,500 years ago:	2.25 m/100 yrs.
7,500—5,500 years ago:	0.45 m/100 yrs.
5,500—3,500 years ago:	0.75 m/100 yrs.
3,500—1,500 years ago:	0.25 m/100 yrs.

The rate of emergence in the last 1,500 years is too small to be determined from the curve.

The striking reduction in the rate of emergence between 7,500 and 5,500 years B.P., followed by an increase in the next period, 5,500 to 3,500 B.P., is remarkable. As neither driftwood nor whalebones were found from the period 7,500—6,000 years B.P., a more detailed curve cannot be constructed for this time. About 7,500 years ago the isostatic rise of the land apparently decreased gradually parallel with an eustatic rise of sea level. This corresponds to the first Tapes-Littorina transgression in Scandinavia (Marthinussen 1962; Berglund 1964; and Mørner 1969). Beaches from this period are not different from other beaches at Svartknausflya, but in other areas of Nordaustlandet, the inner part of a well developed beach, about 6,500 years old, is often cut into bedrock (Blake 1961). Blake points out that this terrace indicates a balance between the isostatic uplift of the land and the eustatic rise of the sea. Because of a higher rate of uplift there has apparently been no such balance in the southern part of Nordaustlandet.

Although other published curves from Svalbard do not suggest any period of reduced emergence starting at 7,500 years B.P. (c.f. Schytt et al. 1968), Knape (1971) has such «notches» in two of his curves from eastern Svalbard. A younger transgression suggested by the data of Hyvärinen (1969), cannot be traced in the curve from Svartknausflya. Otherwise, the results from Svartknausflya essentially correspond to results presented by Blake (1961), Schytt et al. (1968), and Knape (1971). The 6,500 year level fits well with an isobase map presented by Schytt et al. (1968).

The difference in the uplift pattern at Svartknausflya and at Kong Karls Land seems to be of significance, but discussion must await more dates from Kong Karls Land.

Pumice

Pumice was first used to determine former shorelines in Svalbard by Donner and West (1957). Later, Blake (1962) used the occurrence of pumice in his study of Nordaustlandet and he also gave a review of earlier reports of pumice in Svalbard.

Donner and West found pumice at two levels, and Boulton and Rhodes (1974) dated four different pumice levels. The highest pumice level usually has a larger concentration of pumice fragments than the lower levels. This main pumice level has been dated to about 6,500 years B.P., but the datings vary somewhat (Blake 1961). No pumice level of this age was found at Svartknausflya. One level with pumice fragments was found between 15.5 and 16 m above sea level and more than one hundred pieces were counted along a stretch of one kilometre. The fragments were black or greyblack with a maximum diametre of about 10 cm.

One driftwood log embedded beside pumice fragments in the sediments 16.0 m above sea level has an age of 4,560 ±80 years B.P. (T-2396), and another log lying 14.7 m above sea level shows an age of 4,650 ±90 years B.P. (T-2395). This suggests that the pumice level at Svartknausflya can be dated to 4,500—4,600 years B.P. Other finds of single pumice fragments are also marked on Fig. 7, the uppermost lying on a level more than 8,000 years old.

The absence of pumice, whalebones, and driftwood from the period between 7,500 and 6,300 years B.P. is remarkable and may result from special ice and/or current conditions in the area at that time. The pumice level at Svartknausflya probably corresponds to the lower level of Donner and West (1957). Fig. 8 demonstrates the probability of this assertion, and the lower level along Hinlopenstretet should also be dated to about 4,500 years B.P.

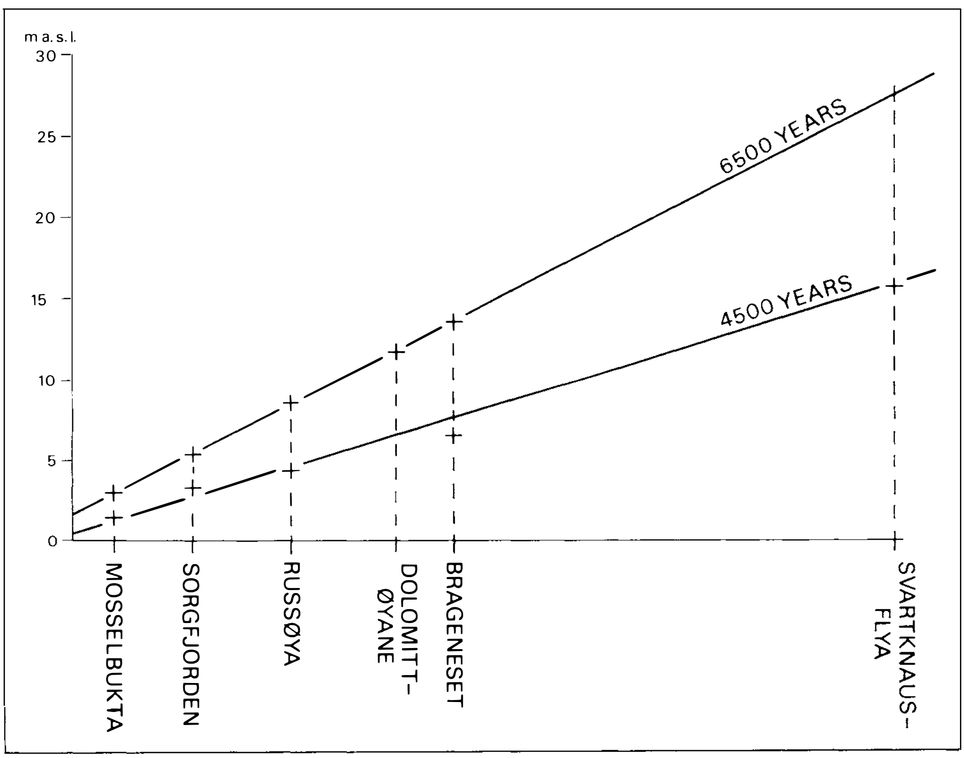


Fig. 8. *Distance diagram showing the tilt of the pumice levels along Hinlopenstretet. Projection axis along Hinlopenstretet (based on observations by Donner and West 1957 and the author).*

Whalebones

The abundance of whalebones is a striking feature on the raised beaches of Svartknausflya. Complete skeletons are found in some places, but single, large bones are most usual (Figs. 2 and 3). Many are frozen in the beach, but smaller bones can also be found on the surface. Bones were sampled at levels where their ages were anticipated to supplement data provided by driftwood. Three bones have been dated and the results either concur with, or are somewhat younger than the driftwood ages obtained.

Dating has been confined to the organic fraction (the socalled collagen fraction). Blake (1975) concludes that the collagen fraction of bones gives a more reliable age determination than the apatite fraction in an Arctic environment. Experience from Svartknausflya and other places in Svalbard (Salvigsen 1977) suggests that dating of the collagen fraction gives a correct age for well preserved whalebones, and that these give a satisfactory dating of the beaches in which they are found. In general, whalebones are well suited for an age determination of old beaches, but driftwood datings are to be preferred if available. Too young dates from whalebones may result from contamination by younger carbon (humic acids) but the bones are then in a poor condition, often covered by vegetation. Whalebones are found up to about 70 m above sea level at Svartknausflya.

Driftwood

Occurrence and identification

Driftwood was collected from as many different levels as possible (Fig. 5). Driftwood logs are frequent up to about 50 m above sea level, but one small log was also found at 65 m above sea level. Large logs embedded in the shingle and frozen in the permafrost were preferred, and only the most suitable specimens were sampled. The outermost and youngest part of the original log was used for dating purposes. In most cases it was found near to the permafrost layer.

Thirty wood samples from the Holocene beaches at Svartknausflya have been identified by Leif M. Paulsen. The results are as follows:

18 *Larix,* 4 *Picea,* 3 *Pinus,* 3 *Salix,* 1 *Populus,* and one unidentified conifer. All are genera found earlier in Svalbard, and most originated from Soviet Arctic regions. More detailed information on the identification and origin of driftwood in Arctic regions is given by Ingvarson (1903) and Eurola (1971). Datings from Svartknausflya show that driftwood logs provide reliable material for the dating of the Holocene beaches. Smaller pieces of wood should not be used as it is impossible to determine whether they occur on their contemporaneous shoreline.

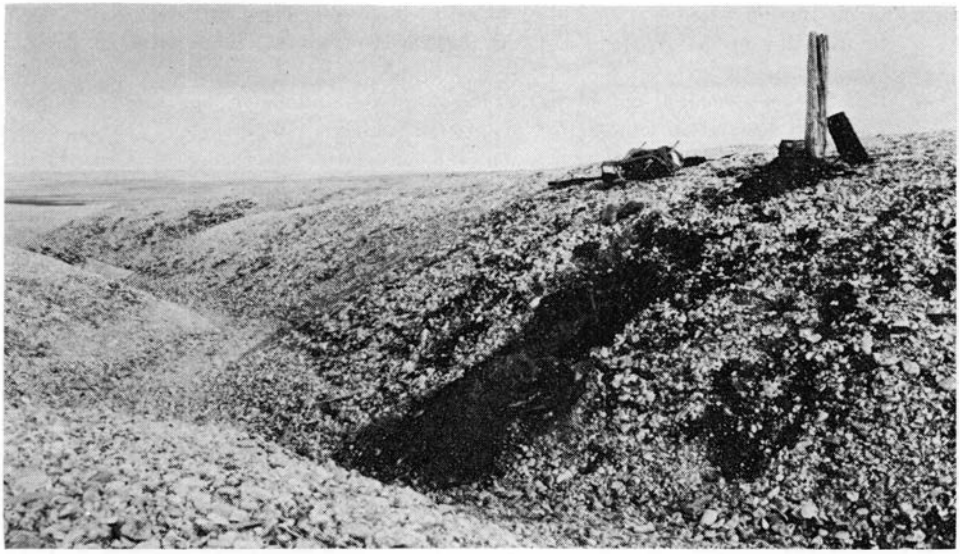


Fig. 9. *The old log (31/T-2396) in situ. The log was found in the excavated pit and was sawed into the two pieces visible in the upper right corner of the picture.*

The old log

A well preserved log *(Picea)* found at 90 m above sea level has been dated to >46,600 years B.P. (31/T-2393). The log had lain in littoral sand and gravel in the permafrost 1.5 m below the surface before its recent exposure by a temporary meltwater stream (Fig. 9). It has 120 annual rings and shows no sign of being overrun by glaciers.

Although far-reaching conclusions cannot be drawn from a single find, two alternatives should be mentioned:

1) It is possible that the log was deposited on Svartknausflya 10—11,000 years ago, after a primary preservation in permafrost in (for example) Siberia.

2) The log may have been deposited on Svartknausflya more than 50,000 years ago, and there was a subsequent lack of erosive ice action to remove it.

Neither alternative seems probable on the basis of present knowledge, but continuing studies may elucidate this problem.

References

ANDREWS, J. T., 1970: A geomorphological study of post-glacial uplift with particular reference to Arctic Canada. *Inst. of British Geographers, Spec. Publ.* No. 4. 156 pp.

BERGLUND, B. E., 1964: The post-glacial shore displacement in eastern Blekinge, southeastern Sweden. *Sveriges Geol. Undersökning. Ser. C,* Nr. 599. 47 pp.

BLAKE, W. Jr., 1961: Radiocarbon dating of raised beaches in Nordaustlandet, Spitsbergen. In: *Geology of the Arctic* (Ed. G. O. RAASCH): 133—145. University of Toronto Press.

— 1962: *Geomorphology and glacial geology in Nordaustlandet, Spitsbergen.* Unpublished Ph. dissertation, Ohio State Univ., Columbus Ohio. 470 pp.

— 1975: Radiocarbon age determination and postglacial emergence at Cape Storm, Southern Ellesmere Island, Arctic Canada. *Geogr. Annaler.* 57 (1—2): 5—71.

BOULTON, G. S. and M. RHODES, 1974: Isostatic uplift and glacial history in northern Spitsbergen. *Geol Mag.* 111 (6): 481—500.

DONNER, J. and R. G. WEST, 1957: The Quaternary Geology of Bragenese, Nordaustlandet, Spitsbergen. *Norsk Polarinst. Skrifter* Nr. 109. 29 pp.

EUROLA, S., 1971: The driftwoods of the Arctic Oceans. *Rep. Kevo Subarctic Res. Stat.* 7: 74—80.

FEYLING-HANSSEN, R. W. and I. U. OLSSON, 1960: Five radiocarbon datings of Post Glacial shorelines in central Spitsbergen. *Norsk Geogr. Tidsskr.* 17: 122—131.

HOLLAND, M. F. W., 1961: The Geology of Certain Parts of Eastern Spitsbergen. *Norsk Polarinst. Skrifter* Nr. 122. 43 pp.

HYVÄRINEN, H., 1969: Trullvatnet: a Flandrian stratigraphic site near Murchinsonfjorden, Nordaustlandet, Spitsbergen. *Geogr. Annaler* 51A: 42—45.

INGVARSON, F., 1903: Om drifveden i Norra Ishafet. *Kongl. Svenska Vetenskaps-akademiens Handlingar* 37. 84 pp.

JAHN, A., 1977: Periglacial forms produced by shore ice at Hornsund (Spitsbergen). *Spitsbergen Expeditions II, Acta Universitatis Wratislaviensis* No. 387: 19—29.

KNAPE, P., 1971: *C-14 dateringar av höjda strandlinjer, synkrona pimpstennivåer och iakttagelser av högsta kustlinje på Svalbard.* Unpubl. lic. dissert., Stockholm Univ. Naturgeogr. Inst. 142 pp.

MANGERUD, J. and S. GULLIKSEN, 1975: Apparent Radiocarbon age of recent marine shells from Norway, Spitsbergen and Arctic Canada. *Quaternary Research* 5: 263—273.

MARTHINUSSEN, M., 1962: C-14 datings referring to shore lines, transgressions and glacial substages in Northern Norway. *Norges Geol. Undersøkelse* Nr. 215: 37—67.

MÖRNER, N.-A., 1969: The Late Quaternary history of the Kattegat Sea and the Swedish west coast. *Sveriges Geol. Undersökning Ser. C,* No. 640. 487 pp.

SALVIGSEN, O., 1977: Radiocarbon datings and the extension of the Weichselian ice-sheet in Svalbard. *Norsk Polarinst. Årbok* 1976: 209—224.

SCHYTT, V., G. HOPPE, W. BLAKE Jr. and M. G. GROSSWALD, 1968: The extent of the Würm glaciation in the European Arctic. *Int. Ass. Scient. Hydr. General Assembly of Bern 1967. Publ.* 79: 207—216.

THOMPSON, H. R., 1953: Geology and Geomorphology in Southern Nordaustlandet (North-East Land), Spitsbergen. *Proc. Geologists' Assoc. 64* (4): 293—311.

Preliminary results of seismic velocity measurements in Spitsbergen in 1977

By GISLE GRØNLIE[1]

Abstract

Compressional seismic velocities are presented from the Isfjorden and the Sørkapp areas of Spitsbergen. The velocities were obtained by shallow seismic refraction measurements on exposed beds of Tertiary, Cretaceous, Jurassic, Triassic, and Hecla Hoek ages. Results from 22 individual beds show generally high seismic velocities in sandstone (4.0—5.0 km/s) and lower velocities in shale (2.9—3.8 km/s). No increase of velocity with age has been found, a feature which is consistent with the rather high degree of consolidation of the rocks in these areas. There is, however, one exception to this: a low seismic velocity (2.98 km/s) is observed in a downfaulted Tertiary sandstone in Øyrlandet. Permafrost probably affects the seismic velocity of sandstone slightly, although this effect is much less than expected because of the high consolidation and low porosites of the rocks.

Introduction

Seismic refraction investigations on exposed bedrock in Spitsbergen were carried out during the summer of 1977. The reason for this study were twofold: first, the in creasing interest in the geology of the Barents shelf, and the steady supply of geophysical data, especially of new seismic velocity sections from this area (Eldholm and Talwani 1977; Sundvor 1974; Sundvor and Eldholm 1976) necessitates knowledge of the seismic velocity sections on land in order to extrapolate the land geology out onto the shelf area.

The other reason for the study was to compare seismic refraction results of selected stratigraphical units with diagenetic studies of the same units. The results, both in situ refraction work and measurements of seismic velocities on rock specimens in the laboratory will be used in conjunction with ongoing diagenetical studies. The latter, which include geochemical, palynological, and micropaleontological investigations are being conducted by

[1] Institutt for geologi, P.O.Box 1047, Blindern, Oslo 3, Norway.

the University of Oslo «Svalbard project group» in cooperation with Norsk Polarinstitutt and results will be published in the near future (Worsley, Manum, Dypvik, Bjærke, pers. comm.; Elverhøi and Bjørlykke, this volume).

In this preliminary report we present ten velocity measurements from different exposed beds of Tertiary to Triassic age from the Isfjorden area and give twelve measurements of beds ranging from the Tertiary to Hecla Hoek in the Sørkapp area.

Field Work

We used a TRIO 12 channel seismic refraction unit from ABEM in the field.

The geophones and the shot were placed on the exposed bed, and the recording then immediately yielded the velocity of each particular bed. In some cases, where shales and claystones overlie sandstones (low velocities overlying higher velocities), we could also observe the velocity of the refracted wave in the underlying sandstone layer, thus obtaining two velocities by one shot. Because of the alternation of shales and sandstones with corresponding low and high velocities, we found it difficult to do ordinary refraction work as underlying shales would cause false velocities and depth estimates to underlying horizons.

Permafrost

A complicating factor in arctic regions is the presence of permafrost in the rocks. Several authors (Scott and Hunter 1977; King 1977) have examined the problem recently. Permafrost is found to a depth of approximately 300 m in central Spitsbergen (diamond drilling, Orheim, pers. comm.). Since all our profiles give surface or close to surface velocities, all our results may be affected by permafrost. King (op.cit.) examined acoustic velocities of frozen sandstones and shales in the laboratory at temperatures ranging from $\div 18^\circ$C to $+4^\circ$C. He found that the compressional velocities in shale were not affected by permafrost within this temperature range. Sandstones, however, showed a rather sharp increase in velocity between 0°C and $\div 5^\circ$C. These sandstones had porosities of approximately 15% and a density of approximately 2.25 g/cm^3.

The mean annual temperature for central Spitsbergen (Longyearbyen and the Isfjorden area) is $\div 4.8^\circ$C (Steffensen 1969). Thus, applying the results of King (1977), this implies that our seismic refraction velocities in sandstones show a value which is of the order of 1 km/s too high. Mean temperatures for the Sørkapp area are not known, but the temperature conditions here are probably quite similar to those at Bjørnøya further south. Bjørnøya has a mean annual temperature of $\div 1.5^\circ$C, which would imply that the sandstone velocities are about 0.6 km/s too high.

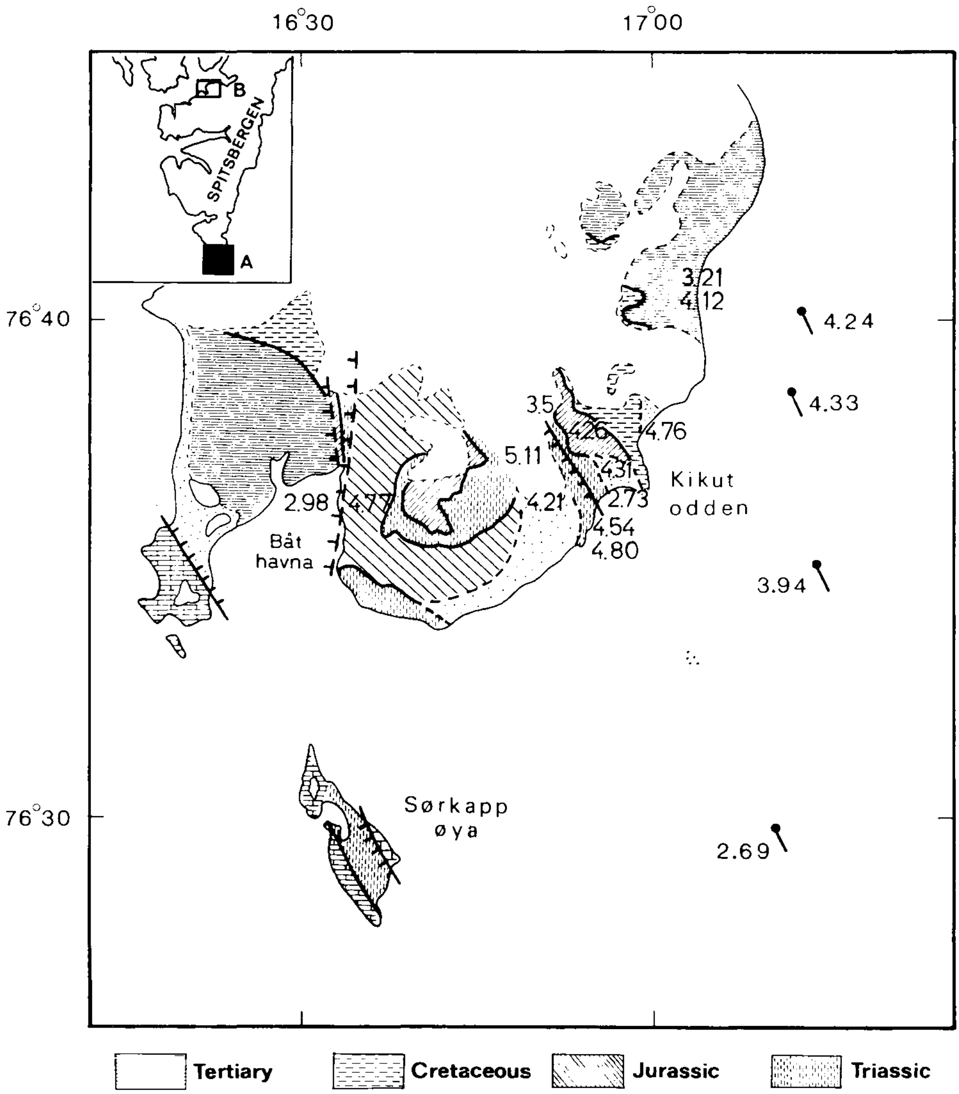


Fig. 1. *Seismic refraction velocities from the Sørkapp area, Spitsbergen. Geology from Flood et al. (1971). Sonobuoy measurements from Winsnes et al. (1977).*

We have made laboratory measurements on several rock samples from the beds which were studied in situ. The seismic velocity in shale observed by the methods are in good agreement. For sandstone however, seismic velocities show a rather large variation, the velocities measured in the laboratory being generally *higher* than the in situ measurements.

We therefore have reason to believe that the seismic velocities of sandstone measured in the field by us are much less affected by permafrost than those observed by King (1977). The reason for this is probably that the

Table 1

Sørkapp — seismic velocities

Epoch	Localities	Formation	Rock type	Velocity km/s	Mean Velocity ± st.dev.	Laboratory Velocity km/s
Tertiary	Øyrlandet/Båthavna		Sandstone	3.21, 2.98, 2.91, 2.80	2.98 ± 0.17	4.08, 4.16, 4.61, 4.04
«	Dumskolten/Skoltsletta		Shale	3.23, 3.19	3.21 ± 0.03	
			Sandstone	4.34, 4.34, 3.79, 3.96, 4.08	4.12 ± 0.26	
Cretaceous	Kikutodden	Rurikfjellet Fm	Sandstone	4.33, 4.28	4.31 ± 0.04	
«	«	«	Sandstone	2.77, 2.68	2.73 ± 0.06	4.08, 4.30
«	«	«	Sandstone	4.44, 4.66, 4.53	4.54 ± 0.11	
«	«	«	Sandstone	4.78, 4.84, 4.87, 4.72	4.80 ± 0.06	4.28, 3.61
«	«	Helvetiafjellet Fm/ Festningen sst Fm	Sandstone	4.70, 4.81	4.76 ± 0.08	4.30
Jurassic	Keilhaufjellet	Agardhfjellet Fm	Shale	3.52, 3.38, 3.60	3.50 ± 0.11	
«	«	Wilhelmøya Fm	Sandstone	4.35, 4.20, 4.24	4.26 ± 0.08	5.40
Triassic	Keilhaufjellet	Botneheia Fm	Sandstone	5.05, 5.07, 5.21	5.11 ± 0.09	6.09
«	Grunnvågsletta	«	Sandstone	4.23, 4.18	4.21 ± 0.04	
Hecla Hoek	Båthavna			4.77	4.77	

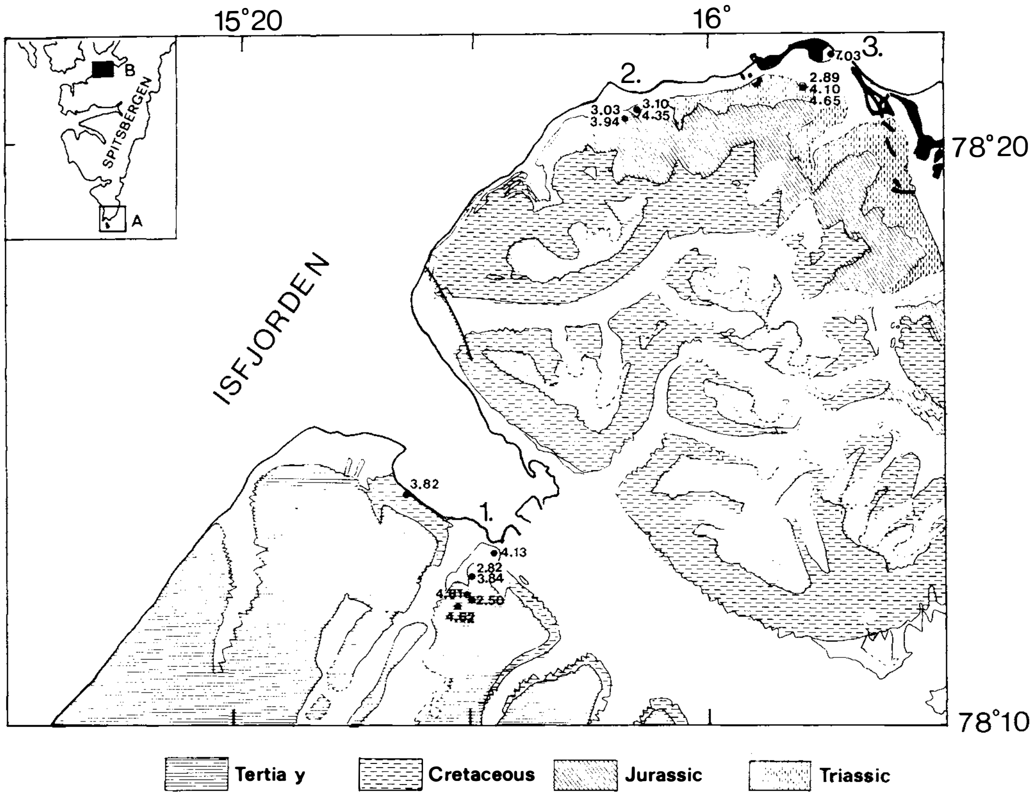


Fig. 2. *Seismic refraction velocities from the Isfjorden area, Spitsbergen. 1. Longyearbyen, 2. Deltaneset, 3. Diabasodden. Geology based on Major and Nagy (1972).*

sandstones in Isfjorden and at Sørkapp show a higher degree of consolidation with lower porosities (3—5%, Elverhøi and Bjørlykke, this volume) and greater densities.

Permafrost may therefore affect our measurements only slightly. However, permafrost may also affect some of the near bottom seismic velocities from the Barents shelf (at least north of Bjørnøya) because of the influence of past glaciations.

Results

A. The Sørkapp area

The seismic refraction velocities from a total of 12 stratigraphic units are presented in Table 1. Fig. 1 shows the location of the profiles and the geology of the area. The sandstone velocities are between 4.2 and 5.1 km/s, and the shale velocities between 3.2 and 3.5 km/s.

A comparison with sonobuoy refraction measurements (Winsnes et al. 1977) close to land shows that both the sandstones (velocities higher than 4.0 km/s)

Table 2

Isfjorden area — seismic velocities

Epoch	Localities	Formation	Rock type	Velocity km/s	Mean velocity ± st.dev. km/s	Laboratory Velocity km/s
Tertiary	Longyearbyen	Sarkofagen	Sandstone	4.57, 4.62, 4.78, 4.46, 4.48, 4.80, 4.65	4.62 ± 0.13	3.81
«	«	Basilika	Weathered zone, frozen	2.89, 2.75	2.82 ± 0.10	
«	«	«	Shale	3.79, 3.88	3.84 ± 0.06	4.41
«	«	«	Loose shale weathered	2.50	2.50	
«	«	« /Firkanten	Conglomerate	4.87, 4.91, 4.66	4.81 ± 0.13	2.55
Cretaceous	« /Dynamitthus	Carolinefjellet	Claystone/sandstone	3.96, 4.29	4.13 ± 0.23	5.03
«	« /Kullkaia	«	Shale/Claystone	3.82	3.82	3.60
Jurassic	Deltaneset	Janusfjellet	Weathered zone	1.57, 1.77	1.67 ± 0.14	
			Shale	2.97, 3.09	3.03 ± 0.08	
			Claystone	3.86, 4.03	3.94 ± 0.12	
Triassic	«	De Geerdalen	Shale	3.12, 3.09	3.10 ± 0.02	
			Claystone/sandstone	4.30, 4.40	4.35 ± 0.07	
«	Diabasodden	«	Shale	2.89, 2.89	2.89	
			Sandstone	4.07, 4.13	4.10 ± 0.04	
			Sandstone	4.51, 4.78	4.65 ± 0.19	
«	«		Dolerite	7.03	7.03	5.30

and other geological units probably continued southward underneath the sea bed. The low velocity of 2.69 km/s may be correlated with the seismic velocity of shale on land.

The sandstone velocity from Øyrlandet/Båthavna (2.98) km/s) is much lower than velocities further east. This can probably be explained by a lower consolidation of Tertiary sandstones in the downfaulted Øyrlandet area (Manum, pers. comm.).

The velocities measured in the laboratory are mostly about 1 km/s higher than the corresonding in situ velocities. This may be explained if one assumes that these samples represent small and compact parts of individual rock units, while in situ velocities represent a mean value over a distance of 100-200 m where macro cracks, minor fault zones and areas of weathering are present.

B. The Isfjorden area

The velocities are presented in Table 2. A total of ten profiles were measured. Fig. 2 shows the location and the geology of the area (Major and Nagy 1972).

The sandstone velocities are all between 4.0 and 5.0 km/s and the shale velocities vary between 2.9 and 3.8 km/s. Seismic velocites in sandstone measured in the laboratory are both higher and lower than the velocities measured in situ, while the velocity observed in shale velocities show similar values for the two methods.

Conclusion

This preliminary study presents results from two areas which are situated in the western part of Svalbard, where consolidation is known to be rather high. This is reflected in our velocity results. The seismic velocities are rather high and show no increase with age in either the Isfjorden or the Sørkapp areas.

Permafrost has probably little effect on the velocities in both areas, because of low porosities.

Acknowledgement

We appreciate the logistic support from Norsk Polarinstitutt and Statoil during the field work in Spitsbergen.

S. Dahlgren, A. Elverhøi, P. Jørgensen, O. Møller, H. Rueslåtten, and A. Solheim are thanked for willing and cheerful assistance in the field.

We are thankful for financial support given by Oljedirektoratet and Norsk Polarinstitutt. Y. Kristoffersen provided the sonobuoy results in Fig. 1.

References

ELDHOLM, O., and M. TALWANI, 1977: Sediment distribution and structural framework of the Barents sea. *Geol. Soc. Amer. Bull.* 88: 1015—1029.

ELVERHØI, A., and K. BJØRLYKKE, 1978: Sandstone diagenesis — Mesozoic rocks from southern Spitsbergen. *Norsk Polarinstitutt Årbok* 1977: 145—157.

FLOOD, B., J. NAGY, and T. WINSNES, 1971: Geological map. Svalbard 1:500 000. Sheet IG, Spitsbergen. *Norsk Polarinstitutt Skrifter* Nr. 154 A.

KING, M. S., 1977: Acoustic velocities and electrical properties of frozen sandstones and shales. *Can. J. Earth Sci.* 14: 100—1013.

MAJOR, H. and J. NAGY, 1972: Geology of the Adventdalen map area. *Norsk Polarinstitutt Skrifter* Nr. 138.

SCOTT, W. J. and J. A. HUNTER, 1977: Application of geophysical techniques in permafrost regions. *Can. J. Earth Sci.* 14: 117—127.

STEFFENSEN, K., 1969: The climate and its recent variations at the Norwegian arctic stations. *Meteorologiske annaler 5*: 215—269.

SUNDVOR, E., 1974: Seismic refraction and refraction measurements in the southern Barents sea. *Mar. Geol* 16: 255—273.

SUNDVOR, E. and O. ELDHOLM, 1976: Marine geophysical survey on the continental margin from Bear Island to Hornsund, Spitsbergen. *Sci. Rep. no. 3, Seismological Observatory, University of Bergen.* 29 pp.

WINSNES, T., Y. KRISTOFFERSEN and A. ELVERHØI, 1977: *Feltrapport 1977.* Norsk Polarinstitutt.

The seismicity of Spitsbergen: preliminary results

By H. BUNGUM[1] and Y. KRISTOFFERSEN

Abstract

A pilot study has been initiated for monitoring of the local seismic activity in Spitsbergen with installation of three microearthquake instruments in Barentsburg, Longyearbyen and Pyramiden in December 1977. 5—10 local earthquakes per day are recorded at each station, and the majority of events occur on the western side of Storfjorden around 77.7°N, 18.5°E. A seismic station to be installed in Svea will greatly improve the location capabilities of the seismic network.

Introduction

The global seismicity is a manifestation of relative motions between crustal plates that are essentially aseismic in their interior (Barazangi and Dorman 1967). The plate boundaries have characteristic morphological expressions depending on the sense of motion, e.g. divergent, transverse, and convergent motion is associated with spreading ridges, fracture zones, and subduction zones, respectively (Wilson 1963, 1965). A plate boundary between Svalbard and Greenland came into existence as a consequence of the opening of the Norwegian Sea about 60 million years ago (Talwani and Eldholm 1977; Birkenmajer 1972) and is presently associated with (see Fig. 1) the Mohns Ridge in the Norwegian-Greenland Sea, the Knipovich Ridge and Spitsbergen Fracture Zone west of Svalbard, and the Nansen Ridge in the Arctic Ocean (Johnson and Heezen 1967; Heezen and Ewing 1961). The majority of earthquakes are associated with these bathymetric features (Sykes 1965; Husebye et al. 1975). However, in northeastern Greenland and on Spitsbergen a number of seismic events occur which are away from the plate boundary

[1] NTNF/NORSAR, Kjeller, Norway.

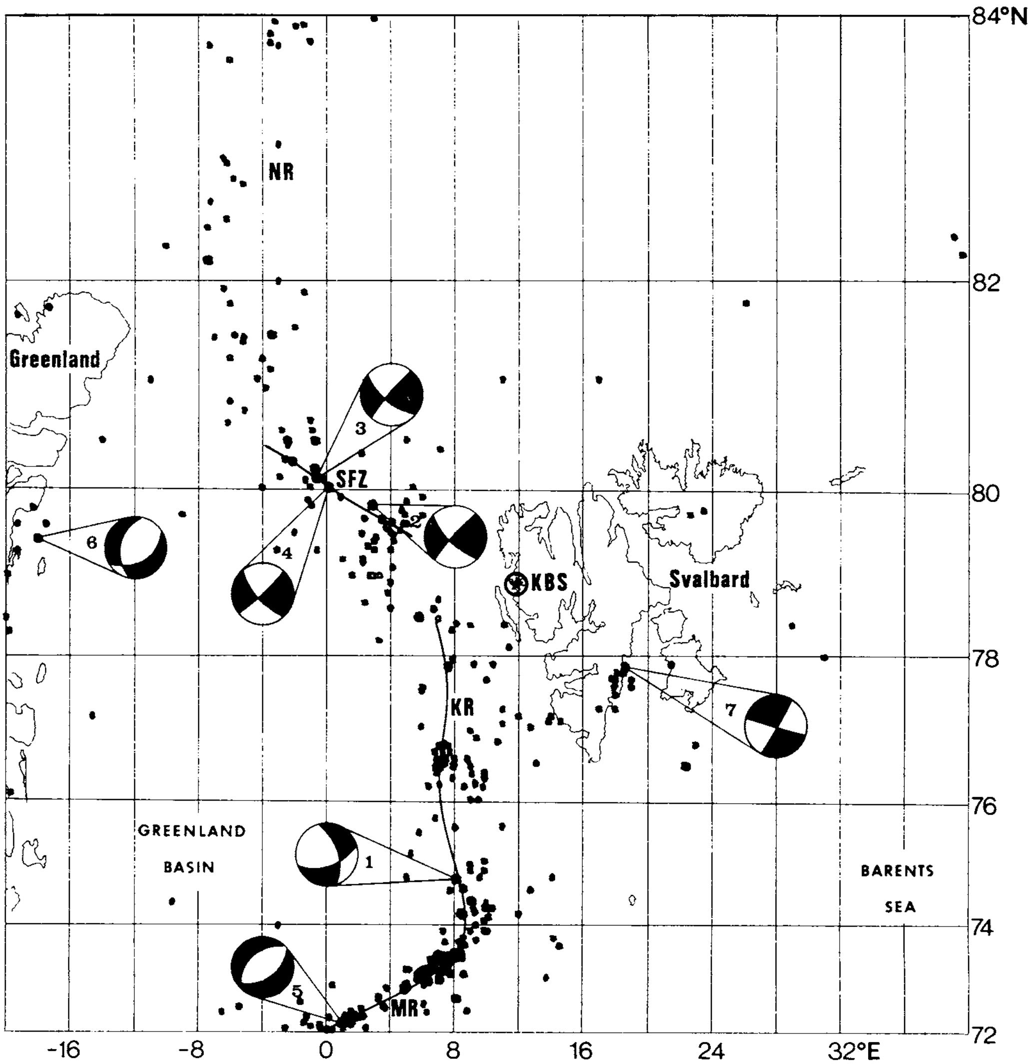


Fig. 1. *Earthquake occurrence in the Greenland/Svalbard region, as taken from SYKES (1965) for 1957—60, from PDE (Preliminary Determination of Epicenters, U. S. Geological Suvey) for 1961—63, and from ISC (International Seismological Centre, Edinburgh) and PDE for 1964—75, with priority for ISC. Only epicentral solutions based on at least 6 stations are used, and the larger symbols indicate a magnitude of at least 5.0. For the focal mechanism solutions, black and white areas indicate areas of compression and dilatation, respectively. The locations of Mohns Ridge (MR), Knipovich Ridge (KR), Spitsbergen Fracture Zone (SFZ) and Nansen Ridge (NR) are also given, as well as the location of station KBS. (From BUNGUN et al. 1978a.)*

and indicate that the interior of the plates are in a state of stress which is released as seismic energy (Bungum et al. 1978a). The proximity of the intraplate seismicity in western Spitsbergen to present and future industrial activity suggests that studies of the contemporary tectonic situation may be very valuable. Norsk Polarinstitutt has therefore in cooperation with NTNF/NORSAR (Norwegian Seismic Array), the Russian mining trust Arktikugol, and Store Norske Spitsbergen Kulkompani initiated a project for mapping of the seismic activity in Spitsbergen. Initially a pilot project with 6 months recording by a network of 3-4 microearthquake stations will be undertaken to provide the basis for recommendations for future work. This paper outlines the pilot project and presents preliminary results from the first 2 1/2 months of operation of the seismograph network from 8 December 1977, to 25 February 1978.

The seismicity of Svalbard

Up until now only very limited data have been available for the study of the seismic activity in and around Svalbard (see Fig. 1). Most of the studies so far have been based on teleseismic data (Hodgson et al. 1965; Sykes 1965; Huseby et al. 1975; Bungum et al. 1978a), giving about 1—2 intraplate earthquakes from Svalbard every year. One of the largest of these (Ms=5.9) occurred in the Storfjorden area on 18 January 1976, an event which had a faulting mechanism atypical for intraplate earthquakes (Bungum 1977; see also Fig. 1).

The first seismic station in Svalbard was in operation at Isfjord Radio (ISF) between 1958 and 1963. Even though no epicenter locations could be obtained, this station did reveal a significant local seismic activity (Sellevoll 1960). Since 1967, a WWSSN station has been in operation at Ny-Ålesund (KBS), from where three-component data were used by Austegard (1976) to show that the seismically active area in Storfjorden (Husebye et al. 1975) also was associated with a rather intense microearthquake activity. However, the locations were not precise enough for a closer delineation of this zone.

During the summer of 1976 and 1977, scientists from St. Louis University, Missouri, USA, operated a number of portable microearthquake stations at various sites in Svalbard. During a field season of 9 weeks in 1977, this team (Mitchell et al. 1977) recorded about 500 local events and located about 50, resulting in the delineation of a relatively small but seismically very active area on the west side of Storfjorden at about 77.7°N.

The seismic network

Three portable Sprengnether microearthquake instruments (Fig. 2) with analog recording were installed in the mining towns Barentsburg (BBG), Pyramiden (PRD), and Longyearbyen (LYR) in December 1977 (Table 1). A digital instrument will be installed in Svea in the spring of 1978. With such siting of the instruments (in settlements) priority was given to ease of operation at the expense of event location accuracy, as the dominant source

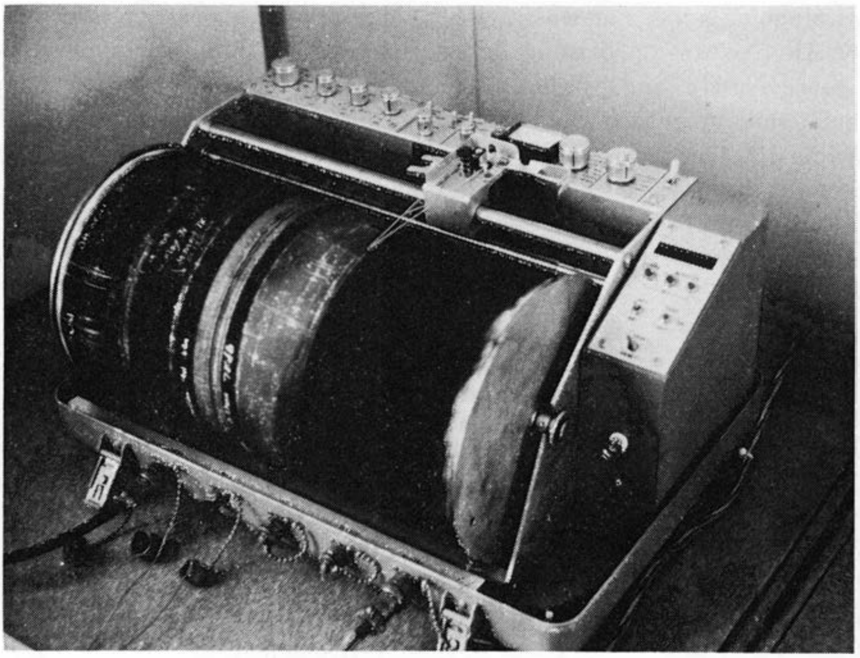


Fig. 2. *Sprengnether microearthquake system MEQ-800.*

Table 1

Site	Code	Lat	Long	Site description
Barentsburg	BBG	78 073	14.24	In abandoned mine shaft below sothwestern side of Bykollen — c. 60 m below the surface
Pyramiden	PRD	78 659	16.303	In hut 2 km east of Settlement. Seismometer is placed on concrete block embedded in moraine.
Longyearbyen	LYR	78 189	15.189	In abandoned mine shaft — Gruve 4. 980 m from mine entrance and c. 200 m below the surface.
Ny-Ålesund	KBS	78 918	11.924	In hut near the research station building. KBS is part of the global WWSSN network and operated by the University of Bergen.

area in Storfjorden is outside the array. Records are changed daily or every other day and mailed to Norsk Polarinstitutt weekly. Microfilm copies of all seismograms will be deposited with the Russian mining trust Arktikugol.

The natural frequency of the seismometers is 1 Hz and the system response peaks at between 5 and 25 Hz, depending upon the type of lowpass filter which has been used. The magnification has most of the time been around 25 000 at 1 Hz and around 100 000 at 5 Hz, with twice as large values (step in 6 dB) during periods with less ambient noise. At the time of installation the temperature at the instrument site in the mines in Barentsburg and Longyearbyen was minus 2—3° Celsius, decreasing to minus 6° C mid-winter. This is outside the temperature range of the seismic recorder (0°—55° C), and incipient unstable operation after the first few weeks of recording necessitated construction of insulated and heated enclosures for the recorders.

The time correction is established either via a portable crystal-controlled clock set by the radio time signal (BBG and LYR), or directly by the radio time signal (PRD). However, due to the temperature instabilities and other factors (such as insufficient training of operators), reliable time corrections have not been available for all stations simultaneously for the data presented in this report.

Data analysis

The data analysis is carried out by NTNF/NORSAR (Bungum et al. 1978b). As reliable time corrections were generally not available, the events have been located using a method based on the assumption of a constant ratio between P (compressional wave) and S (shear wave) velocity in the crust, which makes the S—P times linearly related to the epicentral distance. An event location procedure was then developed where this distance is expressed by a probability density (Bungum et al. 1978b). With three or more stations available the earthquake is located by the point of maximum likelihood and the axis and orientation of the associated confidence ellipses are also computed. With only two stations available the epicenter location is ambiguous.

Preliminary results

An example of a seismogram recorded on smoked paper is shown in Fig. 3. During the first 2½ months of operation a total of 687 earthquakes was detected at one or more of the stations with the majority (75%) being local events (Fig. 4). The number of detected events per day is 9.6, 6.5, 6.3, and 3.4 for LYR, PRD, BBG, and KBS, respectively, after corrections for station downtime have been applied. The peaks in seismic activity (see Fig. 4) on 12 December and 17—18 January are due to a small earthquake swarm from Storfjorden, whereas the peak on 20—21 January are caused by a swarm from the mid-ocean ridge west of Svalbard.

To compute epicenter distances, the S-P travel time relation of Mitchell et al. (1978) was used with the statistical approach mentioned above. The error in reading of P and S arrival times is estimated to be 0.15 and 0.30 sec, respectively. For events from the Storfjorden area located by the three micro-

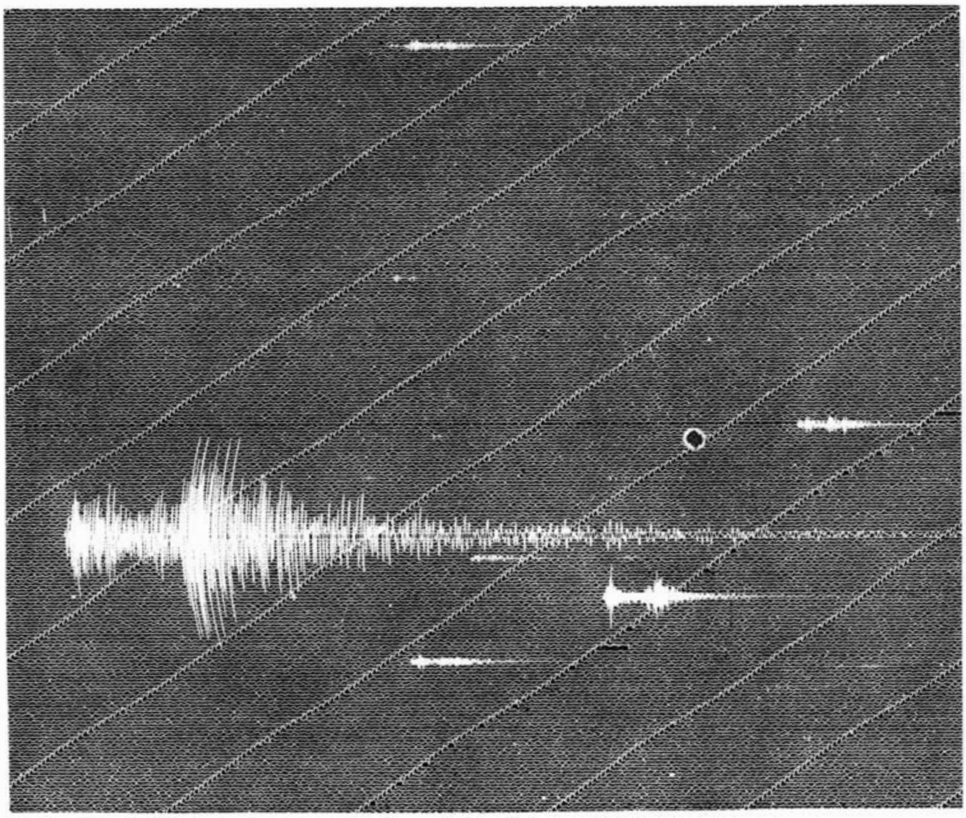


Fig. 3. Seismogram from Longyearbyen (LYR), recorded on smoked paper using a Sprengnether MEQ-800 seismograph. The largest event is from the mid-ocean ridge west of Svalbard, while the rest of the events are intraplate earthquakes from Spitsbergen. The time marks are one minute apart.

earthquake stations (Fig. 5) the axis of the 95% confidence ellipse is 30 and 10 km, respectively, with the main axis pointing in a NE-SW direction.

A total of 115 events could be located using 3 stations (Fig. 5), and the dominant source area is along the east cost of Spitsbergen in Storfjorden. The precision of the locations is so far not good enough for a closer delineation of this highly active earthquake zone since the computed uncertainty ellipse is comparable to the size of the cluster of events. There are three main reasons for the large uncertainty in epicenter location: 1) the major source area is outside the seismic array, which moreover has a less ideal geometrical configuration (being almost linear), 2) lack of reliable time corrections, and 3) lack of precisely known travel times (crustal model). The station to be installed in Svea will significantly improve the array geometry, and initial difficulties with regard to marking of absolute time on the records routinely are expected to be overcome.

Magnitudes have been computed for 231 events from signal amplitude data

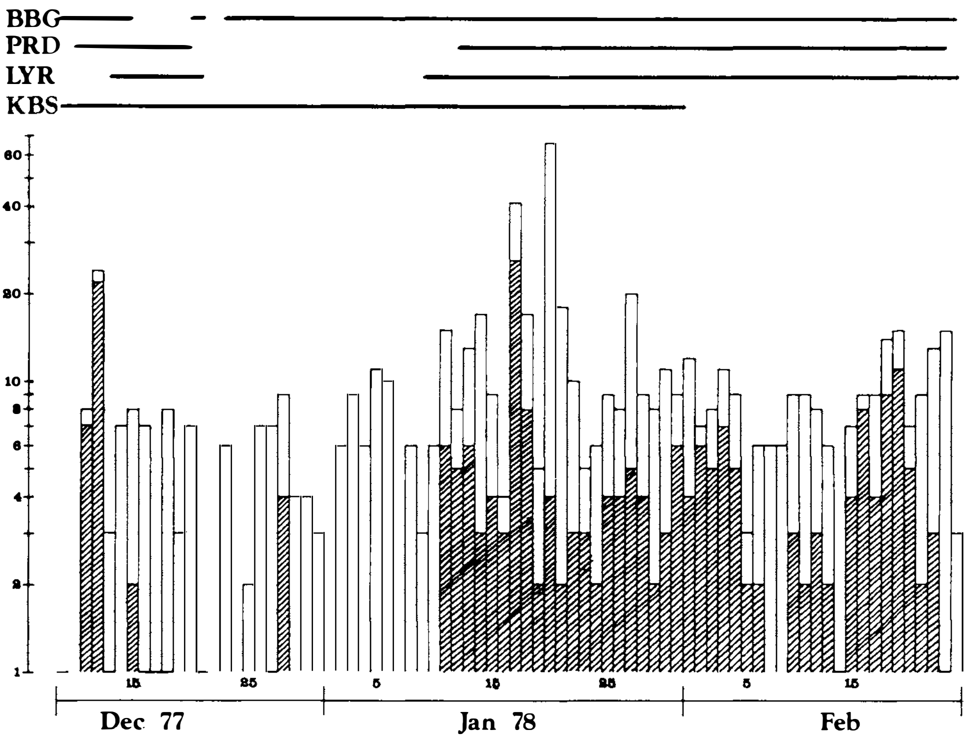


Fig. 4. *Number of detected and located (hatched areas) earthquakes for each day between 8 December 1977, and 24 February 1978. For each station the periods of operation are also indicated (top of figure), for KBS this refers to availability of data.*

following Lee and Lahr (1975). The release for seismic energy generally follows a distribution where the logarithm of the number of events (N) is linearly related to the magnitude (M): $\log N = a - b \times M$. The coefficient b is usually around 1.0, and the results so far from Spitsbergen do not indicate that these events will deviate significantly from this distribution. The magnitudes are all in the range 0—3, with a peak around 1. When more precise locations become available in the future, local attenuation parameters can be developed and the absolute magnitude level can be calibrated when a teleseismically recorded event occurs in Storfjorden.

Discussion and conclusion

Operation of a seismic network in an arctic sub-zero temperature environment is vulnerable in many ways. Reliable instrumentation and consciencious operators are fundamental to a successful data acquisition phase. The results from the first $2^1/_2$ months of operation of a microearthquake network in the mines in Spitsbergen during winter have definitely proved that this is a viable mode of operation. Future improvements will be in array geometry

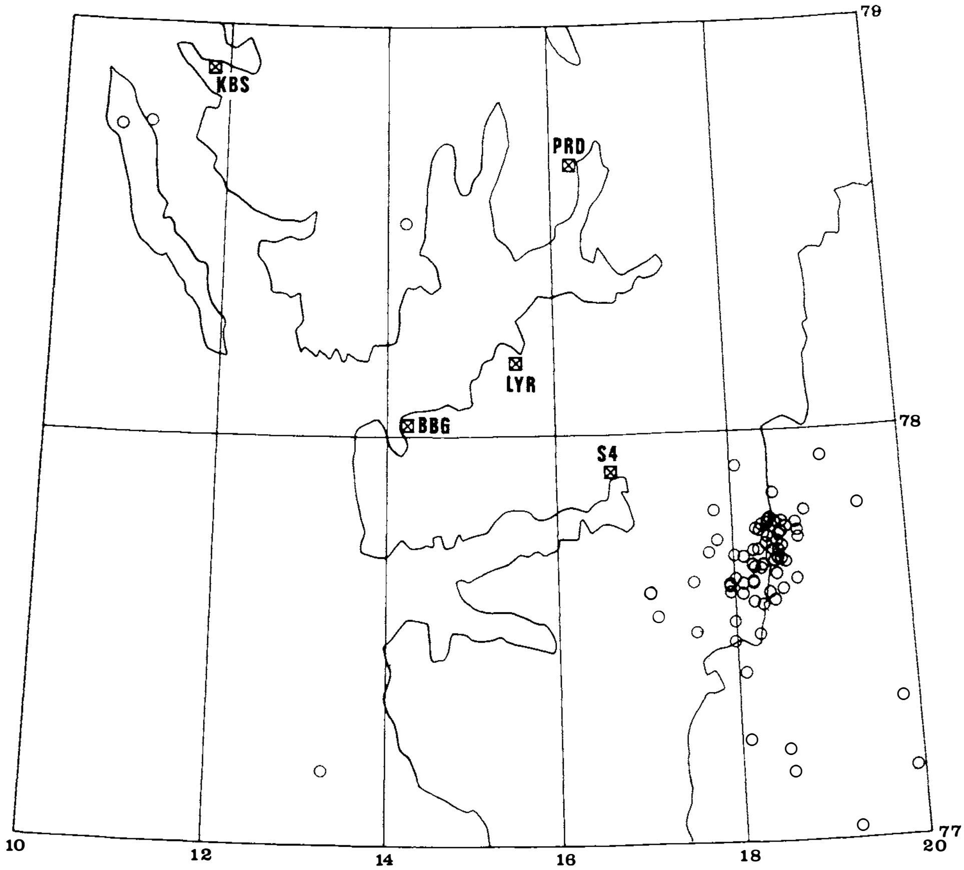


Fig. 5. *Epicenter map of earthquakes located on the basis of the three stations BBG, PRD and LYR. The future station in Sveagruva is also indicated (S4).*

with installation of a station in Svea in May 1978, and in obtaining reliable time corrections routinely. This in turn will provide the basis for more reliable epicenter locations and attenuation parameters which are most relevant to seismic risk. Timed explosions are planned in Storfjorden to calibrate the seismic network.

The eastern coast of Spitsbergen in Storfjorden appears to be an area of high intraplate seismic activity. An average of 7.5 local events per day with a probable origin in Storfjorden have been recorded by the instrument in Longyearbyen. The work of Mitchell et al. (1978) showed most of the epicenters to be confined within a narrow E-W trending zone at 77.7°N about 30 km long and suggested that the fault plane of the 18 January 1976 earthquake (Ms=5.9) in this area (Bungum 1977) was along this seismic zone.

The state of stress in the crust and delineation of active zones of weakness where faulting may take place are valuable information for present and future industrial development in Spitsbergen. When 6—8 months of data have been acquired, the results of this pilot study will be evaluated and recommendations made for future work. Spitsbergen is cut by major fault zones dating back to the Paleozoic (Orvin 1969; Flood et al. 1971; Harland et al. 1974) with no associated teleseismically recorded activity (Husebye et al. 1975). A future semi-permanent network of microearthquake stations in Spitsbergen would be capable of detecting zones that are tectonically active but have a low level of seismic activity.

Acknowledgements

We gratefully acknowledge the excellent cooperation of Mr. V.D. Trifonenkov, Director of the mining trust Arktikugol, Barentsburg, and Mr. A. Orheim of Store Norske Spitsbergen Kulkompani, Longyearbyen, in this project. The operators Mr. V. Posidajev in Barentsburg, Mr. A. Nerutchev in Pyramiden, and Mr. G. Mørck-Olsen of Longyearbyen are complimented for their efforts and interest in maintaining the seismic stations. Mr. A.K. Nilsen (NTNF/NORSAR) installed the instruments and provided able technical assistance.

A successful execution of this project is to a large extent a result of good liaison provided by Sysselmannen på Svalbard, and helicopter assistance on several occasions is gratefully acknowledged. We thank Dr. A. Sørnes (University of Bergen) for providing seismograms from KBS.

References

AUSTEGARD, A., 1976: Earthquakes in the Svalbard area. *Norsk Polarinstitutt Årbok* 1974: 83—99.

BIRKENMAJER, K., 1972: Tertiary history of Spitsbergen and continental drift, *Acta Geol. Polonica 22:* 193—218.

BUNGUM, H., 1977: Two focal-mechanism solutions for earthquakes from Iceland and Svalbard. *Tectonophysics 41:* T15—T18.

BUNGUM, H., E. S. HUSEBYE, and K. A. BERTEUSSEN, 1978a: *Inter- and intraplate seismicity and lithospheric structure in the Svalbard area.* Unpublished manuscript, NTNF/NORSAR, Kjeller, Norway.

BUNGUM, H., H. GJØYSTDAL, B. HOKLAND and Y. KRISTOFFERSEN, 1978b: Seismicity of the Svalbard region: A preliminary report on the microearthquake activity. *NORSAR Tech. Report* 2/78.

FLOOD, B., J. NAGY, and T. S. WINSNES, 1971: Geological Map Svalbard 1:500 000. Sheet 1G, Spitsbergen, southern Part. *Norsk Polarinstitutt Skrifter* Nr. 154a.

HARLAND, W. B., J. L. CUTBILL, P. F. FRIEND, D. J. GOBBETT, D. W. HOLLIDAY, P. I. MATON, J. R. PARKER and R. H. WALLIS, 1974: The Billefjorden fault zone, Spitsbergen, the long history of a major tectonic lineament. *Norsk Polarinstitutt Skrifter* Nr. 161. 72 pp.

HEEZEN, B. C., and M. EWING, 1961: The mid-oceanic ridge and its extension through the Arctic basin. In: *Geology of the Arctic* (G. O. RAASCH, Ed): 622—642. Univ. of Toronto Press.

HODGSON, J. H., M. BÅTH, H. JENSEN, A. KVALE, N. A. LINDEN, L. M. MURPHY, N. V. SHEBALIN, E. TRYGGVASON and E. VESANEN, 1965: Seismicity of the Arctic. *Ann. Int. Geophys. Year* 30: 33—65.

HUSEBYE, E. S., H. GJØYSTDAL, H. BUNGUM and O. ELDHOLM, 1975: The seismicity of the Norwegian and Greenland Seas and adjancent continental shelf areas. *Tectonophysics* 26: 55—70.

JOHNSON, G. L., and B. C. HEEZEN, 1967: Morphology and evolution of the Norwegian-Greenland Sea. *Deep-Sea Research* 114: 755—771.

LEE, W. K. L., and J. C. LAHR, 1975: HYPO71 (revised): A computer program for determining hypocenter, magnitude and first motion of local earthquakes. *U. S. Geol. Survey Open-File report* 75—311.

MITCHELL, B. J., J. E. ZOLLWEG, J. J. KOHSMANN, C. C. CHENG and E. J. HAUG, 1978: *Intra-plate earthquakes in the Svalbard Archipelago.* Unpublished manuscript, Dept. Earth and Atm. Sci., St. Louis Univ., USA.

ORVIN, A. K., 1969: Outline of the geological history of Spitsbergen. *Skrifter om Svalbard og Ishavet* Nr. 78. 57 pp.

SELLEVOLL, M., 1960: Seismisiteten i Svalbardområdet. *Seism. Obs., Univ. of Bergen Norway.*

SYKES, L. R., 1965: The seismicity of the Arctic. *Bull. Seism. Soc. Am.* 55: 501—518.

TALWANI, M. and O. ELDHOLM, 1977: Evolution of the Norwegian-Greenland Sea. *Geol. Soc. Am. Bull.* 88: 969—999.

WILSON, J. T., 1963: Hypothesis of the Earth's Behaviour. *Nature* 198: 925—929.

— 1965: A new class of faults and their bearing on continental drift. *Nature* 207: 343—347.

Numbers, distribution and catching of Barnacle Geese (*Branta leucopsis*) on the Nordenskiöldkysten, Svalbard, in 1977

By MYRFYN OWEN, R. H. DRENT, M. A. OGILVIE[1] and T. M. VAN SPANJE[2]

Abstract

This paper describes an expedition to catch and mark Barnacle Geese on the Nordenskiöldkysten, SW Svalbard, in 1977.

A total of 1333 geese were counted during the moult, of which 1241 individuals (93%) were caught. Geese were classified as adults, yearlings, and goslings and the age structure of the coastal population determined. The presence of a brood patch indicated that at least 158 females had attempted to breed. There was an excess of adult males and it is suggested that females are more vulnerable to predation when nesting.

Non-breeding birds moulted earlier than parental geese and were found in different areas. Moulting geese on the Nordenskiöldkysten were considerably heavier than those caught in Hornsund in 1973, and it is suggested that the area is more favourable for moulting. After moult the geese left coastal pools and gathered mainly on fertile plains below sea bird cliffs. Geese caught were marked with individually coded rings readable at a distance of 200 m. By the end of March 1978, 974 of the 1131 geese newly ringed in 1977 (86%) were resighted in Scotland.

The Nordenskiöldkysten has increased in importance as a breeding and moulting area for Barnacle Geese and some desirable conservation measures are discussed.

Acknowledgements

All members of the 1977 expedition participated in the catching operations and contributed to the collection of data presented in this paper.

We would like to thank the Sysselmannen på Svalbard, Mr L. Eldring, and his assistant, Mr. Jensen, for their unstinting help with the transport of personnel and supplies from Longyearbyen to the Nordenskiöldkysten and for

[1] The Wildfowl Trust, Slimbridge, Gloucester GL2 7BT, UK.

[2] Zoologisch Laboratorium, Rijksuniversiteit te Groningen, Postbus 14, Haren (Gr.), The Netherlands.

their encouragement and cooperation throughout. We are grateful to Mr. M. Norderhaug and his colleagues from the Ministry of the Environment, Oslo, for making arrangements on our behalf and for permission for catching in Svalbard. We are grateful to Mr. K. Bratlien of the Norsk Polarinstitutt for assistance with some of the arrangements and the loan of the hut at Kapp Martin. Dr. Holgerson of Stavanger Museum provided rings free of charge. Our thanks go to Jebsen Ltd. and Store Norske Spitsbergen Kulkompani, who provided free transport for the resident team and their equipment to Longyearbyen.

The expedition received financial support from the North Atlantic Treaty Organisation, The Royal Society, and The World Wildlife Fund. Many individuals and organisations made donations or provided food or equipment free or at a reduced rate, and to these we are most grateful. The Wildfowl Trust and the University of Groningen provided much of the equipment, secretarial, and other services.

We are grateful to the many individuals from the Wildfowl Trust and the University of Groningen who contributed to the success of the project through their advice and practical help.

Introduction

The Barnacle Goose population wintering in the Solway Firth in northern Britain breeds exclusively in Svalbard, with the largest concentration on the south-west coast of Spitsbergen and on Prins Karls Forland (Norderhaug 1970; Owen and Norderhaug 1977). The Wildfowl Trust has been making intensive studies into the ecology and population dynamics of these geese since 1970. As an extension of this programme a joint British-Dutch-Norwegian project was organised in 1976—77 to carry out ecological studies on the species at all stages of its life cycle. This paper reports part of the work of an expedition to Svalbard in the summer of 1977. The main aim of this section of the project was to establish the numbers and distribution of the geese and to catch and mark as many individuals as possible.

The Study Area and Itinerary

The expedition was based on the Nordenskiöldkysten, which extends from Kapp Linné on the south side of the mouth of Isfjorden to Kapp Martin on the north side of Bellsund (Fig. 1). The coastal plain (below the 25 m contour) is 40 km long and varies between 1.5 and 11 km in width. There are many shallow freshwater or brackish pools just behind the high raised beach and these were free of ice by mid-June 1977. Larger inland lakes and waters at higher elevation were frozen until mid-July. The coastal ponds are surrounded by areas of mossy tundra but in some places, particularly between

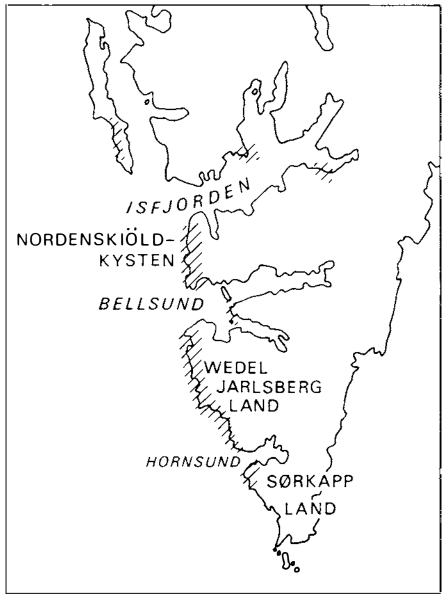


Fig. 1. *A map of South western Svalbard showing the main breeding areas of Barnacle Geese. Adapted from Owen and Norderhaug 1977.*

Gravsjöen and Båtodden, there are more extensive grassy bogs. At the extreme south-eastern part of the coastal plain are the seabird cliffs of Ingeborgfjellet. Beneath the cliffs is a narrow strip of fertile tundra where grass growth is lush in July and August.

Most Barnacle Geese in Svalbard nest on rocky coastal islands. On the Nordenskiöldkysten such islands are found close to shore at the southeast end (Reiniusøyane), the south west (Diabaspynten, now separated from the mainland to become Diabasøya), and a group of islets near Gravsjøen (St. Hansholmane). There are also small skerries and rocks off Kapp Bjørset and north of Båtodden.

The expedition consisted of a «resident» team which was to study the nesting and feeding ecology of the geese, supplemented by a «visiting» team for the catching operations. The resident team consisted of J. Prop and T.M.S. from the University of Groningen and R. Wells and P. Reynolds from the Wildfowl Trust. They were transported by M/S «Nordsyssel» to the study area on 6 June but because of unfavourable weather conditions they and their supplies were dropped at Skierpodden at the south-eastern end of the coast. From here they established two camps, one based on the Norsk Polarinstitutt hut at Kapp Martin and the other, a tent camp, 18 km north at Gravsjøen.

The visiting team consisted of M.O. and M.A.O. from the Wildfowl Trust, R. H. Drent and B. Ebbinge from the University of Groningen, and R. H. Bridson of The Nature Conservancy Council, Scotland. They flew to Longyearbyen and arrived at Kapp Martin on 16 July on M/S «Nordsyssel». The visiting team left the coast on 8 August and the resident team, having been joined on 31 July by M. van Eerden of Groningen University, on 8 September, both by means of M/S «Nordsyssel».

Methods

Numbers and distribution of geese were determined on periodical surveys of the coast between Kapp Martin and Kapp Linné, and during the catching activities. The nature of the coastal plain, with groups of lakes and associated bog, separated by stretches of less hospitable terrain, meant that it was possible to carry out a survey without causing movement of geese from one group of lakes to another, thus minimising counting error. The separation of the goose flocks also enabled each one to be caught without disturbing any others.

The catching of the flightless geese was carried out by a team of 5 to 7 people who made excursions on foot from either of the camps. In every case prior knowledge of the presence of geese had been obtained during a recent survey or by a special reconnaissance. The technique used was to surround the lake on which the birds were swimming, or beside which they were feeding, and to hold them on the water while a catching pen was erected. At some sites the birds were driven overland from large water bodies to nearby smaller ones where catching was easier.

The majority of the lakes were close to the shore, separated from the sea by a storm beach from 20 to 100 metres wide. When disturbed the geese usually swam out into the middle of the nearest lake, but if disturbance persisted they would quickly run across the storm beach and swim out on to the sea, which they clearly regarded as their ultimate sanctuary. For all catches on lakes close to the sea, therefore, the catching team walked along the shore, at the tide's edge, screened from the geese inland by the height of the storm beach. With two or three people positioned immediately between the lake and the sea, and other members of the team on either side, at a prearranged signal, all would walk up on the beach and appear simultaneously to the geese. The people on each flank would then move quickly inland down each side of the lake until they were beyond the flock which, once surrounded, would swim quietly to and fro.

The catching pen consisted of black polythene netting, 1.3 metres high and of 19 mm square mesh. This was attached at 1 metre intervals to 1.9 metre aluminium angle posts. The pen was shaped like a letter C and adjusted in size according to the number of birds waiting to be caught, trying to make enough space for all the birds to fit in but without extra room which might be used by birds trying to take off. Spare netting attached to one end of the pen acted as a gate to be closed behind the flock once it had entered. The pen was placed in a convenient corner of the lake, usually on the seaward side to which the geese would normally try to excape. On each side were stretched 50 metre «wings» of further netting, 1 metre high and of 29 mm square mesh, fixed at 2 to 3 metre intervals to 1.5 m aluminium angle posts. Wherever possible the ends of the wings were brought down to the water's edge, and formed an angle of approximately 120°. The base of the pen, and any weak-looking places along the wings, were reinforced with large stones or lengths of driftwood, which is abundant along the beaches.

Once the pen was up, which usually took between 30 and 45 minutes, the geese were driven off the lake with the aid of a small (one-man) inflatable dinghy, and by people wading and walking along the lake edge. On two occasions the dinghy was not used, the geese being driven solely by people wading. Although the geese had been waiting, sometimes within 100 metres, while the pen was erected in full view, and although some of the catches included birds which had already been caught at least once, there was rarely any problem in persuading the flock to stay together and to enter the confines of the pen.

Each full-grown goose was sexed by cloacal examination, weighed, and had its wing, skull and tarsus measured. It was possible to distinguish yearlings (hatched in 1976) from adults by the presence of a few brown feathers on the wing-coverts. For all adult females the presence or absence of a brood patch was recorded (Hanson 1959). Goslings were sexed and weighed only. Most full-grown geese were marked with metal (monel or aluminium) rings and Darvic (plastic) rings with an individual three-digit code. The tarsi of goslings were too short for the three-digit rings and they were fitted with two-digit plastic rings.

Results

Goose distribution and numbers

In early June 95% of the mainland was snow-covered and groups of non-breeding geese were scattered on snow-free areas throughout the coast. Since the flocks were mobile, an overall count was impossible at this time. Coastal islands were largely clear of snow and nesting geese were laying during the first week of June. As the moult period approached in early July, the flocks concentrated around the coastal pools and by mid-July most of the geese were flightless and catching operations began. The number of geese present in each of the catching areas during the moulting period and the numbers caught are shown in Fig. 2. The coastal plain north of Båtodden is narrow with few ponds and is close to the radio station. No Barnacle Geese moulted in this area.

Most geese in the area were in fact caught; a very few were still able to fly and avoided capture, 13 escaped during the drives and some parents with goslings were in locations where catching was not feasible. These were, however, located and it is probable that the total of 1,333 geese present during the moulting period is accurate to within 1—2%. All but 100 geese moulted on pools within 100—200 m of the sea. These others were largely families and unsuccessful breeders which had flown or walked to inland lakes when these became free of ice in early July.

Catching and marking

Since the locations of the moulting flocks had been established by the resident team, the round-ups were very successful, only once did the team fail

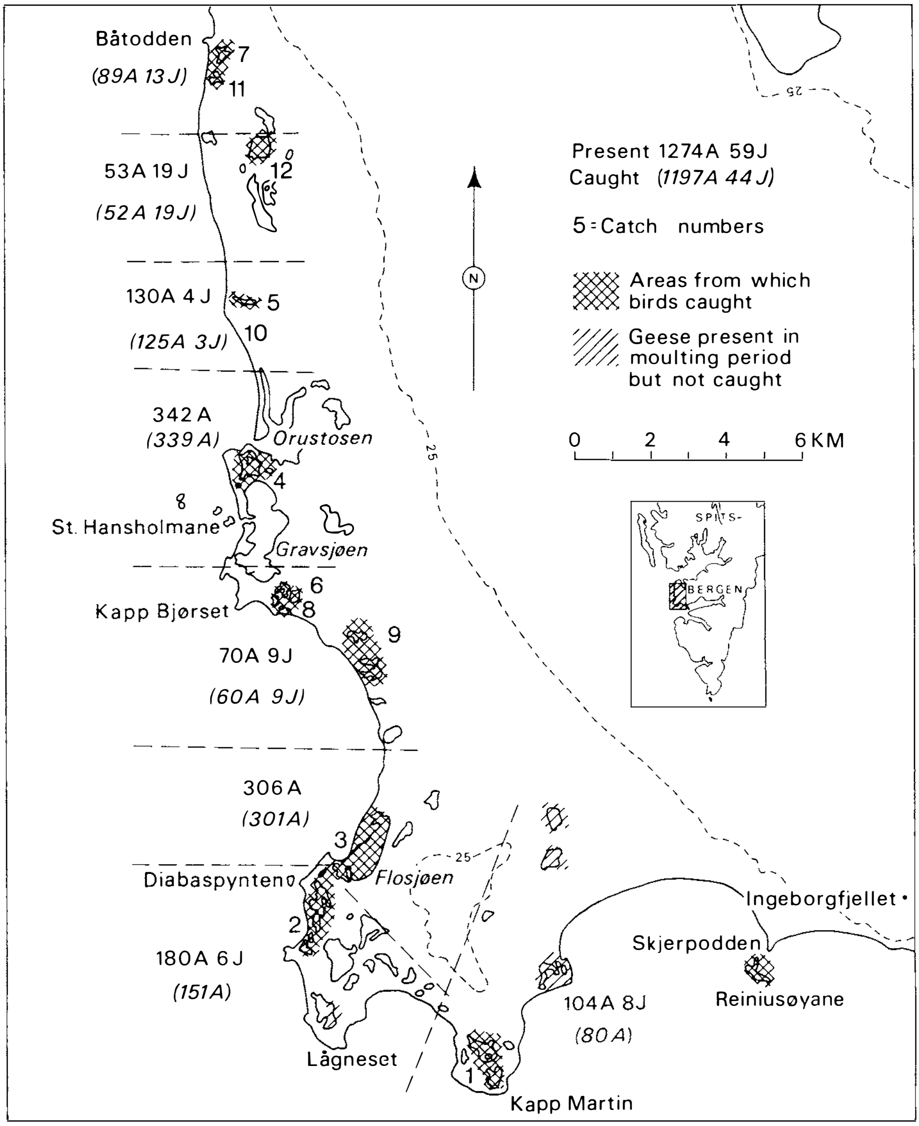


Fig. 2. *Numbers, distribution and catches of Barnacle Geese on the Nordenskiöldkysten, July-August 1977. In the pre-moult period geese were on breeding islands or scattered in snow-free areas. After the moult the main concentration was at Ingeborgfjellet at the south eastern end.*

to catch a flock and this was achieved at a second attempt. The large flocks, mainly immature and nonbreeding birds, were caught first. The families, often accompanied by unsuccessful breeders, were left until the last few days of the catching team's stay. Details of timing of catches and numbers caught and recaptured are given in Table 1. Catch numbers are also included on Fig. 2.

Table 1.
Details of numbers of geese captured and recaptured on the Nordenskiöldkysten 1977.

No.	*Place*	*Date*	*Time*	*Caught* (Juv)	*Repeat*	*Recaptures* *Darvic*	*Recaptures* *Other*	*New Darvic* (Juv)
1	Kapp Martin	18.7	1350	80	0	4	0	76
2	Vinkelvatnet	19.7	1610	151	0	8	3	143
3	Flosjøen[1]	19.7	2330	303	2	17	3	223[2]
4	Oddvatnet[3]	23.7	0300	340 (1 unr)[4]	0	10	2	328
5	Nr. Orustelva	24.7	1500	124	0	1	0	123
6	Femvatnet	26.7	0045	50	15	1	0	15
7	Båtodden	27.7	2215	236 (2 unr)[4]	167	3	1	65
8	Femvatnet	3.8	1400	38	23	1	0	15
9	S. of Femvatnet	3.8	1530	19 (9)	0	0	0	19 (9)
10	Nr. Orustelva	4.8	1215	4 (3)	0	0	0	4 (3)
11	Båtodden	4.8	1555	78(13) (3 unr)[4]	45	0	0	33(13)
12	Stabbvatna	6.8	1910	96(32)	25(13)	5	0	66(19)

Totals				*Recaptures*			
Caught		1519		Dunøyane	1962		2
Repeats		277		Caerlaverock	1963		1
Recaptures		59		Caerlaverock	1966		2
New Ringed		1180		Hornsund	1973	A 3	
New Darvic		1131				J 2	5
Metal only		57		Caerlaverock	1975	A 11	
Individuals caught	A	1197)				J 12	23
		)	1241				
	J	44)		Caerlaverock	1976	A 10	
						J 14	24
				WAGBI[5]			2
							—
							59

1. These birds were moulting on Flosjöen but were driven onto Vinkelvatnet where they were rounded up.
2. Some birds were marked with metal rings only because the supply of darvic rings was exhausted at one camp.
3. This catch also included a Bar-headed Goose *(Anser indicus)* which was moulting with the Barnacle Geese. This was also marked with a darvic ring.
4. A few birds were left without rings because they had previous leg injuries.
5. Wildfowlers Association of Great Britain and Ireland. These were released in northern Britain and joined the flock on the Solway Firth before migrating to Svalbard.

Most of the repeat captures were due to birds moving from a catching area and subsequently being caught at another site. Only two birds marked in Hornsund in 1962—64 were recaptured, compared with 17 in a sample of 350 adults caught in Hornsund in 1973 (Jackson et al. 1974). Observations on the wintering grounds indicate that up to 100 of about 1000 geese ringed in the early 1960s are still surviving. Similarly only five geese ringed in Hornsund in 1973 were recaptured on Nordenskiöldkysten (1.5% of those thought to be alive in 1976), whereas 47 Solway-ringed geese were captured (19% of those alive in 1976). This indicates that Barnacle Geese remain faithful to a breeding area for many years. Significantly more birds ringed as juveniles than as adults were recaptured (28% of those alive in 1976 compared with 13% — Chi-square 8.4 $P < 0.01$). This may indicate a movement of immatures into this area to moult.

Since female geese pluck feathers from the breast after two or three eggs have been laid, it is likely that all females which had completed clutches were identified by the presence of a brood patch. The age and sex distribution of birds caught and an estimate for those not caught is shown in Table 2. The estimate was based on the following assumptions:

a) Since breeders and attempted breeders moult later than yearlings and non-breeders (see below) all geese flying but not with broods on 20 July or later, were assumed to be adults that had attempted to breed and had a sex ratio of 1:1.

Table 2.
Classification by age and sex of Barnacle Geese on the Nordenskiöldkysten 1977.

Catch No.	*AM*	*BF*	*NBF*	*Total F*	*%B*	*YM*	*YF*	*Total Y*	*%Y*	*JM*	*JF*	*FG*	*Juvs*	*Total*
1	28	7	18	25	28	14	13	27	34	0	0	80	0	80
2	73	16	51	67	24	4	7	11	7	0	0	151	0	151
3	84	2	67	69	3	68	79	147	49	0	0	301	0	301
4	97	15	81	96	16	61	85	146	43	0	0	339	0	339
5	54	23	19	42	55	16	12	28	23	0	0	124	0	124
6	9	5	3	8	63	11	8	19	54	0	0	35	0	35
7	23	11	14	25	44	11	9	20	29	0	0	69	0	69
8	7	7	0	7	100	2	0	2	13	0	0	15	0	15
9	5	5	0	5	100	0	0	0	0	2	7	10	9	19
10	0	1	0	1	100	0	0	0	0	2	1	1	3	4
11	10	10	0	10	100	0	0	0	0	3	10	20	13	33
12	26	23	2	25	92	1	0	1	2	12	7	52	19	71
Total	416	125	255	380	33	188	213	401	33.5	19	25	1197	44	1241
Uncaught	36	33	2	35	94	3	3	6	8	—	—	77	15	92
Total	452	158	257	415	38	191	216	407	31.7	—	—	1274	59	1333

M = Male, F = Female, A = Adult, Y = Yearling, FG = Full Grown, J = Juvenile, B = Breeding, NB = Non Breeding

b) Moulting birds which were missed or escaped from catches were assumed to have the same age, sex and attempted breeding ratio as those caught in the same area.

The adult population was composed of 52.1% males and 47.9% females whereas there were only 46.5% males in the yearling and juvenile sample. Fifty of 350 full-grown geese (yearlings not distinguished) caught in 1973 are confidently assumed to have died subsequently (data from resightings of these geese in Scotland, annual resighting rate c. 90%). Of these 32 (64%) were females although the sex ratio was 176M : 174F when caught. There is a significant differential mortality (Chi-square 4.6, $P < 0.05$). This suggests that females have a higher mortality in adult life and this is probably associated with the effects of laying and incubation. Female Snow Geese *(Anser c. caerulescens)* (Harvey 1971, Ankney 1976) and Atlantic Brant *(Branta bernicla hrota)* (Barry 1962) are known to die on the nest in extreme environmental conditions. No evidence of such deaths was found during this study, although all breeding islands (which were not accessible to foxes in 1977) were visited. Foxes are occasionally able to visit nesting islands over ice-bridges (Norderhaug 1970) or land uncovered by extremely low tides (Dittami et al. 1977), and Barnacle Goose wings were found near fox dens in 1977. Female geese are more likely than males to die during the laying period in captivity (J. Kear pers.comm.) and deaths associated with egg-formation and laying may also occur in the wild.

Since Barnacle Geese do not pair until at least their second spring (Owen et al. 1977) the maximum number of possible pairs on the Nordenskiöldkysten was 415. Of these 158 (38%) were recognised as «breeders» (Table 2). A count of used nests on all available islands indicated 185 attempted breeders (45% of pairs). It is not certain which gives the better estimate — the true figure is likely to be between the two. Only 59 goslings were reared on the Nordenskiöldkysten in 1977, with an average brood size of 2.0. This indicated that 30 pairs had nested successfully — 16—19% of those that had attempted to breed and 7.2% of all possible pairs.

The proportion of yearlings was greater than the 27% juveniles recorded in winter flocks in 1976—77 (Owen and Norderhaug 1977). This may indicate that the Nordenskiöldkysten produced more goslings than the remainder of the range in 1976, or, perhaps more likely, that immigration of immatures into the area is continuing.

Weights and timing of the moult

Weight changes and progress of the moult are treated in detail elsewhere (Owen and Ogilvie in press), but a few general remarks are relevant here.

Immatures and non-breeding geese moulted before nesting birds, a pattern observed in other goose species (e.g. Cooch 1961, Ryder 1967), and these groups moulted in different areas. For example 72% of all yearlings were in the two largest flocks, representing 50% of full-grown geese. In the area north of Gravsjøen, 75% of yearlings were at Oddvatnet whereas all parents and 77% of unsuccessful breeders were at least 4 km farther north, although only one used nest was found north of St. Hansholmane. This may indicate active avoidance of the large moulting flocks by breeding geese. However, the larger freshwater lakes south of Båtodden were frozen when non-breeders began moulting, and only later-moulting birds were able to use the better feeding areas around these lakes. A similar separation was also noted in 1975 (J. Dittami pers. comm.). The weights of adult geese moulting later at these better feeding sites were greater than those of earlier moulters ($P < 0.001$ for both sexes).

Weights of geese caught in 1973 (Jackson et al. 1974) are not strictly comparable with those in 1977 since yearlings were not distinguished in 1973. However, a group of geese caught with goslings in 1973 are comparable with those in catches 8—12 in 1977. Males in 1977 were 190 g heavier and females 160 g heavier than in 1973 (P for both sexes < 0.001). Since the birds were caught at the same time of year and at a similar stage of moult, these differences suggest that geese fared better on the Nordenskiöldkysten although spring conditions were more severe in 1977. This probably reflects better feeding conditions for moulting birds there than in Hornsund and possibly better vegetation growth in the warmer summer of 1977.

The catching operations caused a disruption of the feeding pattern of the geese for a short period and weight losses, probably attributable to catching, were recorded in birds caught more than once. Highest losses were recorded in birds caught only three days apart — geese caught after an interval of 8 or more days had lost on average only 3—4 g per day. Geese caught more than once had travelled some distance between catches, and weight losses in these birds were probably greater than in the majority of geese, which remained in the area caught. Thus the catching operations had only a slight, short-term effect on the geese.

Movements following moult

Although the feathers are not completely grown until 35—40 days after the start of moult, the average flightless period is about 25 days (Owen and Ogilvie in press). After they regain the power of flight the geese move out of the moulting lakes to previously unexploited feeding areas. The flock at Oddvatnet declined rapidly in mid-August and by the end of the month there were no geese in the vicinity of Gravsjøen (R. Wells, P. Reynolds pers. comm.). A survey of the whole coast in early September indicated that 1,200 geese were present and about half of these were around the bird cliffs at Ingeborgfjellet, where they fed on the lush grass beneath the cliffs and on the seed-heads of *Polygonum viviparum*. Such areas are extremely important to the geese, allowing them to put on the fat reserves necessary for autumn migration. A similar pattern was observed in Hornsund in 1973, where geese grazed on fertile tundra near Little Auk *(Plotus alle)* colonies following the moult (Jackson et al. 1974).

The first geese arrived in Scotland on 23 September and birds continued to arrive until 14 October. Migrating geese were observed on the coast of Norway in late September. Some of these stopped to rest for a few hours but did not feed (N. Gullestad *in litt,* M. Norderhaug pers. comm.). This contrasts with the pattern in spring, when stops of up to 30 days are made in Norway (Owen et al. 1977). The population was reliably counted in the autumn of 1977, and had 6,800 individuals with 2.4% young. This constitutes a reduction of 400—500 birds since October 1976, but the mortality, at 8—9%, was about average.

By the end of March 1978, 974 out of 1,131 geese (86%) given darvic rings on the Nordenskiöldkysten were resighted in Scotland. These included 34 out of the 44 marked goslings (77%). If goslings and adults are equally likely to be resighted, this indicates only slightly higher mortality of goslings between one month and wintering than of adults during the same time period. This supports the low gosling mortality levels suggested by Owen and Norderhaug (1977).

Discussion

The Nordenskiöldkysten has increased in importance as a breeding and moulting area for Barnacle Geese in the last fifteen years. Norderhaug (1970) reports 47 adults and 41 goslings in 1964 and 10—20 families plus 250 adults in 1965. More or less complete searches were made in both years. In 1975 800 adults and 260 young were seen (Ebbinge and Ebbinge 1977). This was an increase of 280% in a period when the adult population overall had increased by 54% (Owen and Norderhaug 1977). Thus either through immigration, better breeding or lower mortality this area much increased its relative importance. There were 59% more adults in 1977 than in 1975 compared with a population increase of 46%. Since there were more yearlings than expected on the coast in 1977 it appears that immigration of immature birds is continuing.

The Nordenskiöldkysten held about 18% of the Svalbard population in 1977, a higher proportion than some areas receiving protection at present. A visit from sealers on to the main island of the Reiniusøyane during the breeding period resulted in a much lower success rate there (6% of nests successful compared with 23% on the remainder of the coast). The position of this important island near a safe anchorage at the mouth of van Mijenfjorden makes it very vulnerable to such visits, and there is a strong case for giving this island the full protection of bird sanctuary status. Because they are not easily approachable from the sea, the other breeding islands are relatively safe.

A limited amount of human traffic along the coast can be tolerated by the geese, which retreat to a lake or the sea until danger has passed. At times in 1977 there was a regular traffic of helicopters over the coastal strip and these sometimes caused considerable disturbance. This could be minimised if the flight path was restricted to the edge of the mountains or out to sea. If disturbances do not increase, there is no reason why the Nordenskiöldkysten should not increase still further in its importance at least as a moulting area for Barnacle Geese.

Only 4.4% of the coastal population were goslings in 1977, and there are indications that conditions were at least as bad in other parts of the breeding range (M. Norderhaug, pers. comm.). Estimates of age ratio at Caerlaverock indicate an overall proportion of 2.4% young. This makes 1977 the worst year since records commenced in 1958; 1962, the worst year previously, had 5.3%. The brood size in winter was only 1.7, also lower than the average of 2.41 (Owen and Norderhaug 1977).

The result of this exceptional year was to reduce the population by about 400 to 6,800 individuals. The birds are still, however, more than twice as numerous as they were in 1970, and continued protection throughout their range ensures a thriving population.

References

ANKEY, C. D., 1975: Neckbands contribute to starvation in female Lesser snow geese. *J. Wildl. Mgmt.* 39: 825—6.

BARRY, T. W., 1962: Effect of late seasons on Atlantic brant reproduction. *J. Wildl. Mgmt.* 26: 19—26.

COOCH, F. G., 1961: Ecological aspects of the blue-snow goose complex. *Auk* 78: 72—81.

DITTAMI, J., C. THOMFORDE and S. KENNEDY, 1977: Preliminary observations on the nesting of Barnacle Geese in Spitsbergen. *Wildfowl* 28: 94—100.

EBBINGE, B. and D. D. EBBINGE, 1977: Barnacle Geese *Branta leucopsis* in the arctic summer — a reconnaissance trip to Svalbard. *Norsk Polarinstitutt Årbok* 1975: 119—138.

HANSON, H. C., 1959: The incubation patch of wild geese: its recognition and significance. *Arctic* 12: 139—59.

HARVEY, J. M., 1971: Factors affecting blue goose nesting success. *Can. J. Zool.* 49: 223—34.

JACKSON, E. E., M. A. OGILVIE and M. OWEN (1974): The Wildfowl Trust expedition to Spitsbergen 1973. *Wildfowl* 25: 102—116.

NORDERHAUG, M., 1970: The present status of the Barnacle Goose *Branta leucopsis* in Svalbard. *Norsk Polarinstitutt Årbok* 1968: 8—23.

OWEN, M., N. GULLESTAD and A. K. M. St. JOSEPH, 1977: *Barnacle Goose Project 1976—77. Report on section 5, Studies on migration in Norway.* Unpublished report, Wildfowl Trust.

OWEN, M. and M. NORDERHAUG, 1977: Population dynamics of Barnacle Geese *(Branta leucopsis)* breeding in Svalbard 1948—1976. *Ornis Scand.* 8: 161—174.

OWEN, M. and M. A. OGILVIE, in press: Wing molt and weights of Barnacle Geese *Branta leucopsis* in Spitsbergen. *Condor.*

RYDER, J. P., 1967: The breeding biology of Ross' goose in the Perry River region, Northwest Territories. *Can. Wildl. Serv. Rep. Ser.* 3: 1—56.

Breeding success of Barnacle Geese *(Branta leucopsis)* in Svalbard in 1977

By MAGNAR NORDERHAUG[1] and MYRFYN OWEN[2]

Abstract

The paper summarizes results from the British-Dutch-Norwegian field studies in Svalbard in the summer of 1977. Breeding conditions were very unfavourable, due to extremely deep and extensive snow cover and delayed thaw. The production situation in 1977 is comparable with the 1962 season.

1977 data from Svalbard are compared with population study results from the wintering quarters (Scotland). There were 2.4% juveniles in the autumn population in 1977, compared with 47.2—15.0% in the years 1970—1976.

Introduction

During the summer of 1977 an extensive British-Dutch-Norwegian study of the Baranacle geese was organized in Svalbard. A British-Dutch team consisting of twelve persons worked on Nordenskiöldkysten 6 June to 8 September (Owen et al. 1978), and a Norwegian team of three persons worked in the area from Hornsund to Kongsfjorden 21—28 June. This paper summarizes data on the breeding success of the Svalbard Baranacles in their main breeding area in 1977.

Data from the breeding grounds are compared with observations and age counts on the wintering grounds, the Caerlaverock Nature Reserve, Scotland, during the winter 1977/78.

[1] Ministry of the Environment, Myntgt. 2, Oslo, Norway.
[2] The Wildfowl Trust, Slimbridge, Glos. GL2 7BT, England.

General remarks

The main part of the field work took place in the area between the Dunøyane Bird Sanctuary in the south, and the Kapp Linné Bird Sanctuary in the north. This is the most important breeding area for Baranacles in Svalbard. They breed in three sanctuaries within this region, but important breeding concentrations are also found elsewhere. The area between Hornsund and Bellsund is a very important breeding area, and held nearly 30% of the population in 1973 (Jackson et al. 1974). The coast between Bellsund and Isfjorden held 17—18% of the population in 1975 (Ebbinge and Ebbinge-Dallmeijer 1977).

Fig. 1. *Nordre Dunøya (Dunøyane bird sanctuary) on 22 June 1977. Estimated snow-cover: 80%.*

Photo: M.Norderhaug

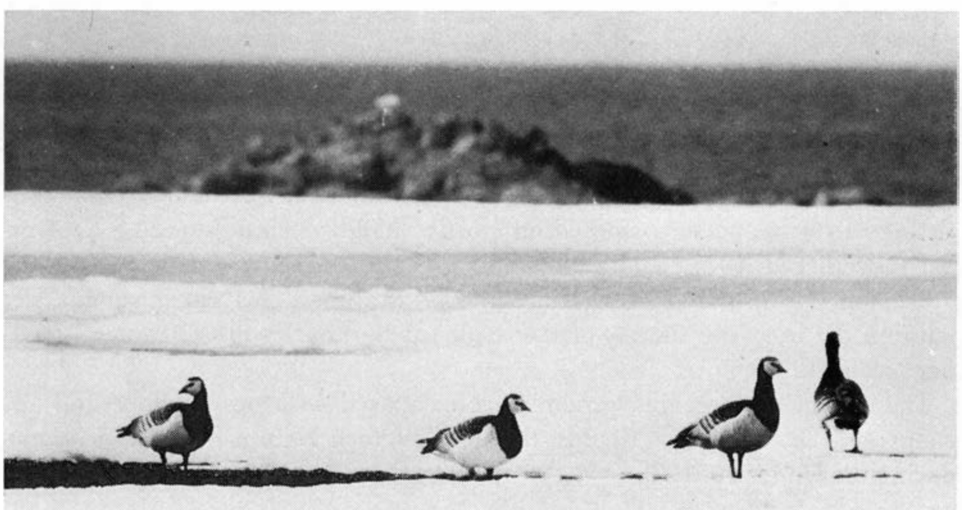


Fig. 2. *Barnacle geese in the Isøyane bird sanctuary on 22 June 1977.*

Photo: M. Norderhaug

The productivity of geese in Svalbard varies considerably from one season to another. This is partly due to variations in the drift ice, Arctic fox predation, and weather conditions during the breeding period, and partly to variations in the ability of the geese to build up body reserves during the winter (Owen and Norderhaug 1977). Accordingly, the proportion of young in the autumn population shows wide fluctuations. In the period 1958—1976 the proportion of young varied between 5.3 in 1962 and 49.2 in 1958 (Owen and Norderhaug 1977).

Breeding conditions in 1977

The summer of 1977 proved to be one of the most extreme breeding seasons in Svalbard in recent years. The situation in some of the main breeding sites was as follows:

Dunøyane bird sanctuary[1]. Visited on 22 June. The islands were surrounded by drift ice, but landing was possible on Nordre Dunøya. About 80 per cent of the ground was snow covered. Only a few nesting territories had been established, but egg-laying had not started.

Isøyane bird sanctuary.[1] Visited on 22 June. The coastal water around the islands was nearly free from drift ice. About 70 per cent of the ground was snow covered. Breeding had just been initiated, but the main part of the population had not started egg-laying.

Olsholmen bird sanctuary.[1] Visited on 22 June. The coastal water was ice-free. There was no snow-cover. All Baranacles had started breeding.

Nordenskiöldkysten. In early June, 95 per cent of the mainland was snow-covered, but coastal islands were largely clear of snow. Egg-laying started in the first week of June. For further details, se Owen et al. 1978.

The average clutch size in nests on Isøyane on 22 June was 2.06 (n = 17). The average clutch size at the start of incubation was 4.0—4.5 (Owen and Norderhaug 1977). Based on this sample, egg-laying on Isøyane started on 20 June and the first clutches were completed on June 25—26. On Dunøyane completed clutches would be further delayed; egg-laying probably did not start until the last week of June.

Observations from the various breeding sites give a clear indication of extreme conditions during the breeding season in 1977. In this connection the situation in the Isøyane/Dunøyane area in 1977 could be compared with the same area (Store Dunøy) in 1965 (see Fig. 3), based on unpublished data from Norsk Polarinstitutt's ornithological field work that year.

[1] Ordinary visits to the bird sanctuaries in Svalbard are prohibited from 15 May to 15 August by a Royal decree of June 1, 1973. The survey from the Dunøyane, Isøyane, and Olsholmen bird sanctuaries was part of a joint program established by the Ministry of the Environment, the Sysselmann of Svalbard, and Norsk Polarinstitutt.

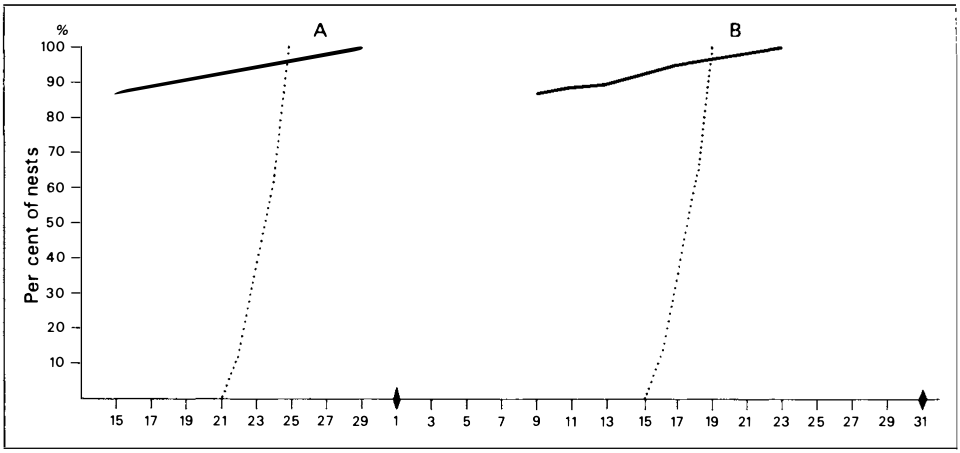


Fig. 3. *Difference in the breeding process of Barnacle in the Hornsund area 1965 and 1977.*
1965 ——— *A: Egglaying (estimated) in the* latest *18 nests on Store Dunøya in 1965. (These 18 nests correspond to about 15%* *of the total breeding population on Store Dunøy that year.)*
B: Hatching (observed) for the same 18 clutches.
1977 ...... *A: Egglaying in the* earliest *17 clutches in 1977 (16 on Isøyane, one on Olsholmen) from observed clutch size June 22.*
B: Hatching (estimated) in the same 17 clutches.
Estimates are based on a brooding period of 24 days after completed clutch.

Egg-laying in the southernmost parts of the breeding area in 1977 was considerably delayed, compared with (1) the situation on Nordenskiöldkysten in 1977, and (2) the situation within the same area in a more normal breeding season (1965). Data from Nordenskiöldkysten in 1977 furthermore suggest a very high nest desertion rate. On Nordenskiöldkysten it was 80 per cent + when egglaying took place in the first week of June. This could indicate a nest desertion rate of about 90 per cent or more in the southern parts where egg-laying started 2—3 weeks later (see data from Scotland below).

Breeding success according to data from Scotland

Further details on the breeding situation in 1977 appear from production studies in the Caerlaverock Nature Reserve during the autumn/winter of 1977/78. They rely on selected pairs ringed on the breeding grounds in the summer of 1973 (Jackson et al. 1974). Data are available on the breeding success of (1) 25 pairs from the Hornsund area: 0 pairs with young (0%), and (2) 24 pairs from the area north of Torellbreen: 2 pairs with young (8.3%). Further details from the population/productivity studies in Scotland 1977/78 are found in Table 1.

Table 1.
Breeding success of Barnacle Geese from various parts of Svalbard 1977 (according to data from Caerlaverock Nature reserve, Scotland, winter 1977/78).

Breeding area	Adult population[1]	Per cent of total	Per cent successful pairs[3]	Number of juveniles[4]	Per cent of total	Per cent juveniles in population
Hornsund	1270	19	0	0	0	0
N. of Torellbreen	790	12	8.3	29	17.8	3.5
Nordenskiöldkysten	1270	19	9.4	53	32.5	4.0
Elsewhere	3310	50	5.5	81	49.7	**2.4**
	6640[2]	100	5.5	163	100	2.4

1. The numbers in Hornsund and north of Torellbreen are based on figures for 1973 and known increase in total population.
2. The number of adults returned to Scotland in the autumn of 1977. The summer population figure may have been slightly higher.
3. Data are based on the proportion of (previously) ringed pairs from the various areas that bred successfully in 1977.
4. The number of juveniles is the number of those reaching the wintering area. The Nordenskiöldkysten total is based on counts in the summer with an estimated mortality of 9 per cent. The mortality estimate is based on adult mortality in 1973 and the difference between the adult and juvenile observation rate in 1977. The relationship between number of young and the proportion of pairs successful in breeding on the Nordenskiöldkysten is used to calculate the number of young produced in the south. Since the total number of young is known from counts and age ratio estimates, the breeding success elsewhere can be calculated.

Discussion

Data from various parts of the breeding area suggest that the breeding conditions for Barnacles in the summer of 1977 were extremely poor. Extreme snow conditions, delayed thaw, drift ice, and persistence of ice bridges to the mainland could be identified as the main negative factors. As pointed out in an earlier paper (Owen and Norderhaug 1977), failure to nest early means that birds delayed in the breeding process due to extreme climatic conditions, have to use up body reserves which otherwise would have been used in egg-laying and incubation. The result is that some birds will have insufficient reserves when egg-laying becomes possible, and others having layed a clutch, will progressively desert it to feed as their reserves are depleted towards the end of incubation. Moreover, young birds from late clutches may still be flightless or in poor physical condition at the time when the autumn migration has to start.

Field experience in Svalbard during the last sixteen years and breeding success data collected in Scotland seem to clearly indicate that the summer of 1977 was the most extreme season recorded.

In 1962 the Barnacle population in the Hornsund area had a nearly complete failure in production of young and the total percentage of first winter birds were 5.3 per cent compared with 2.4 per cent in 1977. In comparison, the percentage of young in this population varied between 47.2 per cent and 15.0 per cent in the 1970's (Owen and Norderhaug 1977).

References

BANG, C., N. GULLESTAD, T. LARSEN and M. NORDERHAUG, 1963: Norsk Ornitologisk Spitsbergen Ekspedisjon, sommeren 1962. *Norsk Polarinst. Årbok* 1962: 93—119.

EBBINGE, B. and D. EBBINGE-DALLMEIJER, 1977: Barnacle Geese *(Branta leucopsis)* in the Arctic summer — a reconnaissance trip to Svalbard. *Norsk Polarinst. Årbok* 1975: 119—138.

JACKSON, E. E., M. A. OGILVIE, and M. OWEN, 1974: The Wildfowl Trust Expedition to Spitsbergen 1973. *Wildfowl* 25: 102—116.

OWEN, M. and M. NORDERHAUG, 1977: Population dynamics of Barnacle Geese *(Branta leucopsis)* breeding in Svalbard. 1948—1976. *Ornis Scandinavia* 2: 161—174.

OWEN, M., R. H. DRENT, M. A. OGILVIE, and T. M. VAN SPANJE, 1978: Numbers, distribution and catching of Barnacle Geese *(Branta leucopsis)* on the Nordenskiöldkysten, Svalbard, in 1977. *Norsk Polarinst. Årbok* 1977 (this volume): 247—258.

Notes on the biology of an Arctic bird rock

By ERLING SENDSTAD[1]

Abstract

The inflow of nutrients and organic carbon in a bird rock with about 750 adult specimens, mainly Kittiwakes *(Rissa tridactyla)*, is studied. These birds are estimated to transport more than 670 kilograms of food ashore to feed their chicks. In this process about 3850 kilograms of excrements are dropped over terrestrial areas close to the bird rock. A high rate of heterotrof activity in the guano under the bird colony is registered. About 1,000 specimens of flying insects per square metre are emerging from this habitat during the summer season.

Introduction

The archipelago of Svalbard has a poorly developed terrestrial ecosystem, as to both complexity, transport of nutrients, and energy transformation. Consequently any energy or nutrient subsidy to this system has a great influence on the surroundings.

The bird rocks represent such subsidies (Remmert 1968; Hartley et al. 1936; Stoff 1936; Lövenskiold 1964). The seabirds, feeding in the biologically rich coastal waters, transport nutrients and organic matter ashore, through their excrements and their feeding of chicks. This transport is consequently of great importance for the understanding of the terrestrial ecology of Svalbard. It is important to achieve a better understanding of the function of bird rocks, not least because the seabirds are among the most probable victims of a potential oil disaster in the Arctic.

Methods

The estimated inflow of organic matter offered to chicks is based on a gross ecological efficiency of 13.5% for the Little Auk *(Plautus alle)* (Norderhaug 1970). It is assumed that the ecological efficiency for the Kit-

[1] SINTEF, N7034 Trondheim, NTH, Norway.

tiwake *(Rissa tridactyla)*, which is the species of principal concern to this study, is somewhat lower than for the Little Auk. This assumption is based on the fact that while the Little Auk seems to be in its optimal habitat in high arctic regions, the Kittiwake is probably not so well adapted, since the High Arctic is not the centre of its distribution. It can further be seen that the Little Auk's food choice is more specialized than the Kittiwake's. Consequently, an ecological efficiency of 10–13% seems reasonable for the Kittiwake (Norderhaug pers. comm.).

The excrement production estimates are based on number of droppings landing on paper strips. These strips are divided into square metres and cover a continuous range of sixteen metres away from the bird rock (Fig. 1).

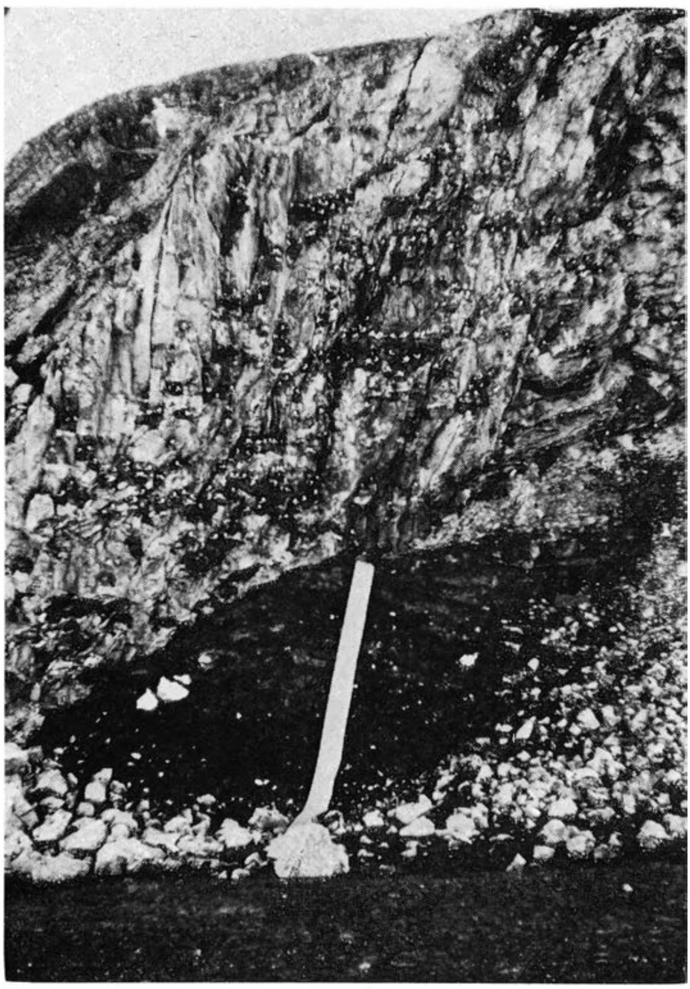


Fig. 1. *The bird rock near Ny-Ålesund, Spitsbergen. A paper strip collecting excrements is shown.*

The weight relations for a mean dropping are based on ten samples. The content of organic carbon and nutrients in the excrements are estimated through analysis of ten mixed samples.

The description of invertebrate life is based on emergence traps (Ryan 1970), Baerman funnels (O'Connor 1967), and high gradient extractors (Macfadyen 1962). The abundance of *Nematoda* and *Protozoa* is estimated through direct microscopy.

Respiration rates of five 100 ml guano replicate samples are estimated using an infrared gas analyser (Ultramat 1. Siemens) with an accuracy of 0.025% CO_2.

Input to the bird rock

This study concerns a small bird rock near Ny-Ålesund, Spitsbergen (79°N, 12°E). The data are from the summer seasons (ultimo June to medio August) 1976 and 1977. The bird rock is inhabited by approximately 700 adult specimens of Kittiwakes, of which 210 pairs are actually breeding. There are further about 50 specimens of Brünnich's Guillemots *(Uria lomvia)* of which 16 pairs are breeding, and six specimens of Black Guillemots *(Cepphus grylle).*

The estimated inflow, as food offered to chicks, is based on the assumption that each pair of Kittiwakes will manage to raise one chick. This seemed to be the general result in the breeding seasons observed. The weight of a chick ready to leave the nest, is estimated to 420 $\pm$7.9 g (SE). This implies that one pair of Kittiwakes has to offer the chick between 3,200 g and 4,200 g of organic material throughout the summer. In this bird rock the inflow therefore exceeds 670 kg organic matter estimated in fresh weight.

In the feeding process, excrements are dropped from adults and chicks. The estimates for excrement production are based on data from early August 1977 (Table 1).

Table 1.
Excrement production under bird rock consisting of about 750 adult specimens. Number of droppings per square metre.

	Distance from bird-rock in metres															
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1300—1400	45	8	2	1	–	–	–	3	–	–	–	1	–	–	1	–
1900—2000	17	17	6	2	4	5	3	–	1	–	–	–	–	–	1	3
2400—0100	20	21	3	–	–	–	–	–	–	–	–	–	–	–	–	–
N per m//h	27.3	15.3	3.7	1	1.3	1.7	1	1	0.3	–	–	0.3	–	–	0.7	1

As can be seen from Table 1, the intensity of droppings diminish abruptly with distance from the rock. More than 80% of the excrements fall within the closest three metres. In a one metre wide and 16 metre long transect from the bird rock the mean estimate of excrement production is about 55 droppings per hour. The mean dropping represents 1.17 ± 0.13 (SE) g wet weight and 0.32 ± 0.03 (SE) g dry weight. This means that the mean inflow of wet excrements per hour in this transect is about 65 g. As the area in question represents about 400 square metres, the mean production under the rock is about 1.6 kg of raw excrements per hour. Assuming an active period for the bird colony of about 100 days, the raw excrement production must be about 3850 kg this summer season. The nutrient status of mixed excrements from the bird rock is given in Table 2.

Table 2.
Nutrient status of mixed excrements from the bird rock. Data given in per cent of wet excrements.

C % (Organic)	N % (Kjeldahl)	P %	K %	Mg %	Ca %
9.50	1.220	0.470	0.325	0.288	0.685
9.81	1.120	0.480	0.316	0.287	0.687

This means that the mixed bird colony this summer transported about 45 kg N, 18 kg P, 12 kg K, 11 kg Mg, 26 kg Ca, and 370 kg organic C to the terrestrial ecosystem as excrements.

Output from the bird rock

Close to the bird rock the fertilization is intense, about 30 kg of wet excrements hitting a mean square metre each hour. In addition, remains of unsuccessful hatching and nesting material is mixed with pure excrements. In this guano system a rich microbial and invertebrate life is developed. The guano is decomposed and nutrients released, giving rise to an increased plant production close to the bird rock.

The CO_2 production from the substrate indicates the rate of decomposition. Samples of 100 ml guano, with a dry weight of 73.25 $\pm$ 2.1 (SE) g, and an organic content of 50.04 $\pm$ 2.2 (SE) % respires, $1.1.10^{-4} \pm 0.2.10^{-4}$ (SE) mol. CO_2 per hour. The result is obtained under the situation of 20.4 ± 1.4 (SE) % water content and $+5°C$. This rate of respiration is about 30 times the rates found in a common lichen heath in Spitsbergen. The respiration of 1.1 CO_2 represents 5.3 K.cal. (Macfadyen 1970). This implies that about 32 K.cal. are lost as CO_2 per 100 ml substrate per assumed active period of 100 days.

The invertebrates of the guano are represented by *Collembola, Acari, Dipter larvae, Nematoda,* and *Protozoa.* The development of invertebrate life in the guano is given in Table 3.

Table 3.
Invertebrate life in the guano under the bird rock.
Data in mean number per litre substrate.

Summer season 1976.

Group	6/22	7/2	7/11	8/6
	N/l ± SE	N/l ± SE	N/l ± SE	N/l ± SE
Collembola	7700 ± 600	650 ± 50	100 ± 20	400 ± 100
Acari	10 ± —	50 ± —	150 ± 50	4700 ± 900
Dipter Larvae	—	50 ± —	10 ± —	850 ± 150
Nematoda	?	$6.3.10^4 \pm 1.8.10^3$		$3.6.10^4 \pm 2.4.10^1$
Protozoa	?	$1.4.10^6 \pm 8.3.10^4$	$1.5.10^6 \pm 1.3.10^5$	$2.0.10^6 \pm 3.3.10^5$

As an addition to the cryptic invertebrate life in the guano, many flying insects emerge from this habitat as well. This fauna element was caught by emergence traps. Throughout the summer about 1000 specimens of *Neolaria prominens* emerged from a mean square metre. These *Heleomyzidae* were accompanied by approximately 50 specimens of *Mycetophilidae* and about ten specimens of *Trichoceridae.*

This rich invertebrate life in the guano is a prominent energy source for an insect feeding bird like the snow bunting *(Plectrophenax nivalis).* It is interesting to note that as the *Collembola* has its abundance peak in the spring, the *Acari* is most abundant in the autumn (Table 3). Between these two extremities there is an emergence peak of *N. prominens* in the period 6—16 July. Strictly speaking, these facts cannot be compared, but they show that the invertebrates as a food source for birds are alternatively abundant throughout the summer season.

Discussion

The bird rocks have a dualistic ecological function in the arctic terrestrial ecosystem. First they represent a direct food source to predators and scavengers. The production of chicks and unsuccessful eggs in the bird colony and invertebrates from the guano, are the two main direct energy transport routes from the bird rock. The indirect effects are perhaps even more important. As is stated in this paper, quite large amounts of organic carbon and nutrients are transported into the terrestrial ecosystem, resulting in an increased production of herbs and grasses close to the bird rock. To understand the ecological consequences of these general observations, research has to focus on the functional aspects of bird colonies. An attempt is therefore made to estimate the quantities of organic matter and nutrients transported into the terrestrial ecosystem by the sea birds. It must be stressed, however, that the calculated quantities presented here are based on several assumptions and must be interpreted with care. It is for example possible that the chemical composition and rate of excrement dropping may vary significantly during the summer season. The length of the summer season and the birds' breeding success also vary from year to year. Finally, some excrements dropped hit the rocks close to the nest, and not the collecting paper strips. The presented estimates must therefore be regarded as fairly crude. Still I am inclined to conclude that the bird rocks in the Arctic act as oases in the polar desert. The sea birds perform a relatively important biogeochemical function as they link the productive marine biota to the terrestrial ecosystem, and as such they initiate the development of complex terrestrial food-webs.

Acknowledgement

This paper is a part of the biological investigations carried out by the Norwegian MAB project (Man and the Biosphere). I wish to thank my colleagues there for their assistance in collecting data. I am also indebted to Magnar Norderhaug for his critical review of the manuscript.

References

HARTLEY, C. J. and J. FISCHER, 1936: The marine foods of birds in an inland fjord-region in West-Spitsbergen. Part 2. *Journal of Animal Ecology 5.*

LÖVENSKIOLD, H. L., 1964: Avifauna Svalbardensis. *Norsk Polarinstitutt Skrifter* Nr. 129. 460 pp.

MACFADYEN, A., 1962: Improved funnel-type extractors for soil arthropods. *Journal of Ecology* 30: 171—184.

— 1970: Soil metabolism in relation to ecosystem energy flow and primary and secondary production. In: Methods of study in soil ecology (Ed. J. Philipson). *Proceedings of Paris symposium organized by UNESCO and the IBP Programme. UNESCO 1970.*

NORDERHAUG, M., 1970: The role of the Little Auk *Plautus alle* (L), in Arctic ecosystems. *Antarctic Ecology* 1: 558—570.

O'CONNOR, F. B., 1967: The Enchytraeidae. In: *Soil Biology:* 212—257. (Eds. Burges, A. and F. RAW) Academic Press, London & New York.

REMMERT, H., 1968: Über die Bedeutung volkreicher Meeresvogelkolonien und pflanzenfressender Landtiere für die Tundra Spitsbergens. *Veröffentlichungen des Instituts für Meeresforschung in Bremerhaven* (Eds. Gerlach, S. A. und W. Hönk) XI (1): 47—59.

RYAN, J. K., 1970: Devon Island Invertebrate Research. In: *Devon Island I.B.P. Project High Arctic Ecosystem:* 293—314. Project report 1970 and 1971, Alberta.

STOFF, F. C., 1936: The marine foods of birds in an inland fjord-region in West-Spitsbergen. Part 1. *Journal of Animal Ecology 5.*

Glaciological work in Svalbard in 1977

By OLAV LIESTØL

Abstract

In 1977 mass balance measurements were carried out by Norsk Polarinstitutt on three glaciers in Norway. Storbreen showed a negative balance of —54 g/cm². Hardangerjøkulen —72 g/cm², and Blomsterskardbreen —140 g/cm². This relatively larger negative balance was due to low winter accumulation as the summer temperature was about average. In Spitsbergen Austre Brøggerbreen and Midre Lovénbreen were both nearly in balance with a calculated net balance of —4 g/cm² for Lovénbreen and —11 g/cm² for Brøggerbreen.

Length fluctuations of ten glaciers were measured of which five were advancing.

Storbreen, Jotunheimen

The winter snow accumulation was below normal on all glaciers in southern Norway especially on those west of the watershed. The snow accumulation map for the 1200 m elevation worked out by the Norwegian Meteorological Institute showed about 60% of normal accumulation for the glacier area in southern Norway. On Storbreen the accumulation was 94 g/cm², which is 68% of the average of the last 28 years and also the lowest figure measured in the same period. The summer temperature was slightly below average, and so was the ablation of 148 g/cm². Because of the extremely low accumulation the result of the budget year was therefore a negative balance of —54 ± 10 g/cm².

As mentioned in earlier reports the thinning of the glacier takes place in the lower part, especially in the snout where the ice is almost stagnant. A new rock nob emerged a couple of years ago. In earlier years an ice rise indicated shallow glacier depth. Below the nob in the front the ice must be regarded as dead. Another interesting feature is the stratified glacifluvial outwash found under and in front of the snout as the glacier retreats. The glacier has obviously overridden these sediments without disturbing them.

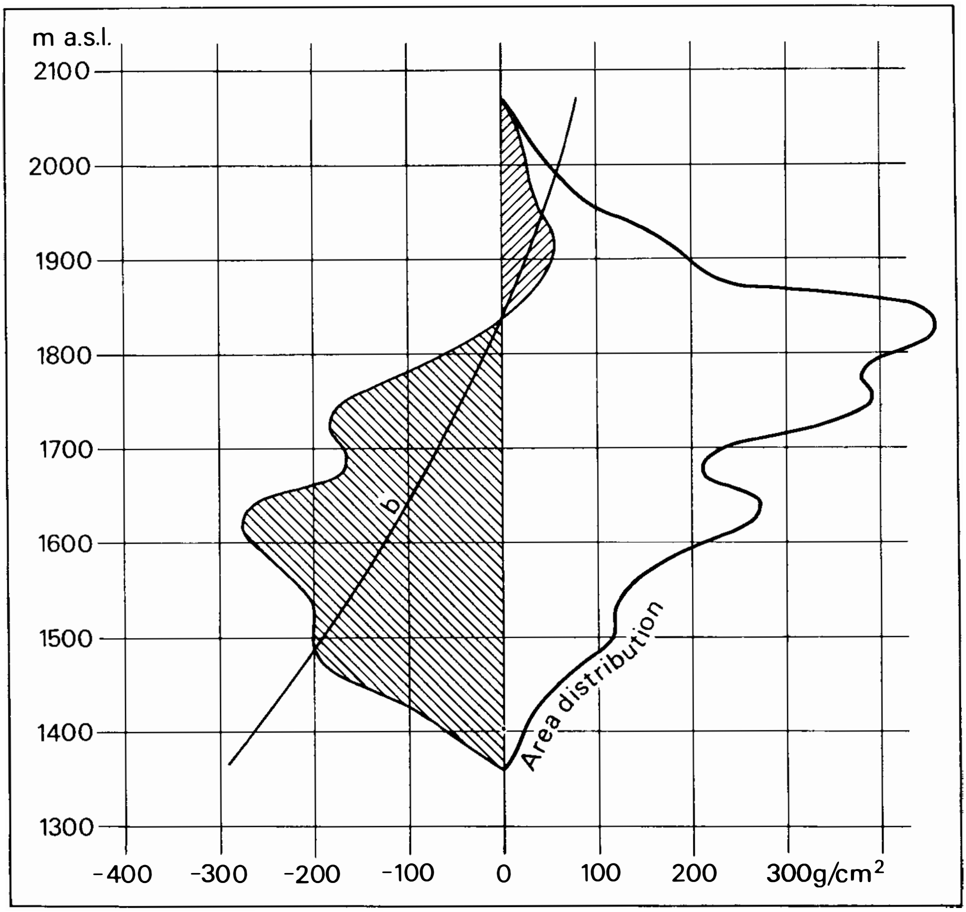


Fig. 1. *Mass balance variations on Storbreen 1976—77 in relation to height above sea level.*

Hardangerjøkulen

Accumulation was measured in early May and showed a figure far below normal as on the Storbreen glacier. The average for the last fifteen years is 195 g/cm^2, while it was 120 g/cm^2 in 1977, which is 62% of the average. The ablation measured on three different occasions, the last one in November, was about average, 192 g/cm^2; the balance was thus —72 g/cm^2.

Glaciers in Spitsbergen

In Spitsbergen glacier work was carried out on Austre Brøggerbreen and Midre Lovénbreen. Accumulation was measured in the beginning of June. Snow density was measured at three height intervals and core drilling performed at about ten intervals to find the autumn and winter superimposed ice. In the uppermost part of the glaciers this superimposed ice was difficult to distinguish from ice formed the previous summer. Only direct measurements at the stakes gave reliable figures. This ice was quite evenly distributed over the glacier surface in the spring of 1977 and amounted to 5.5 g/cm^2.

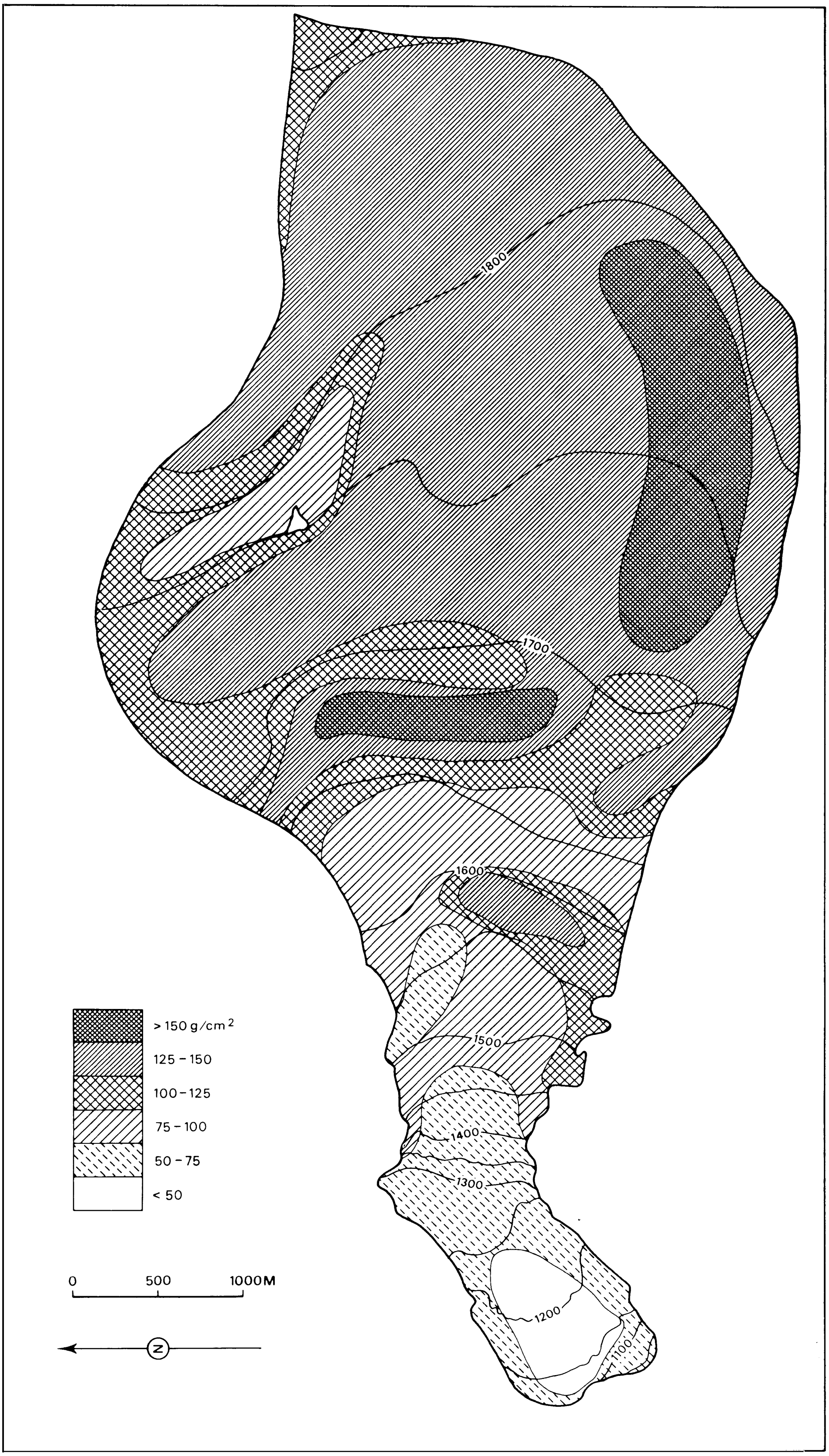


Fig. 2. *Distribution of snow accumulation in the part of Hardangerjøkulen that flows to the outlet glacier Rembesdalsskåki.*

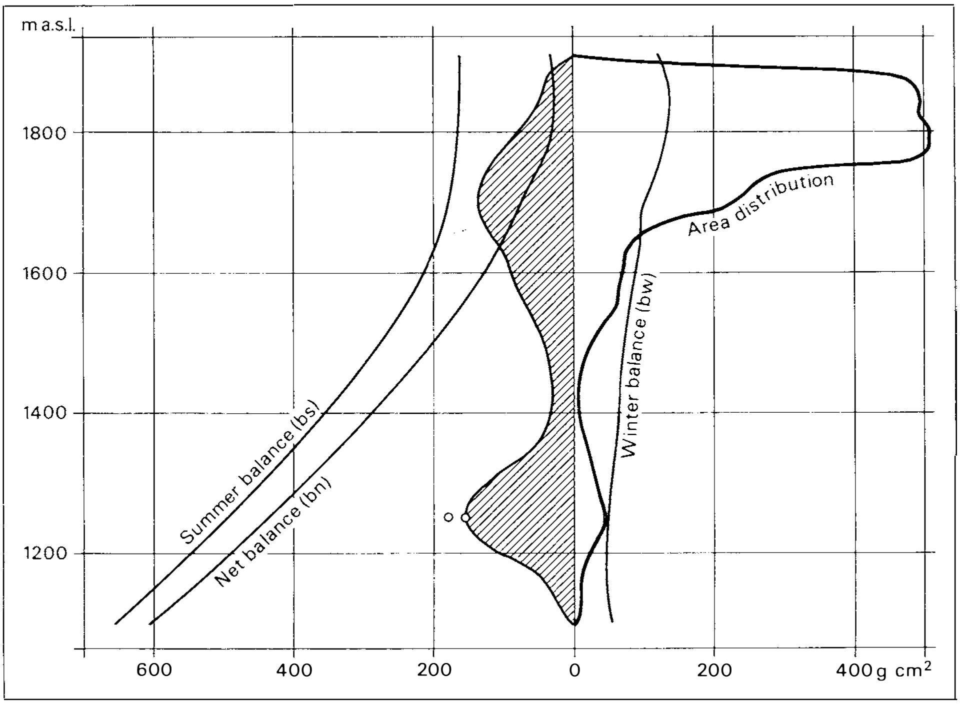


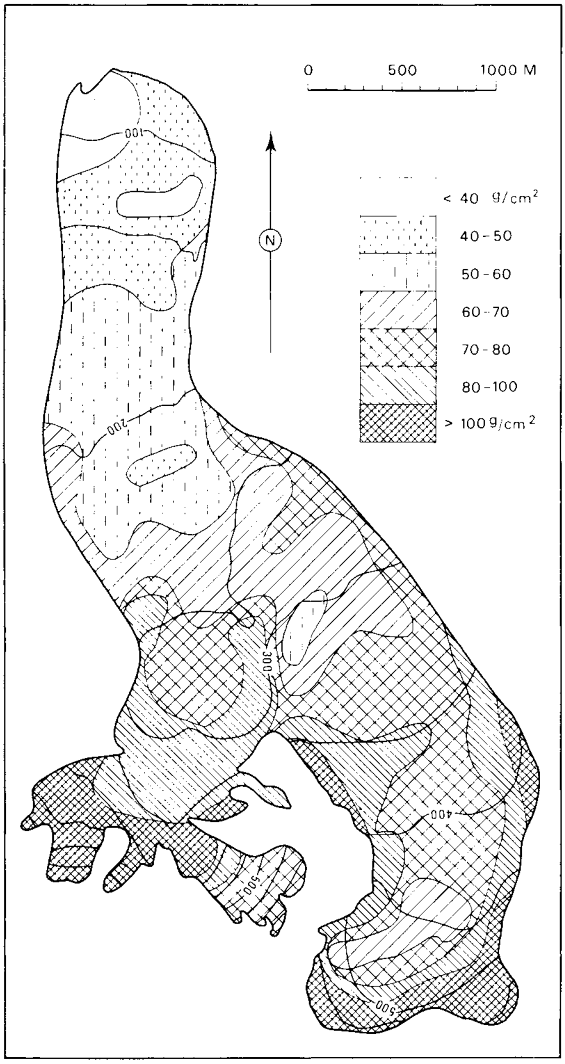
Fig. 3. *Variation in mass balance on Hardangerjøkulen (Rembesdalsskåki) 1976—77 in relation to height above sea level.*

About 10% of the total snowfall came in the first half of June. The accumulation figure was 76 g/cm² at Brøggerbreen and 80 g/cm² at Lovénbreen. As will be seen from Table 1, this is above the average of the last ten years.

The ablation stakes were redrilled once during the summer and measured

Table 1.
Mass balance figures in g/cm² for Austre Brøggerbreen and Midre Lovénbreen 1967—77

Year	Austre Brøggerbreen $\bar{c}$	$\bar{a}$	$\bar{b}$	Midre Lovénbreen $\bar{c}$	$\bar{a}$	$\bar{b}$
1966—67	77	142	-65			
1967—68	57	67	-10	48	51	-3
1968—69	40	133	-93	41	125	-84
1969—70	37	91	-54	36	89	-53
1970—71	65	123	-58	70	116	-46
1971—72	95	126	-31	98	120	-22
1972—73	74	82	-8	82	84	-2
1973—74	75	167	-92	70	159	-89
1974—75	78	109	-31	83	104	-21
1975—76	72	117	-45	75	110	-35
1976—77	76	87	-11	80	84	-4
1967—77	68	113	-45	68	104	-36



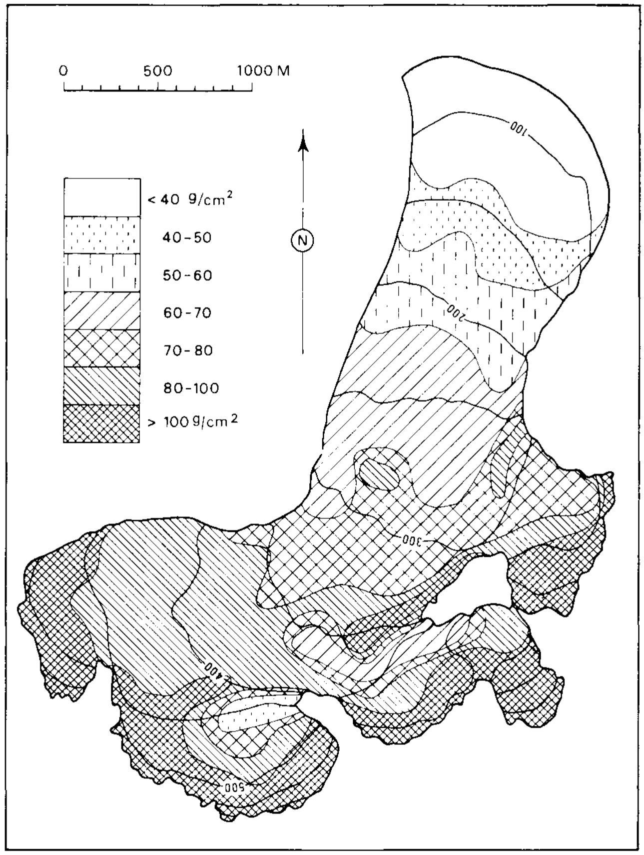


Fig. 5. *Distribution of snow accumulation on Midre Lovénbreen 1976—77.*

Fig. 4. *Distribution of snow accumulation on Austre Brøggerbreen 1976—77.*

last on 13 October. A small amount of superimposed ice had then already been formed. The table shows that the glaciers within the borders of uncertainty were in equilibrium, and that none of the eleven years shows a positive balance.

Other investigations

The Norwegian Water Resources and Electricity Board carried out measurements on seven glaciers of which two, Engabreen and Høgtuvbreen, are situated in Northern Norway. The mass balance figures for these glaciers and for the five others mentioned in this paper, are presented in Table 2. Mass balance figures for glaciers in Southern Norway are presented in Fig. 7.

The fluctuation of the length of eleven glacier tongues were measured and the results are presented in Table 3.

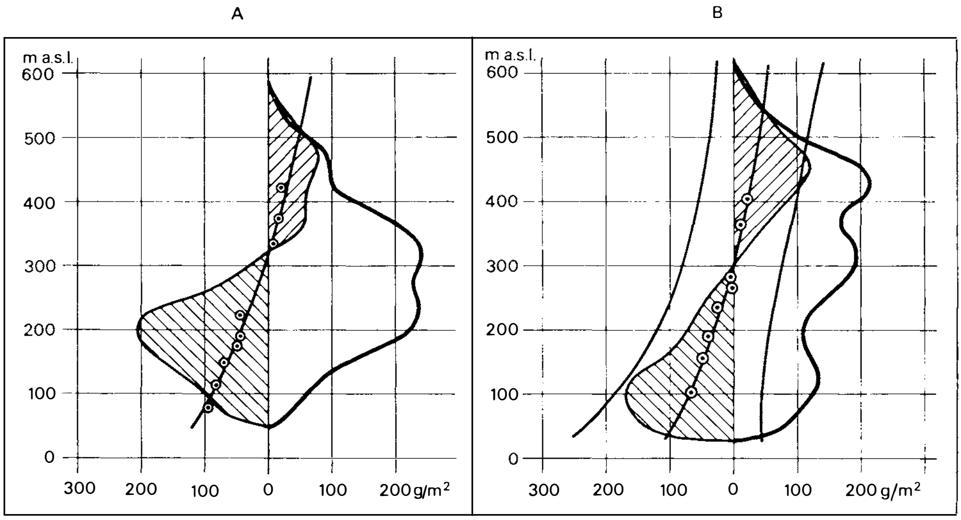


Fig. 6. *Mass balance variations in relation to height above sea level of Austre Brøggerbreen (A) and Midre Lovénbreen (B) 1976—77.*

Table 2.
Mass balance measurements of different glaciers in Norway and Spitsbergen 1976—77

Name of glacier	Area Km²	Winter balance g/ cm²	Summer balance g/ cm²	Net balance g/ cm²
South Norway				
Blomsterskardbreen	—	—	—	–140
Hardangerjøkulen	17.3	120	192	–72
Ålfotbreen	4.8	233	289	–56
Nigardsbreen	47.2	152	229	–77
Storbreen	5.3	94	148	–54
Hellstugubreen	3.3	68	140	–72
Gråsubreen	2.5	51	90	–39
North Norway				
Høgtuvbreen	2.6	220	272	–52
Engabreen	38.0	208	120	+88
Spitsbergen				
Austre Brøggerbreen	6.1	76	87	–11
Midre Lovénbreen	5.8	80	84	–4

Table 3.
Fluctuations in length in metres of some glacier tongues.

Jotunheimen		*Jostedalsbreen*	
Storbreen	–8	Briksdalsbreen	+23
Styggedalsbreen	+2	Fåbergstølbreen	–28
Leirbreen	–6	Stegaholtbreen	–12
		Austerdalsbreen	–1
Folgefonni			
Bondhusbreen	+7	*Svartisen*	
Buarbreen	+2	Engabreen	+31

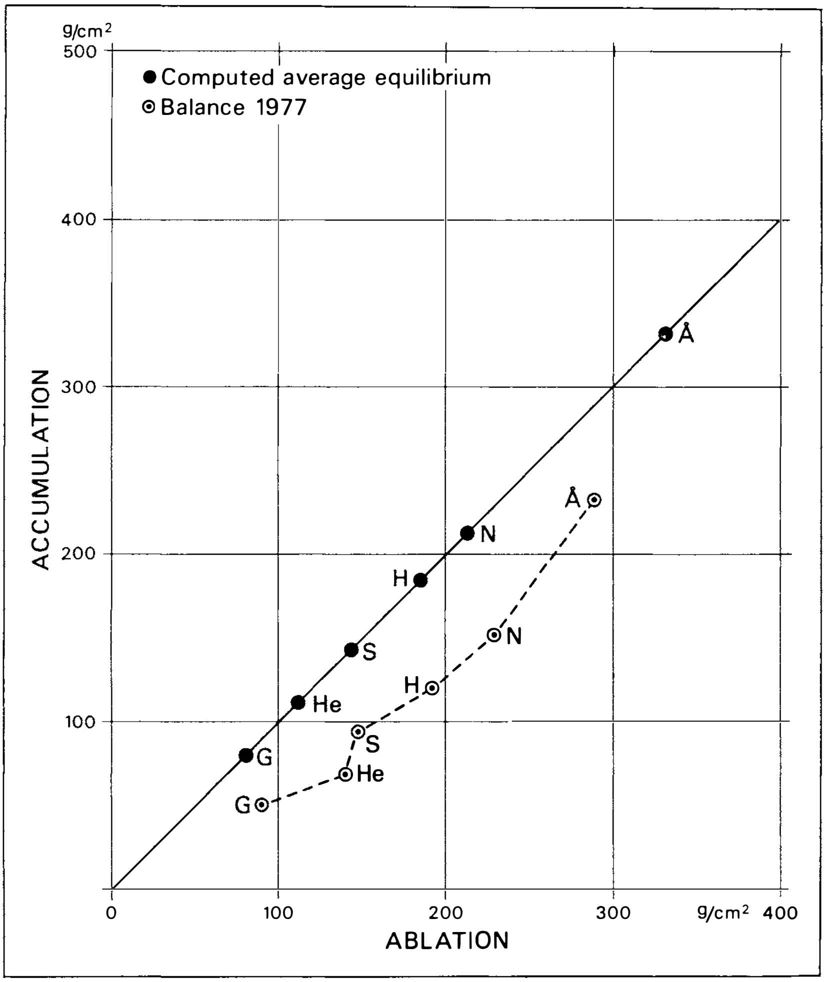


Fig. 7. *Relation between accumulation and ablation compared to the mean of a year with a computed balance budget and a «normal» mass exchange.*

G = *Gråsubreen*
H = *Hardangerjøkulen*
He = *Hellstugubreen*
N = *Nigardsbreen*
S = *Storbreen*
Å = *Ålfotbreen*

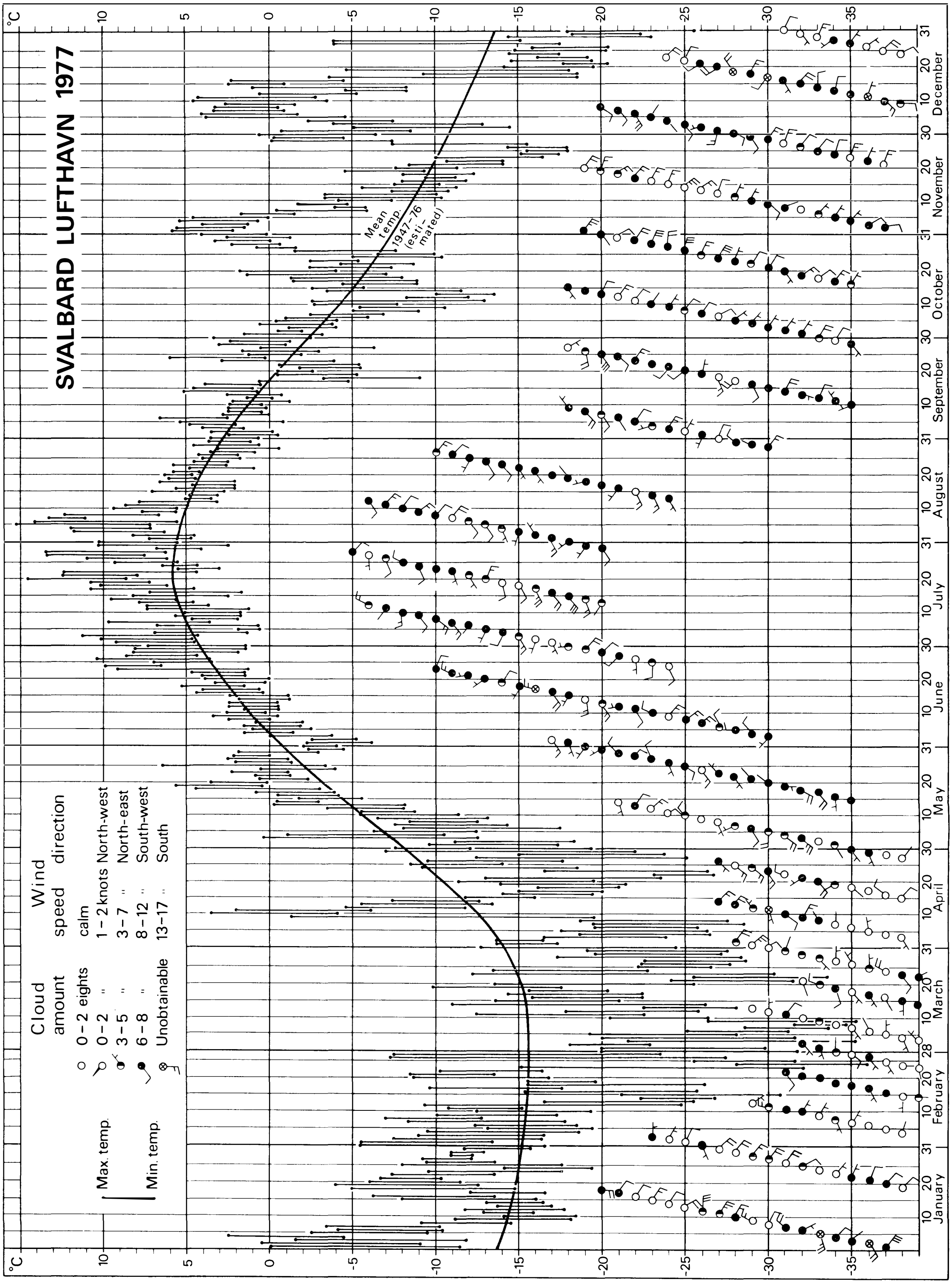
The weather in Svalbard in 1977

By VIDAR HISDAL

The diagram presents the following meteorological elements observed at Svalbard Lufthavn during 1977: daily maximum and minimum temperatures, cloud amount, and direction and speed of the wind. The cloud and wind observations entered are those taken at 12 GMT. The figure also shows the estimated mean annual temperature variation for the period 1947—76. The way of estimating these long-term averages, by means of data from neighbouring stations, is indicated in a previous article («The weather in Svalbard in 1976», *Norsk Polarinstitutt Årbok* 1976). Symbols used are explained by examples in the diagram.

The table contains monthly mean temperatures for 1977, as well as their deviations from the corresponding means based on the years 1947—76. The term «normal» used in the following refers to this latter period.

During the first week of the year several cyclonic centres passing over or near Svalbard brought relatively mild air from lower latitudes. The second week was dominated by a high-pressure area over Greenland and the Polar Basin, and the weather was characterized by northerly to northeasterly winds and about normal temperatures. The last half of January as well as the first twelve days of February were again more influenced by cyclonic activity, although generally the centres passed south of the area. Temperatures stayed mostly above the average for the season. During the rest of February the air circulation was associated either with a high-pressure ridge to the west, giving clear, cold winter weather, or to passages of relatively weak depressions, resulting in milder spells. The lowest temperature of the year at Svalbard Lufthavn, —35.9°C, occurred on 24 February. The months of March and April were unusually cold. The weather during the larger part of this period was dominated by a northerly to northeasterly air flow between high-pressure areas centred to the west or north and depressions to the south or southeast. Frequent clear skies gave strong radiational cooling of the ground. This


SVALBARD LUFTHAVN 1977
°C
10
5
0
-5
-10
-15
-20
-25
-30
-35
Max. temp.
Min. temp.
Cloud amount
0 – 2 eights
0 – 2 "
3 – 5 "
6 – 8 "
Unobtainable
Wind speed direction
calm
1 – 2 knots North-west
3 – 7 " North-east
8 – 12 " South-west
13 – 17 " South
Mean temp. 1947–76 (esti-mated)
January
February
March
April
May
June
July
August
September
October
November
December
10
20
28
30
31

Monthly mean temperatures for 1977 (T) and their deviations (d) from the means of the period 1947—76.

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Svalbard Lufthavn	T	-11.0	-17.9	-23.5	-15.9	-4.6	1.5	5.9	4.9	0.2	-4.1	-6.9	-9.5
(estimated:)	d	3.8	-2.4	-8.1	-4.3	-0.4	-0.5	0.3	0.3	-0.3	1.0	2.3	2.8
Hopen	T	-11.5	-11.3	-18.2	-14.2	-3.9	-0.8	1.4	1.6	-0.1	-2.2	-3.8	-9.1
	d	1.4	1.0	-4.8	-3.6	0.8	-0.4	-0.6	-0.6	-0.8	0.8	3.4	1.4
Bjørnøya	T	-6.5	-7.1	-12.3	-8.8	-2.0	0.1	2.6	4.7	2.2	-0.4	-1.3	-5.0
	d	0.9	-0.2	-5.0	-3.5	-0.6	-1.1	-1.8	0.3	-0.6	-0.2	1.7	0.7

applies especially to the first part of the period, when the sun was below the horizon by night and very low in the sky in the daytime. On 44 of the 61 days of these months, the minimum temperature of the airport was below —20°C, and in March nine days had minima below —30°C. The only pronounced break in this cold, anticyclonic weather situation occurred in the period 9—14 April, when well-developed low-pressure systems, bringing mild air from the south, gave a marked temperature increase. Thus, on 10 and 11 April the maximum temperature at the airport were as high as 3.5° and 2.0°C respectively, and the precipitation fell partly as rain. Except for a short milder spell about 3 May, due to a depression coming from the west over Greenland, the first third of this month was cool, with invasion of air from the Polar Basin. Later on cyclonic centres passing the Barents Sea or Svalbard itself, brought milder air. At Svalbard Lufthavn the last half of May had thirteen days with maximum temperatures exceeding 0°C. The end of May and the beginning of June were again influenced by cooler, northerly winds. During the larger part of June, however, the temperature stayed close to the average for the season, the air circulation most of the time being governed by cyclones moving over or just south of the Svalbard area. The last week of the month had a more anticyclonic weather type, with rather long sunny periods and temperatures somewhat above normal.

The anticyclonic weather characterizing the last part of June, with moderate winds and long sunny spells, prevailed during the first days of July and, also, during the middlemost part of his month. The rest of July as well as large parts of August had much cloudy weather with frequent precipitation, occasioned by passages of a series of weak depressions. The highest summer temperatures at the airport were recorded on 20 July, 14.5°C, and on 5 August, 15.1°C, the latter value representing the annual maximum. Both days had transport of air from lower latitudes in front of low-pressure systems, at the same time as the sky was clear or nearly clear most of the day, resulting in strong solar heating. Cyclonic activity continued to be a pronounced feature of the Svalbard weather in September. The periods 9th to 12th and 17th to 22nd represent two longer breaks in this general situation. During the latter period, which was governed by a cold, northerly air stream, temperatures as low as —9.0°C were observed at the airport. Both the end of

September and the beginning of October were comparatively mild. However, the weather grew gradually cooler towards the middle of the month, as it got more dominated by an anticyclone over the Polar Basin. During the last half of the month the temperatures were about or above normal, with considerable cyclonic activity. Especially the last five days of October and the first six days of November had a strong southerly air flow, associated with an extensive low-pressure area. On all these days the airport had temperature maxima well above freezing. Three days had maxima above 5°C, and a large part of the precipitation reached the ground as rain or drizzle. During the middlemost part of November the paths of the cyclonic centres were situated south or southeast of Svalbard, and the temperatures varied about the normal for the season. The days 23—26 November were influenced by air from the Polar Basin, and were accordingly appreciably colder. During the last days of the month cyclones again approached and passed the archipelago, and the temperature increased considerably. This mild, cyclonic weather was predominant during the first half of December as well. For all days but one in the period from the 5th to the 16th of the month, the maximum temperatures at the airport were above 0°C, with a highest reading of 4.6°C on the 10th. Except for a short, relatively mild spell around the 28th, the last two weeks of December were considerably colder. Air from the north or northeast entered the region in the rear of depressions that became quasi-stationary in the Kara Sea region.

Looking at the tabulated mean temperatures, we find for all stations that the months of March and April were much colder than normal, especially the former, whereas January and the start of the new winter, November — December, were comparatively mild. The unusually low temperatures in March were due to persistent northerly to northeasterly air streams, as well as to frequent clear skies, which at this time of the year involve cooling of the ground and, accordingly, of the surface air layer. Large parts of the summer season were rather cool. This is particularly true for the month of July on Bjørnøya. According to a series of monthly mean temperatures for this island, starting in 1920, a lower July mean has occurred only twice (1951 and 1965). The annual amount of precipitation did not deviate markedly from normal. At all stations the largest amount of precipitation in the course of one month was measured towards the end of the year: Svalbard Lufthavn 36 mm (25% of annual precip.) in December, Hopen 86 mm (17% of annual precip.) in November, and Bjørnøya 66 mm (19% of annual precip.) in October.

Sea ice conditions and drift of Nimbus-6 buoys in 1977

By TORGNY E. VINJE

General outline

The distribution of sea ice concentrations higher than 3/8 at the end of each month, is given in Fig. 1. The figure also shows the median border and the enveloping curves for maximum and minimum extension of sea ice concentrations higher than 3/8 for the period 1966—75, discussed by Vinje (1977).

During most of January there was a persistent outflow of air northwestwards from the continent over the Barents Sea. Between 13 and 26 January this developed an area of open water northwest of Zemlja Franca Iosifa as illustrated in Fig. 2. At the end of January this persistent outflow had developed an extreme sea ice extension in the southern part of the Barents Sea as well. Otherwise Fig. 1 indicates a clear development of the Jan Mayen Gyro, but with less ice than normal north of 75°N.

In February the extension of sea ice was at its minimum in the Icelandic Sea, and at its maximum west of Spitsbergen. Otherwise the conditions were relatively close to normal.

At the end of March and April the maximum extension of sea ice still existed west of Spitsbergen. In May the sea ice in the Greenland Sea stretched extremely far towards the east. To some extent this may have been caused by the relatively persistent NW winds in the area that month.

The disintegration of the sea ice in the Barents Sea did not seem to follow the usual pattern in 1977. The main opening-up south of Zemlja Franca Iosifa occurred relatively late. At the end of June an extraordinarily large opening was observed extending towards the SW of the archipelago instead of towards the south which is usual. This development started in the beginning of June and was also indicated by observations made in May (see Fig. 3) (cf. discussion below).

In the Jan Mayen area the eastward extension of the ice edge was still relatively extreme at the end of June. The amount of ice in the East Greenland

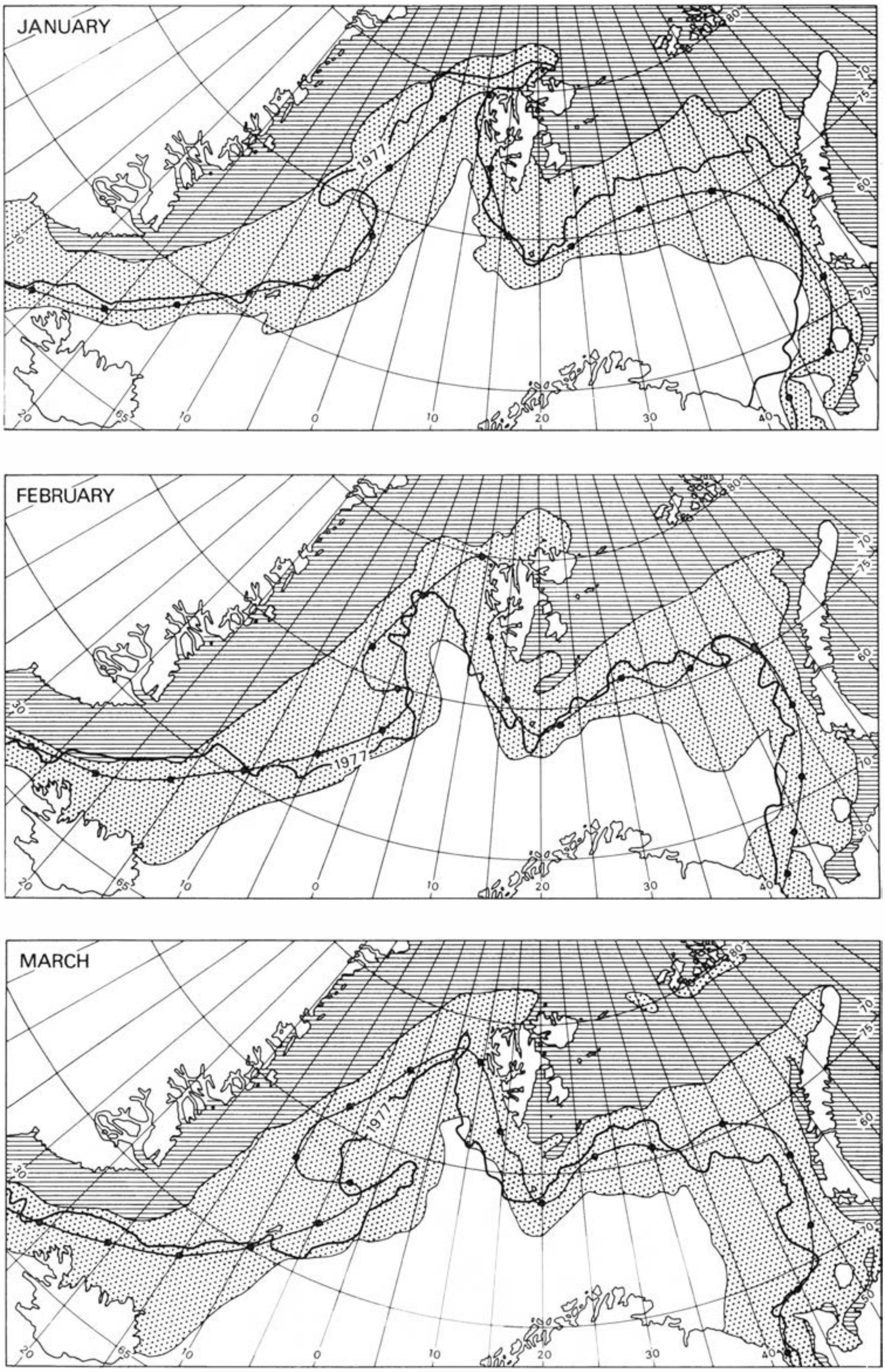
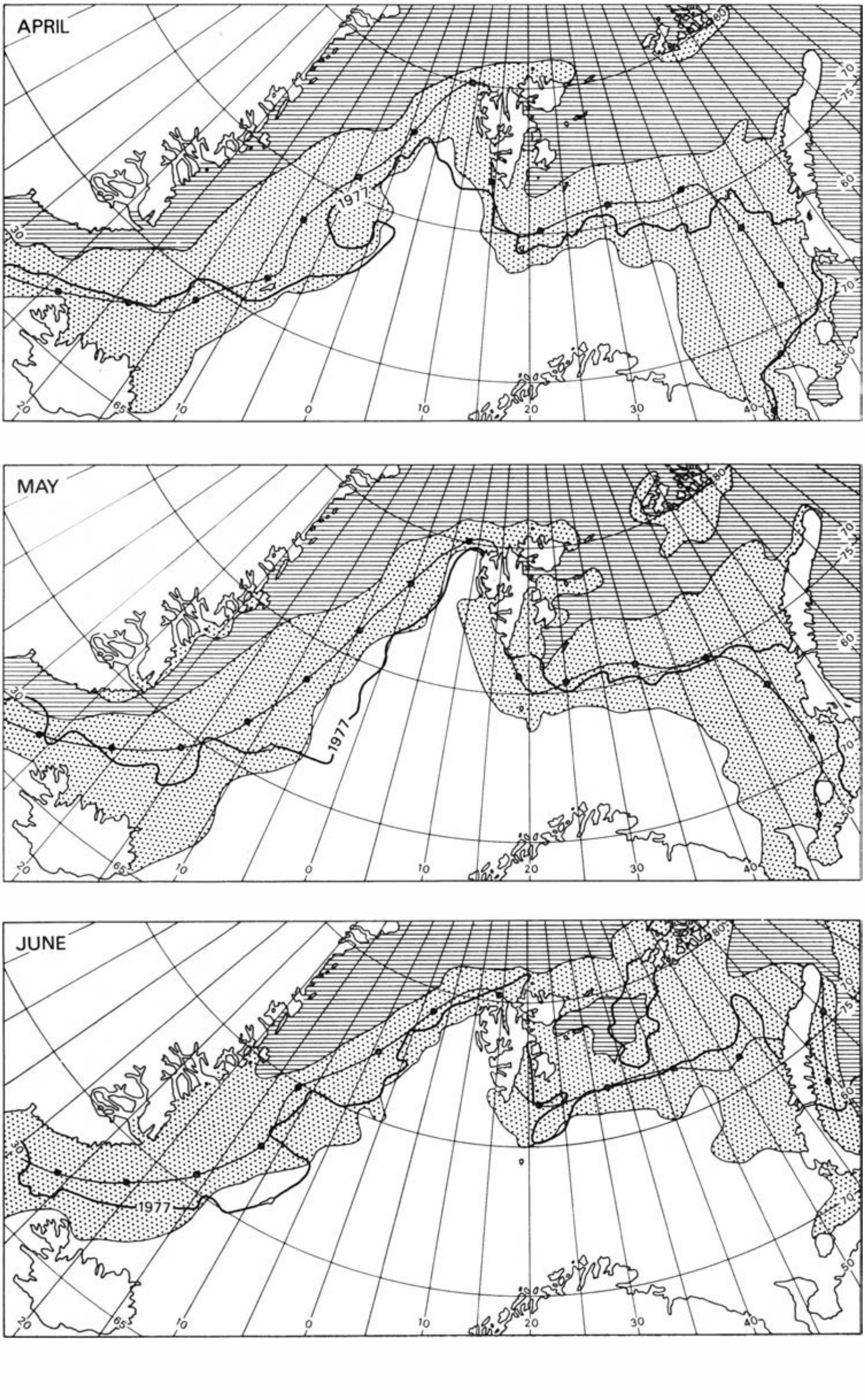
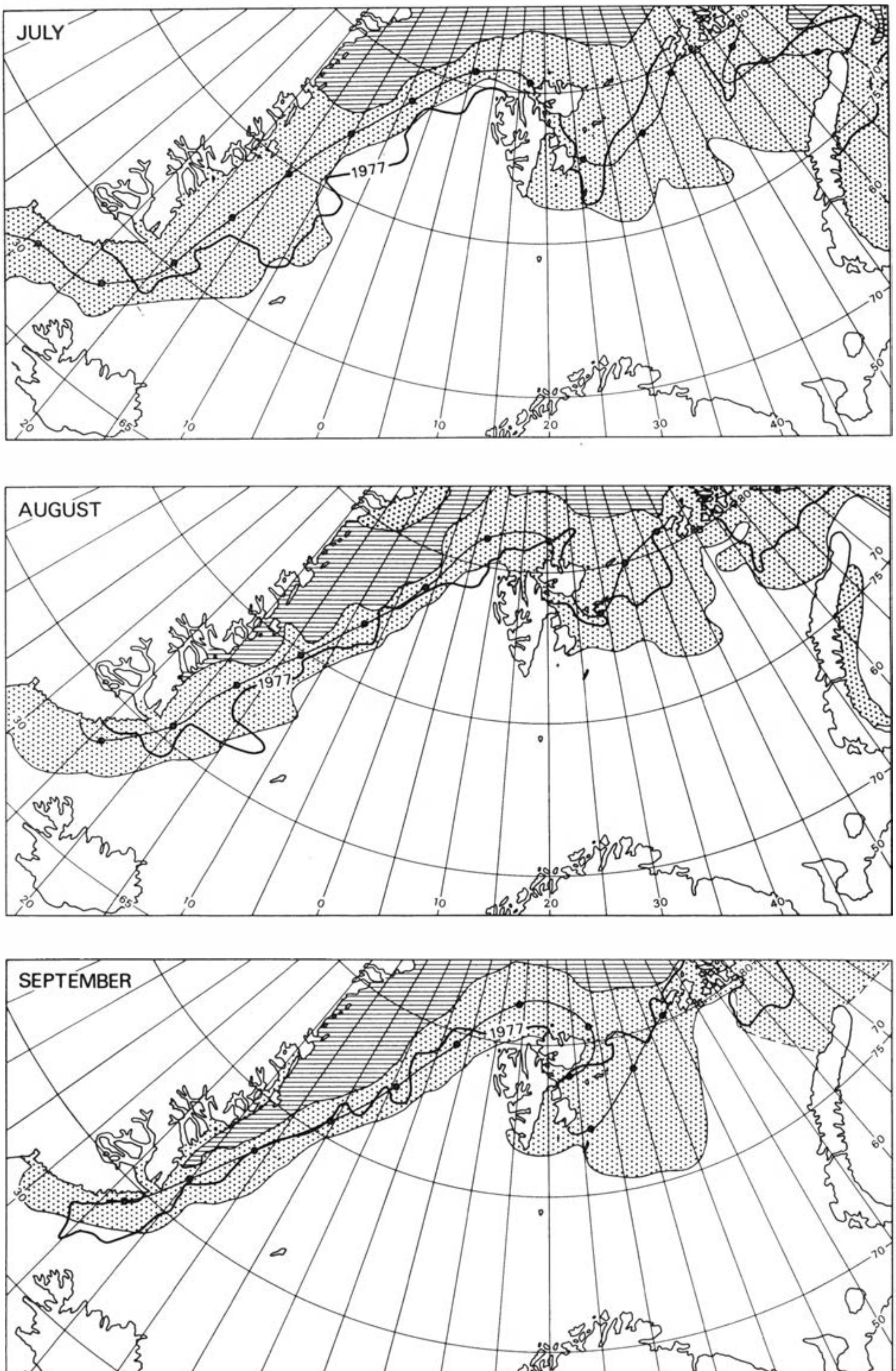
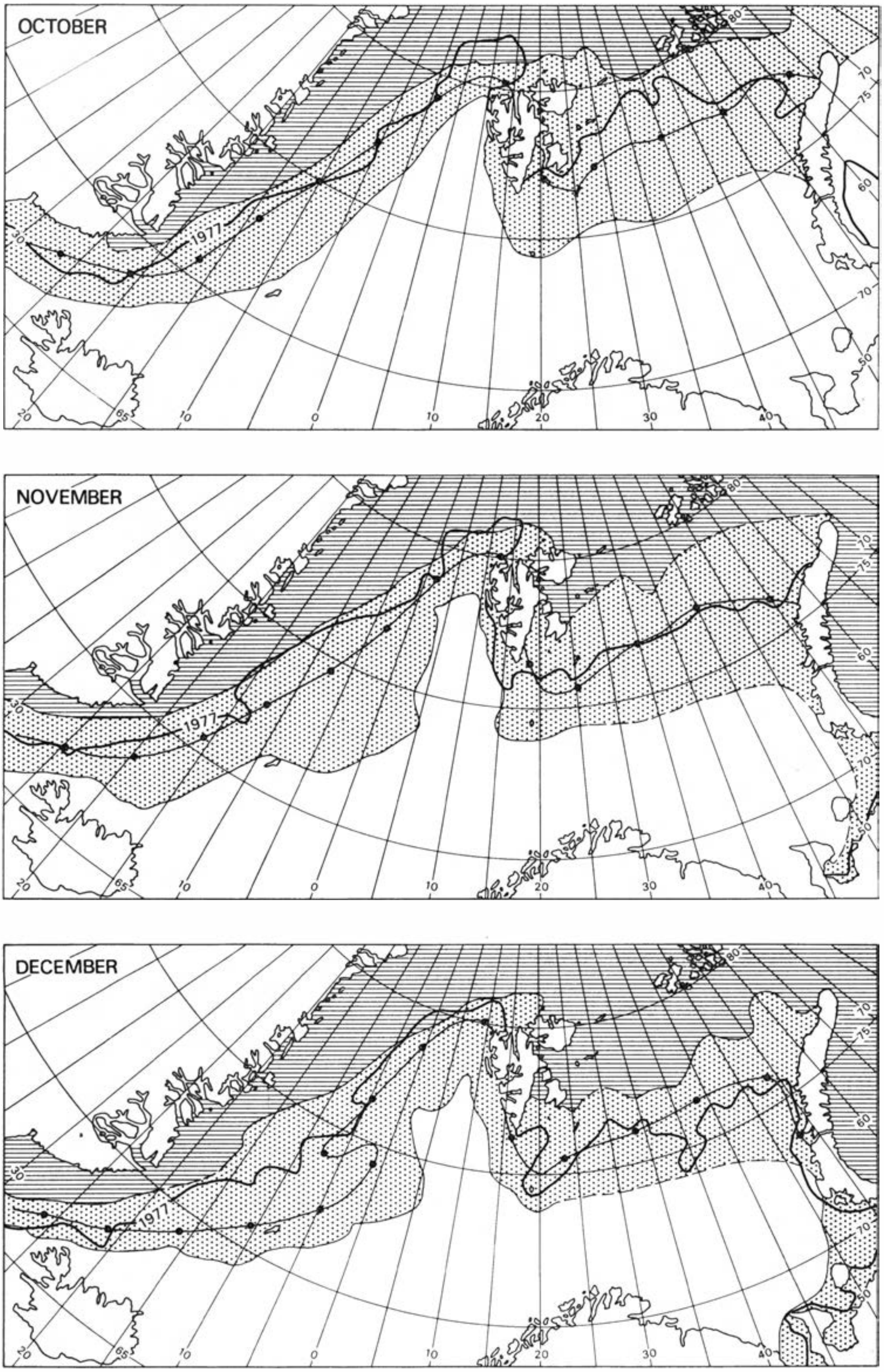


Fig. 1. *Sea ice conditions at the end of each month of the year: —— 1977 —— . Enveloping curves indicating the most northern or southern extension of sea ice concentrations above 3/8 for 1966—75: ——— . Median border south of which sea ice (concentrations above 3/8) is observed in less than 50% of the cases in the ten-year period: ——●—— .*


APRIL
1977
MAY
1977
JUNE
1977
20
65
10
0
10
20
30
40
50
60
70
75
80


JULY
1977
AUGUST
1977
SEPTEMBER
1977
20
65
10
0
10
20
30
40
70
50
60
75
80


OCTOBER
1977
NOVEMBER
1977
DECEMBER
1977

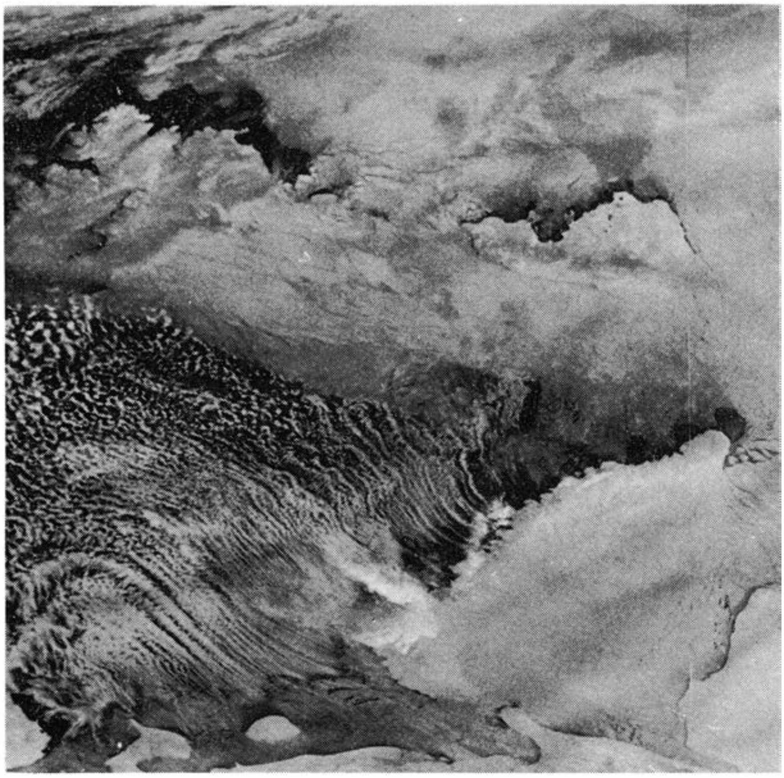


Fig. 2. *Image of the sea ice and weather conditions in the Barents Sea as obtained from the U.S. Nimbus-6 Satellite received at the Tromsø Satellite Telemetry Station on 26 January. Note the large open water areas north of Svalbard (upper left) and Zemlja Franca Iosifa.*

Current was also relatively large in late July with an extreme maximum in some areas north of 75°N. As the atmospheric pressure gradients were weak for these months, the mentioned deviatons are supposedly caused by oceanic circulation.

The variation in the sea ice conditions in August and September followed a more or less normal course. At the end of October there was an extreme maximum in the western part of the Kara Sea which, at least partly, might have been caused by the prevailing easterly winds that month.

NW of Spitsbergen a considerable opening-up took place at the end of October. A relatively extreme northern position of the ice edge was also observed in the area during the rest of the year. The weather conditions seemed to favour this development, as the monthly average atmospheric circulation shows weak winds in September, prevailing easterly winds in October and November, and southerly winds in December.

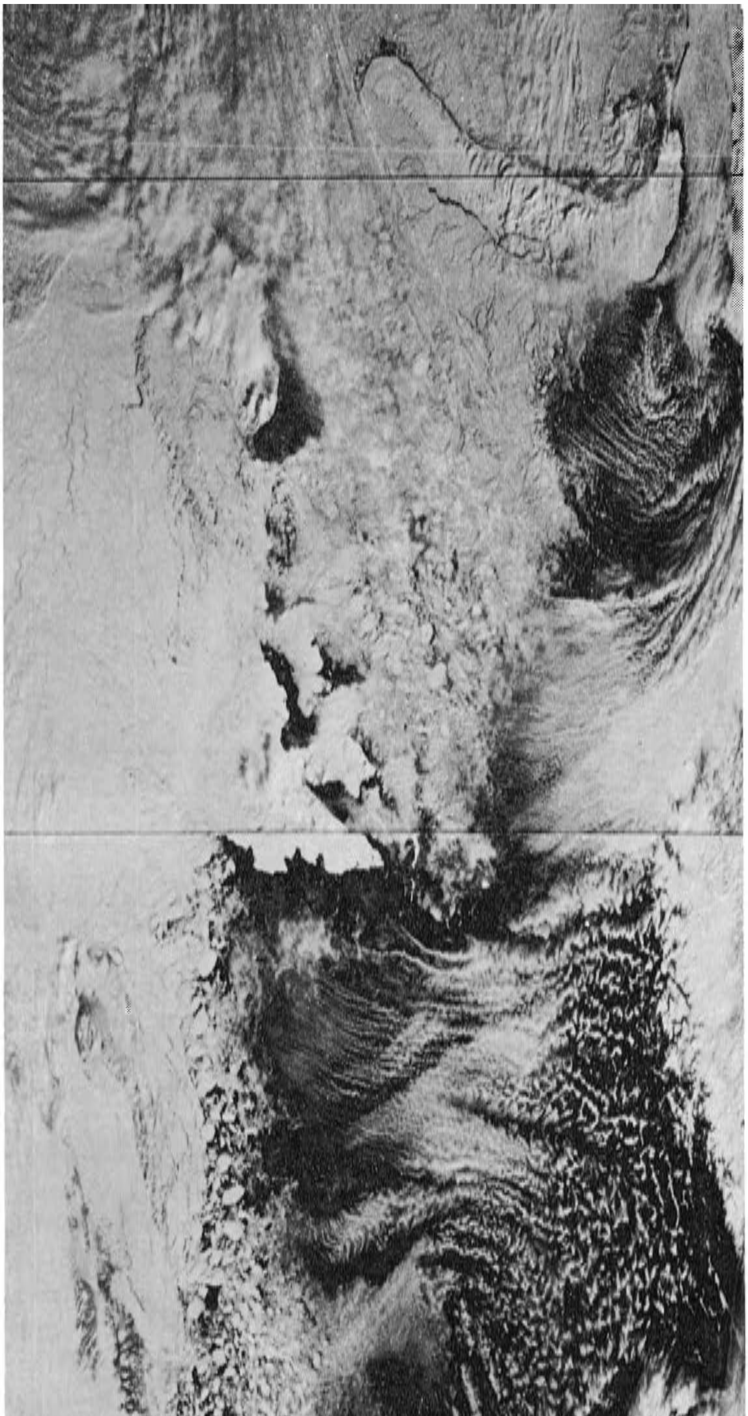


Fig. 3. Image showing the sea ice and weather conditions on 7 May. Note the large individual floes and also the effect on cloud formation of the ice field (Odden) NE of Jan Mayen.

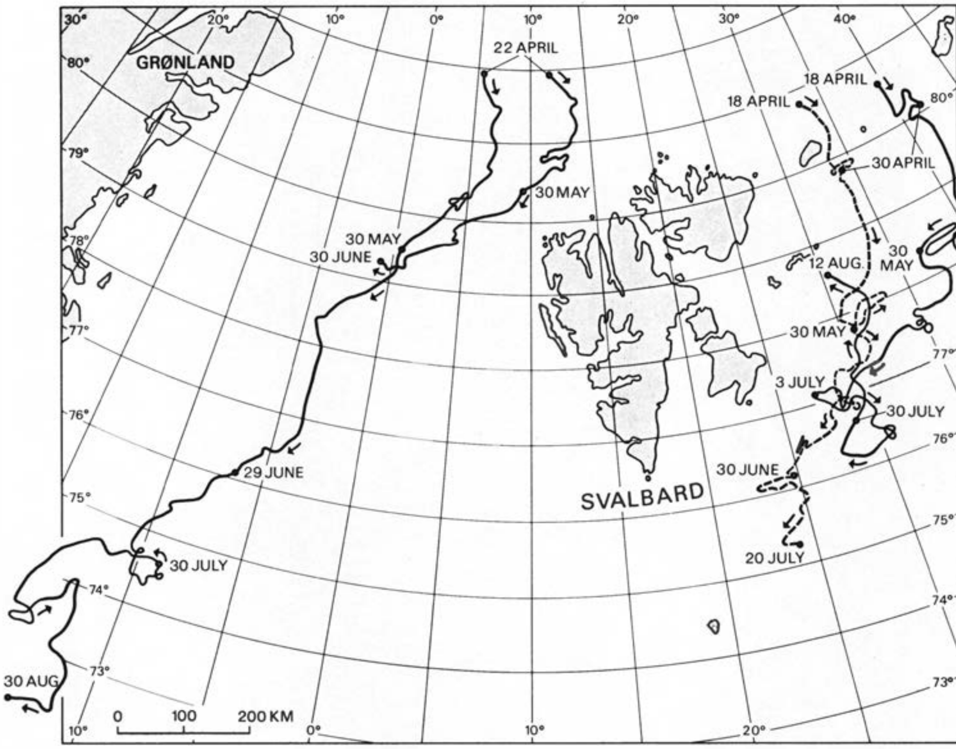


Fig. 4. *The drift paths of four automatic Nimbus-6 stations placed on ice floes in April 1977.*

Drift of satellite located buoys

On 18 and 22 April four automatic Nimbus-6 stations were placed on ice floes by Cessna-185 piloted by Mrs. I. Pedersen. (A description of these stations has been given by Vinje and Steinbakke (1977).) A preliminary presentation, Fig. 4, shows some interesting features relevant to the above discussion. There was a more or less continuous out-flow of ice from the Polar Ocean into the eastern part of the Svalbard archipelago over a relatively long period, lasting from 18 April through May, June, and the first part of July. The observed long lasting out-flow may explain why the disintegration in this area does not follow the usual pattern. The drift speed through the passage between the islands was between 13 and 9 cm sec^{-1}, while the average drift for May and June was 8—9 cm sec^{-1} towards the SSW. This considerable import of multi-annual ice, together with the fact that the ice edge had a more or less normal southern extension, indicate that considerable melting must have taken place in the area in May and June. The melting is supposedly caused by warmer water masses as well as radiation, since the cold, fairly weak prevailing northerly winds should have an opposite effect.

It is interesting to compare the drift velocities observed for May and June with the wind-caused drift calculated by Lunde (1965) for the same area (77.5°N—30°E) using Zubov's formula. For the period 1946—63 Lunde finds a maximum wind-caused drift of 4.5 cm sec^{-1}, i.e. half the value observed for floe drift in the same area in 1977. This illustrates the marked effect of the currents on the ice drift over the shallow banks east of Svalbard which has often been reported by ships operating in the area.

The out-flow through the Fram Strait was governed by north-westerly winds at the end of April and the first part of May. The drift speed between 80 and 81°N was close to 7 cm sec^{-1} for both stations. Between 80 and 75°N the average drift speed was 16.7 cm sec^{-1}. This increase in speed agrees with the well known acceleration which takes place in this area as the drift ice leaves the Polar Ocean.

Ice drift estimates from VHHR

From the VHHR images (Very High Resolution Radiometry) received from the Tromsø Satellite Telemetry Station, it was possible to estimate ice drift speeds for some periods with fair weather conditions. Most of the year the weather was too cloudy for such estimates and for 1977 drift speed values were obtained for the first five months only (Table 1).

Table 1.
Average drift speeds of ice floes as obtained from VHRR.
Drift direction around 020°.

Period	Latitude	Longitude	Speed cm sec-1
17–31 Dec 1976	80.0°	3°W	14.7
16–21 Jan 1977	78.2°	9°W	7.8
«	76.3°	13°W	13.0
«	75.2°	14°W	15.5
14–25 Febr	82.7°	5°W	3.5
«	80.9°	5°E	4.6
«	80.4°	3°W	10.5
11–25 Febr	80.5°	9°W	10.1
21–26 March	82.4°	0°W	7.8
«	81.2°	3°W	7.8
«	81.2°	6°E	7.8
16–24 April	81.5°	0°W	10.4
4–12 May	80.1°	6°E	14.5
«	79.8	0°W	12.8
«	79.0°	3°W	14.5
«	78.8°	2°E	12.8
«	77.8°	3°W	17.7
«	77.3	8°W	14.5

Considering the drift speed observed between 79 and 81°N a minimum speed of the out-flow through the Fram Strait is indicated for February — March. In February this may partly be caused by prevailing SE winds. In March, however, there was a prevailing NNE wind which should stimulate the out-flow. The indicated minimum may therefore possibly reflect the effect of the ongoing consolidation of the ice.

Acknowledgements

Two of the automatic satellite stations were funded by the Norwegian National Committee for GARP. Thanks are extended to NASA for making it possible for us to perform the Nimbus/RAMS experiments, and to the Norwegian Meteorological Institute for its cooperation in the data processing. Mr. Ø. Finnekåsa made the necessary data programs.

References

DET NORSKE METEOROLOGISKE INSTITUTT: Sea ice charts, twice weekly. Oslo.

DEUTSCHER WETTERDIENST: *Die Grosswetterlagen Europas.* Offenbach.

FLEET WEATHER FACILITY: Weekly sea ice charts. Suitland.

LUNDE, T., 1965: Ice conditions at Svalbard 1946—1963. *Norsk Polarinstitutt Årbok* 1963: 61—80.

VINJE, T. E., 1977: Sea ice conditions in the European sector of the marginal seas of the Arctic, 1966—1975. *Norsk Polarinstitutt Årbok* 1975: 163—174.

VINJE, T. E. and P. STEINBAKKE, 1977: Nimbus-6 located automatic stations in the Svalbard waters in 1975. *Norsk Polarinstitutt Årbok 1*975: 109—117.

Radiation conditions in Spitsbergen in 1977

BY TORGNY E. VINJE

Introduction

Continuous radiation measurements were started in Ny-Ålesund (78°50'N, 11°30'E) in the beginning of 1974 with the purpose of learning more about the local climate and, particularly, of studying the heat budget of the extensive area of open water which may be found at these high latitudes all year round.

To avoid impurities on the glass and polyethylene domes, all instruments are artificially ventilated. They are inspected daily by the personnel tending the observatory. A description of instruments and calibration methods is given by Vinje in Norsk Polarinstitutt Årbok 1974.

Results

The monthly sums of some of the radiation components registered are given in Table 1, together with the albedo of the surface.

The annual sum of the global radiation, 59,800 cal cm^{-2}, is 5.5% higher than the maximum observed during the 10-year period at the neighbouring station Isfjord Radio from 1951 to 1960 (Spinnangr 1968). Much of this difference is caused by a relatively high June value which is as much as 42% higher than the lowest value observed since 1974 at Ny-Ålesund (Vinje 1975—77). Because of the multiple reflections there is a clear accordance between snow cover and cloud cover on the one side and global radiation on the other. As the weather conditions are normal for the season (Hisdal 1978), the comparatively high June value is probably caused by the late disappearance of snow that year, 30 June 1977, compared with 10 June in 1976 when the minimum global radiation was observed. The corresponding monthly average albedo is 0.199 and 0.625.

Table 1

Monthly sums, ly month^{-1}, of radiation components at Ny-Ålesund in 1977

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
G		55	2015	8396	14940	16032	10537	5339	2246	239			59799
a			0.789	0.784	0.790	0.625	0.135	0.131*	0.250	0.720			
A	14594	12695	12373	13089	16877	18433	20458	19852	18403	18021	15851	15894	196540
BL	—1867	—935	—856	657	1785	5246	7405	3491	305	—922	—1588	—1307	11414
BS	—5897	—5764	—6305	815	9826	13032	9450	4166	594	—2255	—3979	—4597	9086

G = global radiation
a = albedo
A = long-wave radiation from the atmosphere
BL = total radiation balance of the surface
BS = calculated total balance under similar cloud cover of a surface of temperature 0°C and with an albedo of 0.1
* = average from previous three years because of instrument failure

From 17 June the diffuse short wave radiation is measured by an Eppley temperature compensated pyranometer. The atmospheric long wave counter radiation is calculated from registrations by the Schulze radiometer. By screening off the sun we reduce the problems regarding the deviation from the cosine law of the radiometer.

References

HISDAL, V., 1978: The weather in Svalbard in 1977. *Norsk Polarinstitutt Årbok* 1977: 279—282.

SPINNANGR, G., 1968: Global radiation and duration of sunshine in Northern Norway and Spitsbergen. *Met. Ann.* 5 (3). Oslo.

VINJE, T. E., 1975—77: Radiation conditions in Spitsbergen. Annual reports in *Norsk Polarinstitutt Årbok.*

Observations of animal life in Svalbard in 1977

By THOR LARSEN

Abstract

Observations of birds and mammals in Svalbard were collected from 21 persons and expeditions in 1977. There are also some observations from 1976 from Bjørnøya. Some quantitative information has been obtained on the eider *(Somateria mollissima)*, the pink-footed goose *(Anser fabalis brachyrhynchus)*, and the barnacle goose *(Branta leucopsis)*. The musk-ox population in Svalbard has decreased dramatically, and probably only two animals were left in 1977. Most observations are from Bjørnøya, Spitsbergen, and Edgeøya. The majority of observations were made between June and September, but there are also spring and autumn observations from Bjørnøya.

Introduction

Information on the fauna of Svalbard has been obtained from 21 observers and expeditions to Svalbard in 1977. From Bjørnøya there are also some observations from 1976. The observations are from the Isfjorden area, Ny-Ålesund, Kongsfjorden, Reinsdyrflya and Liefdefjorden, Mosselhalvøya, Kong Karls Land, Edgeøya, and Bjørnøya.

Quantitative information on reindeer *(Rangifer tarandus platyrhynchus)* is not presented here, except for Edgeøya, since data on this species is obtained through the MAB programme, and will be published separately. I am grateful to the following persons and groups for their contribution of data and information: B. Amundsen (BA) from Femtebreen, K. Birkenmajer (KB) from Agardhbukta and Sabine Land, K. Bratlien (KBR) from Longyearbyen, Eie, Jørgensen, and Støen (E/J/S) from Mosselhalvøya, N. Elfarvik (NE) from Bjørnøya, N. Gullestad (NG) from Mitrahalvøya, T. Hansen (TH) from Reinsdyrflya and Liefdefjorden, S. Karlsen (SK) from Kongsfjorden, O. Kindberg (OK) from Bjørnøya, Ø. Lauritzen (ØL) from Kapp Wijk, R. Olgierd (RO) from van Keulenfjorden, P. Prestrud

(PP) from the Ny-Ålesund area, T. Punsvik (TP) from Helvetiadalen, the Dutch Reindeer Expedition Edgeøya Svalbard (REES) from Edgeøya. J. Reisegg (JR) from Kapp Wijk, O. Salvigsen (OS) from Reinsdyrflya and Liefdefjorden, O. Steine (OST) from Sveagruva, H. Staaland (HS) from Adventdalen, K. Yazaki (KY) from Agardhbukta, R. Aabakken (RAA) from Nordenskiöld Land, and J. Åkerman (JÅ) from Kapp Linné.

Most information has been given on the questionnaires, but data have also been obtained from various reports (Oosterveld 1977; Owen et. al. 1978).

Mammals

M u s k o x *(Obvibos moschatus):* Several animals died during 1977, and the total population is probably of no more than two or three animals at the end of 1977. (RAA).

H a r e *(Lepus sp.):* Tracks possibly from a hare, were seen and documented on photographs in Agardhbukta in March (KY).

R e i n d e e r *(Rangifer tarandus platyrhynchus):* The total reindeer population in Edgeøya was estimated to between 1,000 and 1,200 animals in the summer of 1977 (REES). A few observations were made of reindeer outside their normal range. Seven adults and three juveniles were seen in Væringsdalen in July and August (KB). Tracks from at least two adult animals were seen in the snow in Mosselbukta on 13 August (E/J/S). One male and two female reindeer were seen on Svenskøya in March and April (RAA). Tracks and faeces showed that there are reindeer also on Kongsøya (author). One male reindeer was seen on Mitrahalvøya on 17 July (NG).

P o l a r b e a r *(Ursus maritimus):* Observations from Kong Karls land in March and April and from the sea between Svalbard and Frans Josef Land in August, are treated in special reports and publications. There are also a few summer observations from Spitsbergen, possibly of the same animal. Observations of a single adult were made in Adventdalen on 2 July (HS), at Sveagruva on 25 July (OST), and from Helvetiadalen/Revneset on 3 August (TP). A young bear occurred in Magdalenefjorden in July, where it killed a man (RAA). Two mating bears were observed on Bjørnøya on 12 March (OK). Two other mating bears were seen in Mohnbukta in April (Hagen, this volume).

W a l r u s *(Odobenus rosmarus):* Six adult animals were observed outside Femtebreen on 8 May (BA). 12—13 adults were seen on Moffen on 12 August (E/J/S).

Birds

G r e a t n o r t h e r n d i v e r *(Gavia immer):* Two adults in Fyrsjøen on 9 July (JÅ). Two adults at Erikbreen on 23 July. One adult in Freemannsundet on 18 August (REES).

Teal *(Anas crecca):* On Bjørnøya, observations were made on five different localities: one male and one female on 19 May, and one male on the same date on another locality. Two males and one female on 22 May, two males and two females on 24 May, and one male on the same date on another locality. (NE).

Tufted duck *(Aythya fuligula):* Four females and one male were seen at Framnes, Bjørnøya, on 18 May, and on Flakmyrane on 20 May (NE).

Goldeneye *(Bucephala clangula):* One male in Herwighamna, Bjørnøya, on 11 November 1976 (OK).

Long-tailed duck *(Clangula hyemalis):* About 50 adults stayed at Bjørnøya throughout the winter 1976/77 (OK).

Steller's eider *(Polysticta stelleri):* Three males and five females in Nordhamna, Bjørnøya, on 10 April. They were also observed on 2 May (OK).

King eider *(Somateria spectabilis):* 70—80 adults in Forlandssundet at Kjærsvika on 12 July (PP). About 40 adults at Agardhpynten on 6 August (KB), and about 200 adults in Agardhbukta on 12 August (KB).

Eider *(Somateria mollissima):* See Table 1.

Pink-footed goose *(Anser fabalis brachyrhynchus):* See Table 2.

Brent goose *(Branta bernicla hrota):* Two adults in Nordre Flakmyrvatn, Bjørnøya, on 29 May (NE). Four adults at Velkomstvarden on 19 August (TH).

Barnacle goose *(Branta leucopsis):* See Table 3.

Sparrow hawk *(Accipiter nisus):* One adult at Bjørnøya Radio 12—14 April (OK).

Table 1.

*Observations of large flocks of eider (*Somateria mollissima*) in Svalbard in 1977. Flocks of less than 50 birds not listed.*

Locality/Date	Number	Observer/Remarks
Bjørnøya, winter 1976/77	about 100	Wintering (OK).
Bjørnøya, 9/2	800—1,000	Migrating (OK).
Forlandssundet at Kjærsvika, 12/7	350—400	(PP)
Kongsfjorden, 17—19/7, six localities	—	609 nests, of which 77 were damaged. 1—3 eggs in 88 nests inspected (SK).
Lyseren — Ebeltofthamna, 5/8	288 males, 1,158 females, 475 juveniles	Average clutch size 3.2 (NG).
Sterneckøya, 7—12/7	350—400 adults	120 nests observed, with 1—3 eggs in each (RO).

Table 2.
Observations of pink-footed goose (Anser fabalis brachyrhynchus) *in Svalbard in 1977.*

Locality/Date	Number	Observer/Remarks
Kapp Olsen, Bjørnøya, 18/5	72 adults	First observation (NE)
Bjørnøya Radio, 29/5	52 adults	NE
Blomstrandhavna, 12/7	30—40 adults, 10 juveniles	PP
Blomehalvøya, 27/7	268 adults	ØL
Habenichtbukta, 30/7	66 adults, 61 juveniles	REES
Diesetvatna, 10/8	about 100 adults and juv.	NG
Sørdalsflya, 18/8	162 adults	TH
Kongsfjorden, late August/early September	Several small flocks	Migration? (PP)

Table 3.
Observations of Barnacle goose (Branta leucopsis) *in Svalbard in 1977.*

Locality/Date	Number	Observer/Remarks
Bjørnøya, 17—24/5	About 600	Observed during spring migration. Up to 200 birds in one flock (NE).
Ny-Ålesund area, summer 1977	120—150 individuals	PP
Nordenskiöld-kysten, June to September	1,333 adults	Counts. Gosling production was a record low (Owen et al. 1978).
Kapp Lee area, primo September	200 adults, 50 juveniles	REES
Bjørnøya radio, 10/9	About 550 adults	Migration (OK).
Bjørnøya radio, 3/10	54 adults	Last observation in 1977 (OK).

Greenland falcon *(Falco rusticolus candicans):* One adult bird at Ny-Ålesund on 24 and 27 September. Another bigger adult on 8 and 9 October (PP).

Merlin or kestrel *(Falco columbarius* or *F. tinnunculus):* One adult in Lunckevika and Tunheim, Bjørnøya, on 20 May and 22 May, respectively (NE).

Water rail *(Rallus aquaticus):* One adult was found at Bjørnøya Radio on 18 November 1976. The bird died after a few days (OK).

G o l d e n p l o v e r *(Pluvalis apricaria):* One adult at Bjørnøya Radio on 1 July (NE).

S n i p e *(Gallinago gallinago):* One adult found dead at Hansvatnet, Bjørnøya, on 3 May (OK).

J a c k s n i p e *(Lymnocryptes minimus):* One adult found dead at Bjørnøya Radio on 28 October (OK).

W o o d c o c k *(Scolopax rusticola):* One adult at Russehamna, Bjørnøya, on 16 October 1976 (OK).

K n o t *(Calidris canutus):* 18 adults at Flakmyrvatna, Bjørnøya, on 29 May (NE).

L i t t l e s t i n t *(Calidris minuta):* One adult in Walther Thymensbukta, on 22 August (REES).

D u n l i n *(Calidris alpina):* One adult at Småflakvatna, Bjørnøya, on 8 July 1976 (OK).

S a n d e r l i n g *(Crocethia alba):* One adult at Måketjørna, Bjørnøya, on 27 June (NE). Three adults at Kapp Linné, on 20 July (JÅ).

R u f f *(Philomachus pugnax):* One male in Habenichtbukta, on 31 August (REES).

G r e a t s k u a *(Catharacta skua):* 80 to 100 adults at Tyvjoflya, Bjørnøya, on 8 July 1976 (OK). Three adults at Stuphallet, on 15 July and two at Kapp Guissez on 2 August (PP). Two adults on Mitrahalvøya on 18 July (NG).

I v o r y g u l l *(Pagophila eburnea):* Two new colonies have been established in Hårfagrehaugen on Kongsøya since 1974. Each colony has approximately 35—40 breeding pairs (author).

H e r r i n g g u l l *(Larus fuscus):* One adult in Russebukta on 9 August (REES).

B l a c k - h e a d e d g u l l *(Larus ridibundus):* Three adults at Bjørnøya Radio on 26 May (NE). One adult in Longyearbyen on 5 June (HS). One pair at Isfjord Radio 4—9 July (JÅ).

R o s s g u l l *(Rhodostethia rosea):* Seven different birds were seen in the drift ice between Kong Karls Land and Frans Josef Land in August (author).

S n o w y o w l *(Nyctea scandiaca):* One female in Kobbebukta, Bjørnøya, on 3 February (OK). One adult at Leefjellet, on 15 August, and another at Ferriflota, on 16 August (REES).

S k y l a r k *(Alauda arvensis):* Two adults at Bjørnøya Radio, on 1 October 1976 (OK).

S w a l l o w *(Hirundu rustica):* One adult found dead at Bjørnøya Radio on 11 January (OK). One adult in Herwighamna, Bjørnøya, on 18 June (NE).

H o o d e d c r o w *(Corvus cornix):* One adult was observed at Bjørnøya Radio on 13 April (OK), in Evensenbukta, Bjørnøya, on 14 May, in Teltvika, Bjørnøya, on 20 May, and at Tunheim, Bjørnøya, on 21 May (NE).

Rook *(Corvus frugilegus):* One adult at Bjørnøya Radio on 14 April (OK).

Fieldfare *(Turdus pilaris):* One adult at Bjørnøya Radio 5—29 October 1976 (OK).

Redwing *(Turdus musicus):* From five to twelve adults were seen at different localities on Bjørnøya between 3 and 29 October 1976 (OK).

Blackbird *(Turdus merula):* Three males and five females at Bjørnøya Radio, on 17 November 1976 (OK). One male and one female at Bjørnøya Radio on 12 April (OK).

Wheatear *(Oenanthe oenanthe):* One adult at Bjørnøya Radio on 28 May (NE). One pair, probably breeding, at Ossian Sars fjellet on 19 July (PP).

Whinchat *(Saxicola rubetra):* One adult at Bjørnøya Radio on 23 September 1976 (OK).

Robin *(Erithacus rubecula):* Two adults at Bjørnøya Radio on 21 October 1976 (OK).

Willow warbler *(Phylloscopus trochilus):* One adult at Tunheim, Bjørnøya, on 10 October 1976 (OK).

Meadow pipit *(Anthus pratensis):* One adult on the beach at Ossian Sars fjellet on 19 July (PP).

Rock pipit *(Anthus spinoletta):* One adult at Bjørnøya Radio on 16 July 1976 (OK).

Wagtail *(Motacilla alba):* One adult at Bjørnøya Radio on 1 September 1976 (OK).

Starling *(Sturnus vulgaris):* Two adults at Bjørnøya Radio on 1 September 1976 (OK).

Redpoll *(Carduelis flammea):* One adult at Kapp Olsen, Bjørnøya, on 22 October 1976 (OK).

References

HAGEN, GERD, 1978: An observation of polar bear mating in Svalbard. *Norsk Polarinstitutt Årbok* 1977: 252—253.

OOSTERVELD, P., 1977: *Reindeer/Environment Research Program Edgeøya, Svalbard, 1977. Preliminary report on fieldwork, Edgeøya, July 17th — Sept. 12th 1977.* Typewritten. 6 pp.

OWEN, M., R. H. DRENT, M. A. OGILVIE, and T. M. VAN SPANJE, 1978: Numbers, distribution and catching of baranacle geese *Branta leucopsis* on the Nordenskiöldkysten, Svalbard, in 1977. *Norsk Polarinstitutt Årbok* 1977: 247—258.

Norsk Polarinstitutts virksomhet i 1977

Av TORE GJELSVIK

Organisasjon og administrasjon

PERSONALE

Norsk Polarinstitutt hadde 34 faste stillinger i 1977, det samme som foregående år. Pr. 31.12. var en stilling som avdelingsingeniør (topograf) og en stilling som administrasjonssekretær ubesatt.

Som et resultat av lønnsforhandlingene 1977 ble med virkning fra 1.5.77 stillingene som førstehydrograf og førstetopograf omgjort til overingeniørstillinger, stillingene som hydrografer, topografer, geodet og inspektør til avdelingsingeniørstillinger, og stillingene som oppmålingsteknikere til ingeniørstillinger.

Den faste staben:

Direktør	Gjelsvik, Tore, dr. philos.
Underdirektør	Lundquist, Kaare Z., o/kapt.
Kontorsjef	Lund, Reidar, cand. jur.
Forsker (lønnskode 0072):	
Glasiolog	Liestøl, Olav, cand. real.
Geolog, operasjonssjef	Siggerud, Thor, cand. real.
Geolog	Winsnes, Thore, cand. real.
Forsker (lønnskode 0071):	
Meteorolog	Hisdal, Vidar, cand. real.
Geolog	Major, Harald, cand. real.
Geolog	Ohta, Yoshihide, Ph. D.
Glasiolog	Orheim, Olav, Ph. D.
Havisforsker	Vinje, Torgny, cand. real.
Forsker (lønnskode 0070):	
Geolog	Hjelle, Audun, cand. real.
Biolog	Larsen, Thor, cand. real.
Geolog	Lauritzen, Ørnulf, cand. real.
Geolog	Salvigsen, Otto, cand. real.

Hydrografer:	
Overingeniør	Hornbæk, Helge, høyere skipsførereksamen
Avdelingsingeniør	Fjørtoft, Jon, marineløytnant
Avdelingsingeniør	Moen, Erik, høyere skipsførereksamen
Topografer:	
Overingeniør	Helle, Sigurd, cand. mag.
Avdelingsingeniør (geodet)	Steine, Ola, jordskiftekandidat
Avdelingsingeniør	Sundsby, John, cand. real.
Konsulent	Hagevold, Peter, cand. mag.
Avdelingsingeniør	Arnesen, Bjørn
Ingeniør	Mandt, Reidar
Ingeniør	Mehlum, Øivind
Bibliotekar	Lund, Reidunn
Materialforvalter	Bratlien, Kåre
Administrasjonssekretær	Andersen, Eva
Førstekontorfullmektig	Øverland, Signe
Kontorfullmektig	Edwardsen, Gudrun
Laborant	Møller, Jon
Kontorassistent, fra 4.9	Gregersen, Anne
Kontorassistent, til 12.6	Rynning, Anne Mette

Midlertidig engasjerte:

Redaksjonssekretær (timelønnet)	Brekke, Annemor
Hjelpearbeider, fra 11.7	Christensen, Guttorm
Maringeolog, fra 1.5 (lønnet av NTNF på Barentshavprosjektet)	Elverhøi, Anders, cand. real.
Geofysiker (timelønnet)	Finnekåsa, Øivind, cand. mag.
Assistent	Huseth, Rolf Egil
Kontorassistent	Knudsen, Elsa
Tegneassistent (deltidsstilling)	Kopperud, Espen
Geofysiker (lønnet av NTNF på Barentshavprosjektet)	Kristoffersen, Yngve, Ph. D.
Ingeniør, fra 12.4 (vikar)	Nilsen, Tormod Holth

Stipend og forskningsoppdrag er gitt til:

Cand. mag. Pål Prestrud, kr. 10 200,— til dekning av utgifter i forbindelse med hovedfagsoppgave om årstidsvariasjoner i energiomsetningen hos polarrev.

Cand. mag. John Gjelberg, kr. 6 000,— som støtte til hovedfagsoppgave om sedimentologiske undersøkelser på Bjørnøya og Spitsbergen.

Cand. mag. Aage Tørris Ekker, kr. 16 000,— til fortsettelse av hovedfagsoppgave om kortnebbgås på Svalbard.

Cand. real. Tore Prestvik, kr. 3 000,— til delfinansiering av analyseutgifter vedrørende prøver av vulkanske bergarter på Spitsbergen.

Cand. mag. Else Ormåsen, kr. 1 500,— til bearbeidelse av innsamlede sedimentprøver fra Svalbard i forbindelse med hovedfagsoppgave i mikropaleontologi.

Cand. mag. Jørn Thomassen, kr. 7 000,— som støtte til hovedfagsoppgave om isbjørnens adferd og jaktteknikk i Svalbardområdet.

Cand. mag. Christian Keller, kr. 9 000,— til delvis dekning av vikarutgifter mens han deltok i Nordisk Arkeologisk Ekspedisjon på Grønland.

Cand. mag. Sven A. Bäckstrøm, cand. mag. Max Aage Eien og cand. mag. Halvdan Ramberg Moe, kr. 2 000,— hver til delvis dekning av utgifter ved paleontologiske og sedimentologiske undersøkelser på Svalbard.

Cand. mag. Øistein Haga, kr. 3 000,— til dekning av reiseutgifter og opphold på Svalbard i forbindelse med hovedfagsoppgave i kvartærgeologi.

Førsteamanuensis Gisle Grønlie, kr. 5 000,— til delvis dekning av trykningsutgifter for et batymetrisk kart han har utarbeidet over Norskehavet og Grønlandshavet.

Kartgrafiker Reidar Mandt, kr. 3 119,— til dekning av utgifter ved gjennomgåelse av kurs i kartografi ved Kungliga Tekniska Høgskolan i Stockholm.

Cand. mag. Rolf Bjørnstad og cand. mag. Morten Schaaning, kr. 3 100,— hver til dekning av utgifter ved innsamling av marinbiologiske prøver fra havområdene ved Svalbard.

Cand. mag. Svein Bergersen, kr. 9 000,— til et prosjekt om bygging og testing av nye instrumenter for jonosfæreundersøkelser ved Siple Station i Antarktis.

Forsker Steven de Bie, kr. 2 500,— til delvis dekning av utgifter ved opphold i Bergen i forbindelse med arbeid med avhandling om reinens utvikling på Edgeøya siden 1969.

Siv.ing. Bjørn Anders Fossum, kr. 10 000,— i forbindelse med bearbeiding av navigasjonsdata fra Antarktisekspedisjonen 1976/77.

Amanuensis Thor Kvinge, kr. 2 500,— til delvis dekning av utgifter ved deltakelse i møte i International Coordinating Group for the Southern Oceans.

REGNSKAP FOR 1977

Kap. 950. Poster:

		Bevilget:		*Medgått:*
1. Lønninger	kr.	3 890 000	kr.	3 984 900
9. Deltakelse i Antarktisekspedisjonen, kan overføres	kr.	2 500 000	kr.	3 062 000
10. Kjøp av utstyr	kr.	70 000	kr.	69 900
15. Vedlikehold	kr.	5 000	kr.	5 100
20. Ekspedisjoner til Svalbard og Jan Mayen	kr.	2 830 000	kr.	2 666 300
21. Forskningsstasjonen på Svalbard	kr.	1 275 000	kr.	1 299 600
22. Vitenskapelig samarbeid i Arktis	kr.	600 000	kr.	260 700
29. Andre driftsutgifter	kr.	1 400 000	kr.	1 566 600
70. Stipend	kr	100 000	kr.	100 000
	kr.	12 670 000	kr.	13 015 100
Kap. 31. Fyr og radiofyr på Svalbard	kr.	50 000	kr.	33 700
Kap. 3950 Inntekter:				
01. Salgsinntekter	kr.	80 000	kr.	89 800
03. Inntekter ved diverse tjenesteyting	kr.	10 000	kr.	0
52. Refusjon fra Svalbardbudsjettet	kr.	1 000 000	kr.	1 000 000
	kr.	1 090 000	kr.	1 089 800
Kap. 4905. Tilfeldige inntekter	kr.	0	kr.	800

Kommentar til regnskapet

Kap. 950.

Post 1. Lønninger. — Merutgiften skyldes økte lønnsutgifter som følge av lønnsregulering pr. 1.5.1977.

Post 9. Deltakelse i Antarktisekspedisjonen. — I tillegg til bevilgningen for 1977, kr. 2 500 000,— er kr. 507 000,— overført av ubrukte midler for 1976, slik at de samlede midler for 1977 var kr. 3 007 000,—. Merutgiftene i forhold til dette beløp er da *kr. 55 000,—*, som skyldes større bunkersutgifter for ekspedisjonsfartøyet enn beregnet.

Post 20. Ekspedisjoner til Svalbard og Jan Mayen. — Mindreutgiftene skyldes at det ikke var mulig å få leiet helikopter til bruk under ekspedisjonen på Svalbard.

Feltarbeid

NORGE

Geofysikk

Massebalansen på Storbreen i Jotunheimen og på Hardangerjøkulen ble målt av Olav Liestøl, Kjell Repp og Bjørn Wold. Forenklede balansemålinger ble foretatt på Blomsterskardbreen (Folgefonni).

Bretungenes lengdevariasjoner ble målt på 11 breer. Fem breer gikk frem, mens resten gikk tilbake. Briksdalsbreen gikk frem 23 m og er nå lengre fremme enn den har vært siden 1948.

SVALBARD

Norsk Polarinstitutt opprettholdt i 1977 feltvirksomheten på Svalbard dels i egen regi og dels ved å yte støtte til annen forskning. Den biologiske virksomheten startet med isbjørnundersøkelser i mars og april, og det geofysiske arbeidet i Ny-Ålesund-området ble gjenopptatt i mai. I alt deltok syv mann i vinter- og vår-ekspedisjonene.

Instituttets sommerekspedisjonsvirksomhet ble planlagt, organisert og ledet av forsker Thor Siggerud. Foruten besetningene på fartøyene var det 38 deltagere med under hele ekspedisjonen og to deltagere i kortere tid. I tillegg deltok også fem på Barentshavprosjektet som hovedsakelig er finansiert utenom ekspedisjonsbevilgningen, men hvor feltarbeidet er nær knyttet sammen med hydrograferingsarbeidet.

Av deltagerne var fjorten fast ansatte ved Norsk Polarinstitutt og to helårsengasjerte. En deltok i både vår- og sommerekspedisjonen. Syv av deltagerne var engasjert for sommeren som fagmedarbeidere med ansvar for eget faglig arbeid, 29 var engasjert som assistenter o.l. med varierende faglige kvalifikasjoner.

På ekspedisjonsfartøyet var ytterligere to forskere med for hele sesongen og to i kortere tid. Disse drev med undersøkelser finansiert av andre midler eller hadde stipendium fra Norsk Polarinstitutt.

I 1977 kunne Norsk Polarinstitutt ikke klare å skaffe helikoptre, og partiene, som arbeidet spredt over hele Svalbard, ble understøttet av ekspedisjonsfartøyet M/S «Polarstar» med kaptein Johan Holstad. Fartøyet lastet i Bodø 14.7 og returnerte 6.9. Feltpartiene hadde geologiske, biologiske, geodetisk-topografiske og hydrologiske arbeidsoppgaver. Ombord i ekspedisjonsfartøyet ble drevet biologiske observasjoner og tatt marinbiologiske oseanografiske prøver. Fra ekspedisjonsfartøyet ble tatt og sendt synoptiske meteorologiske observasjoner til Meteorologisk Institutt.

Ekspedisjonsfartøyet seilte i løpet av sommeren rundt Svalbard. Det foretok også undersøkelser i isområdet østover fra Svalbard til den sovjetrussiske territorialfarvannsgrensen ved Frans Josef Land. Isvanskelighetene var relativt små for det forholdsvis kraftige stålfartøyet som ble brukt til ekspedisjonsfartøy.

Hydrograferingsfartøyet M/S «Olaf Scheel» med kaptein Ingolf Røren, lastet utstyret i Bodø 13.6 og returnerte til Bodø 7.9.

Havhydrograferingen med M/S «Olaf Scheel» måtte foregå i et lavere prioritert arbeidsområde på grunn av drivisforholdene øst for Svalbard, og foregikk utenfor den sørvestre del av Spitsbergen og sørøst for Bjørnøya. Geofysiske og maringeologiske arbeider ble utført samtidig. Hydrografering i indre farvann foregikk i Isfjorden med hydrograferingsbåten «Svalis».

På Jan Mayen støttet instituttet arbeidet til to hovedfagstudenter i glasiologi og kvartærgeologi.

Ekspedisjonen ble stort sett gjennomført etter programmet uten uhell eller ulykker.

Ekspedisjonen støttet og samarbeidet med flere grupper: Kulturvernkonsulenten for Svalbard (to deltagere), University of Wisconsin (tre deltagere), University of St. Louis (to deltagere), MAB-prosjektet, o.a. Ren transportstøtte ble gitt grupper fra Universitetet i Oslo, Miljøverndepartementet, Norges Landbrukshøyskole og Sysselmannen på Svalbard. Tilfeldig assistanse ble også ydet andre når det passet. Flere av instituttets stipendiater ble støttet med utrustning og transport.

Etter henstilling fra Sysselmannen unnsatte ekspedisjonsfartøyet en fransk gruppe med tre deltagere på Amsterdamøya. Den var sluppet opp for mat fordi den ikke ble hentet av hurtigruten som avtalt. Likeledes etter henstilling fra Sysselmannen, ble 15 sveitsiske og østerrikske turister hentet i Magdalenefjorden, etter at en av deltagerne var blitt drept av isbjørn. Begge disse gruppene ble transportert til Longyearbyen.

Geofysikk

Liestøl oppholdt seg på Svalbard fra 24.5 til 28.6, hele tiden i Ny-Ålesund. Han foretok en detaljert måling av akkumulasjonen på Lovén- og Brøggerbreene. Dessuten ble utviklingen av den påfrosne is på breoverflaten fulgt. På Lovénbreen ble alle stengene skiftet ut.

Det hydrologiske prosjekt i Brøggerbreens dreneringsområde startet i 1976 og ble fortsatt med slam- og vannføringsmålinger, men i tillegg ble det tatt prøver av sedimentkjerner i fjorden utenfor Bayelva. Dette arbeid har nå fått en egen årlig bevilgning fra Den norske hydrologiske komité. Arbeidet ble for en vesentlig del utført av Kjell Repp som oppholdt seg i Ny-Ålesund fra 25.6 til 16.8.

Vidar Hisdal oppholdt seg ved Forskningsstasjonen i Ny-Ålesund i tiden 24.5 til 27.6. Han fortsatte målingene av dagslyset under ulike værforhold og solhøyder, og av atmosfærens reduksjon av den direkte solstråling. Videre ble det utført sammenlignende registreringer av innkommende lys fra skydekket over åpent vann og over en snedekket overflate. Ved hjelp av et nytt spektralpyrheliometer ble det startet en serie observasjoner av atmosfærens totale vanndampinnhold over stasjonen.

Torgny Vinje var i april i Ny-Ålesund og klargjorde fire Numbus satellittstasjoner for isdriftmålingene. To stasjoner ble satt ut på østsiden mellom Nordaustlandet og Frans Josef Land (Barentshavprosjektet), og to i Framstredet mellom Grønland og Spitsbergen (GARP-prosjektet). En femte stasjon var defekt og ble returnert for reparasjon.

De dagene det ikke var kontroll og transport av de automatiske stasjonene, arbeidet han på Forskningsstasjonen med kalibrering og justering av alle strålingsinstrumentene.

Hydrografi

Fra hydrograferingsbåten «Svalis» ble det foretatt opplodding i målestokken 1:50 000. Is- og værforholdene var gode og hele Nordfjorden og et godt stykke ut i Isfjorden, i alt 600 km², ble målt. Motorola-systemet ble med godt resultat brukt helt ut til 35 km's avstand. Det ble arbeidet i skift med to lag. Arbeidet ble ledet av hydrograf Helge Hornbæk, assistert av hydrograf Leif Nordli samt feltassistentene Sivert Utheim, Jon Reisegg, Ingvar Vifladt og Viggo Eriksen.

M/S «Olaf Scheel» drev havlodding i døgndrift med posisjonssystemet HI-FIX. Toktet ble ledet av hydrograf Erik Moen, assistert av hydrograf Jon Fjørtoft og engasjert elektroingeniør Erik Mørk, samt feltassistentene Harald Grønlien, Svein Aasen og Siri og Jo Ellefsen. De høyest prioriterte områdene var blokkert av is, blant annet var det ikke mulig å få etablert HI-FIX stasjoner hverken på Hopen, Ryke Yseøyane eller Kong Karls Land. I tilknytning til tidligere loddinger ble det først arbeidet på Hornsundbanken og senere sørøst for Bjørnøya. I alt ble det gått ca. 4380 n. mil loddelinjer.

Geodesi-topografi

Ola Steine oppholdt seg i Longyearbyen 19—28. april for å skaffe opplysninger om snøscooterløyper og hytter for turkart i målestokk 1:200 000. Noen løyper ble synfart.

Steine og assistent Svein Gulbrandsen kom til Ny-Ålesund 9. juli hvor tidevannsmåleren ble skiftet ut. Det trigonometriske nettet ved Brøggerbreen ble fortettet, og en avstand over breen ble målt med tellurometer.

Partiet kom til Longyearbyen 15. juli og skulle etter planen reise videre til Sveagruva noen dager senere. M/S «Polarstar» klarte ikke i denne omgang, på grunn av isvansker, å ta seg fram til Sveagruva med feltutstyret og den andre feltpartiassistenten, Tormod Holth Nilsen. Oppdraget måtte utsettes. Partiet fulgte i mellomtiden M/S «Polarstar» til Ny-Ålesund og fortsatte oppmålingene for glasiologen ved Midre Lovénbreen og Austre Brøggerbreen.

Partiet reiste så fra Ny-Ålesund 22. juli med M/S «Polarstar» og kom til Sveagruva 24. juli. Lavlandet omkring den indre del av Van Mijenfjorden ble målt og knyttet til hovednettet. En tidevannsmåler — TG-3A — ble montert i Sveagruva. Partiet kom til Longyearbyen 12. august og assisterte firmaet Viak A/S som drev kartlegging for SVSK, med avstandsmålinger med tellurometer. Med M/S «Nordsyssel» som transportmiddel ble fyrlyktene i Barentsburg og i Pyramiden innmålt. Videre foretok partiet med hjelp av helikopter som befant seg i Longyearbyen, passpunktmåling øst for Tempelfjorden. Partiet reiste tilbake fra Longyearbyen med M/S «Polarstar».

John Sundsby med assistentene Arild Bjarkø, Jakob Heradstveit og Tom Johansen, utførte i perioden 19. juli til 10. august presisjonsnivellement og tyngdemålinger over en forkastning i Flowerdalen på sørsiden av Sassenfjorden. Partiet foretok tilsvarende målinger på strekningen Longyearbyen — Vestpynten. I alt ble 23 km nivellert frem og tilbake og tyngden ble målt i tredve nivellementsbolter. Partiet avsluttet feltarbeidet 2. september.

Etter kontrakt med Fjellanger Widerøe A/S ble vertikalfotograferingen fra fly fortsatt med en ny type kamera (Wild RC10-kamera). En tremannsgruppe, bestående av Gösta Johansson (flyger), Arild Holm (navigatør) og Kjell Gunnar Sigfridsson (fotograf), opererte fra Svalbard Lufthavn med en Turbo Commander 690A i tidsrommet 28. juli til 27. august.

Fotograferingen omfattet en del av Kvitøya, Storøya, en del av Nordaustlandet, Tusenøyane, Brøggerhalvøya og deler av Edgeøya, de østligste deler av Nordenskiöld Land og de vestligste deler av Sabine Land og av Heer Land. Hotellneset og litt av Platåberget med Longyearbyen ble fotografert i stor målestokk. Været var dessverre ikke så godt at all planlagt fotografering kunne utføres.

Geologi

På grunn av feltarbeid i Antarktis i den nordlige vintersesong, samt deltagelse i et symposium om antarktisk geologi i august i USA, ble den geologiske feltinnsats på Svalbard av instituttets egne folk mindre enn vanlig. Til gjengjeld ble instituttets innsats i Barentshavprosjektet i betydelig grad trappet opp, og dessuten ble norsk geologisk arbeid på Svalbard ved forskere fra universitetene betydelig øket. Barentshavprosjektet ble startet i 1970 og i flere år bare drevet av en engasjert geolog. På grunn av for små bevilgninger og mangel på utstyr hadde instituttet siden 1971 bare kunnet drive terrestriske undersøkelser. Thore S. Winsnes som har ledet arbeidet, hadde et stort arbeid med å skaffe midler og utstyr til å få igang den marine virksomhet. Ph. D. Yngve Kristoffersen og cand. real. Anders Elverhøi ble engasjert for å utføre arbeidet, på henholdsvis det maringeofysiske og maringeologiske område.

De pågående geofysiske og geologiske undersøkelsene i Barentshavprosjektet kan inndeles i marine og terrestriske undersøkelser:

Marine undersøkelser

Kartlegge mektigheten av løsmasser på havbunnen i Barentshavet og strukturer i de øverste 200 m av de underliggende prekvartære sedimenter.

Kartlegge strøkretning av, samt beregne dyp til magnetisk basement på kontinentalsokkelen.

Studier av overflatesedimentene på kontinentalsokkelen, herunder isutbredelsen under siste istid og de pågående sedimentære prosesser.

Terrestriske undersøkelser

Generell sedimentologisk studie og lydhastighetsmålinger av den postkaledonske lagrekke på Svalbard som basis for tilsvarende undersøkelser av blokkmateriale og sonarbøyemålinger fra kontinentalsokkelen.

Diageneseundersøkelser av de post-kaledonske bergarter på Svalbard og kontinentalsokkelen.

Kristoffersen, assistert av Oddvar Skarbø, utførte geofysiske målinger fra M/S «Olaf Scheel» under det hydrografiske toktet i tidsrommet 13. juli til 18. august og utnyttet også fartøyet når hydrograferingen var innstillet. Målingene omfattet registreringer med sparker og marinmagnetometer, henholdsvis leiet av Institutt for Kontinentalsokkelundersøkelser (IKU) og utlånt av Norges Geologiske Undersøkelse (NGU). Videre ble det gjort refraksjonsmålinger med sonarbøyer. Målingene foregikk mellom Hornsund og Bellsund og sør for Bjørnøya. I sistnevnte område ble det påvist at en undersjøisk rygg med en tektonisk komplisert struktur sannsynligvis er forårsaket av diapirdannelse. Videre ble det påvist et større morenetrinn på 300 m dyp på Leirdjupet i kanten av Spitsbergenbanken.

Elverhøi og Kristoffersen med assistentene Hanne Øines, Oddvar Skarbø, Anders Solheim og Sven Dahlgren, foresto et maringeologisk tokt med M/S «Olaf Scheel» i tidsrommet 21. august til 1. september i områder omkring Bjørnøya, blant annet på diapirstrukturen. Det ble tatt prøver med skrape, gravitasjonskjernetaker og grabb, leiet av Institutt for Kontinentalsokkelundersøkelser (IKU).

I tillegg foretok Elverhøi med assistentene Solheim og Dahlgren, geologisk prøvetaking for diagenesestudier på Sørkapp Land i lag fra trias, kritt og tertiær. Dette skjedde delvis i samarbeid med David Worsleys gruppe fra Geologisk Institutt, Universitetet i Oslo. I tilknytning til det terrestrisk geologiske feltarbeid foretok en annen gruppe fra samme institutt, under ledelse av Gisle Grønlie, refraksjonsseismiske undersøkelser av lydhastigheter i trias og yngre lag. De foreløpige resultater tyder på at hastighetene er relativt høye og lite forskjellige innenfor denne del av lagserien.

Norsk Polarinstitutts geologiske feltvirksomhet på Svalbard omfattet forøvrig undersøkelser av permokarbon, deler av trias- og devon/kulm-sedimenter i indre isfjorden av Ørnulf Lauritzen med assistentene Carl Dons og Egil Finnerud, samt kvartærgeologiske undersøkelser i Woodfjordområdet av Otto Salvigsen i samarbeid med den finske geolog Henrik Österholm, og med Tore Hansen som assistent.

Det årlige møte for de nordiske geologiske direktører fant sted på Svalbard 12—19. juli med Tore Gjelsvik som vert og ekskursjonsleder. En dags ekskursjon i indre Isfjorden ble ledet av Lauritzen.

I løpet av året kom det i gang et mikroseismisk samarbeidsprosjekt på Svalbard mellom Norsk Polarinstitutt, NORSAR, Store Norske Spitsbergen Kulkompani A/S og det sovjetiske gruveselskap, etter en plan utarbeidet av Kristoffersen, Norsk Polarinstitutt, og Eystein Huseby, NORSAR. Prosjektet består i å kartlegge jordskjelvaktiviteten med henblikk på å kunne vurdere risikoen for skader på gruveanleggene på Svalbard, spesielt i Sveagruva og Pyramiden. Disse ligger nær en av de største forkastningssonene på Spitsbergen, og i 1976 oppsto skader i Pyramiden under et middels sterkt jordskjelv med sentrum nær østkysten ved Storfjorden. I løpet av høsten ble det installert seismisk utstyr i de to russiske gruvebyene og i Longyearbyen. Norsk Polarinstitutt står for driften av prosjektet, og resultatene bearbeides av NORSAR.

Biologi

T. Larsen med assistentene R. Aabakken, Ottemo, og C. Wessel, og med finansiell støtte fra Miljøverndepartementet, foretok registreringer av isbjørnhi på Kong Karls Land i mars og april.

I april ble det foretatt registreringer av isbjørnspor og isbjørnutbredelse i Framstredet, som ledd i et flerårig samarbeidsprosjekt om isbjørn mellom University of Montana, Zoologisk Museum, København, og Norsk Polarinstitutt. Observatører var henholdsvis B. O. Gara, C. Vibe og P. Wegge. Sistnevnte vikarierte for Larsen inntil han kom tilbake fra feltarbeidet på Kong Karls Land. Det ble fløyet i alt 40 timer med småfly over drivisen ut fra Ny-Ålesund for å kartlegge isbjørnforekomster og isbjørntrekk i Grønlandshavet og i området nord for Svalbard. Arbeidet var påtenkt som et pilotprosjekt for senere mer systematiske undersøkelser, med bedre bestandstellinger, studier av bestandssammensetning, merkinger og telemetriundersøkelser.

Larsen med assistentene J. Thomassen og S. Oppegaard, drev isbjørnundersøkelser, blant annet levendefangst, merkinger og tellinger i farvannene mellom Svalbard og Frans Josef Land, ved hjelp av ekspedisjonsfartøyet i tidsrommet 27. juli til 25. august.

I tiden 2. august til 14. august arbeidet T. Larsens parti på Kongsøya, blant annet for å tilrettelegge planlagte vinterundersøkelser i 1978. På Kongsøya ble det også foretatt faunistiske registreringer og ringmerkinger, blant annet av et større antall ismåker. To marinbiologer (R. Bjørnstad og M. Schaaning) deltok i sommertoktet ombord.

I løpet av sommeren arbeidet en rekke biologiske feltpartier, ledet av forskere fra andre institutter, med forskjellige oppgaver for Norsk Polarinstitutt på Svalbard. Hans Støen med assistentene J.A. Eie og I. Jørgensen foretok således limnologiske undersøkelser på vestsiden av Ny Friesland. Likeledes arbeidet E. Alendal med assistentene E. Wrånes og C. Kovalewski med reintellinger på Barentsøya, og T. Bergvik med assistentene R. Hjelmstad og H. Skard med botaniske undersøkelser, hovedsakelig i de samme områdene.

Instituttet samarbeidet med The Wildfowl Trust, Nordland Distriktshøgskole og Miljøverndepartementet med fortsatte hvitkinngåsundersøkelser på Svalbard. Det ble gjort bestandsberegninger, studier over hekkesuksess og foretatt ringmerkinger av hvitkinngjess langs Nordenskiöldkysten.

Faunistiske observasjoner ble samlet inn fra Norsk Polarinstitutts feltpartier og en rekke andre kilder.

Fyr og radiofyr

Ettersynet av fyr og radiofyr ble utført av Kåre Bratlien med assistanse av mannskapet fra M/S «Nordsyssel». Foruten M/S «Nordsyssel» ble også Sysselmanns-helikopteret benyttet til fyrettersynet.

Navigasjonslys for helikopter i Billefjorden

I samarbeid mellom Luftfartsdirektoratet og Norsk Polarinstitutt ble det oppført åtte batteridrevne navigasjonslys mellom Svalbard Lufthavn og den sovjetiske gruveby Pyramiden. Kåre Bratlien foresto arbeidet i marken i tidsrommet 11. oktober til 8. november.

JAN MAYEN

I et fellesprosjekt mellom Norsk Polarinstitutt og Geologisk Institutt, Avd. B, Universitetet i Bergen, arbeidet Jan Mangerud med assistentene Einar Anda og Asbjørn Hiksdal på Jan Mayen i juni og i forskjellige perioder fra august til oktober, de to sistnevnte med stipendium fra Norsk Polarinstitutt. Bremålingene av Sørbreen og Kerchoffbreen ble fortsatt sammen med en rekke meteorologiske målinger. Geomorfologiske og kvartærgeologiske undersøkelser ble gjennomført over det meste av øya, og en del prøver innsamlet for dateringer.

ANTARKTIS

Deltagerne i Den Norske Antarktisekspedisjonen 1976/77 reiste fra Norge i romjulen, og forlot Falklandsøyene 3. januar med M/V «Polarsirkel» med Magnar Aklestad som kaptein. Foruten 21 vitenskapsmenn besto ekspedisjonen av en to-manns filmgruppe fra NRK og en argentinsk gjesteforsker, oseanograf C. Bertollo.

Ekspedisjonen var ledet av Olav Orheim med Torgny Vinje som nestleder. Overfarten til Dronning Maud Land var begunstiget av gode værforhold og uvanlig lite drivis. 10. januar ble en ni-manns gruppe satt iland på Riiser-Larsenisen. Stedet de ble ilandsatt viste seg å være adskilt fra hoveddelen av is-shelfen, og 15. januar ble gruppen flyttet noen kilometer østover. Her opprettet fem mann, under ledelse av Vinje, leiren Camp Norway 3 i posisjon 72°19'S, 16°14'V. De andre fire, under ledelse av Hjelle, fortsatte 160 km innover til Vestfjella og etablerte leiren Camp Norway 4 i posisjon 73°44'S, 14°46'V. Disse ni på land arbeidet uavhengig av båtpartiet til de ble hentet 17. februar. De brukte fire snøscootere til transport og kjørte til sammen ca. 7000 km. I samme tid foretok M/V «Polarsirkel» en rekke undersøkelser i det sentrale og sydlige Weddellhav og tilbakela en distanse på i alt ca. 8000 km.

Landprogrammet

Geofysikk

Vinje, Yngvar Gjessing, Universitetet i Bergen, og John Snuggerud, Teledirektoratet, studerte luftsirkulasjonen like over snøflaten, ved en 8 m høy mast utstyrt med en rekke måleinstrumenter. En automatisk Nimbus-satellittstasjon som ble plassert i Vestfjella, ble dessverre taus etter tre måneder.

Gjessing, Kjell Repp og Bjørn Wold satte ut massebalansestaker forskjellige steder på Riiser-Larsenisen, stakene ble innmålt for senere bestemmelse av isbevegelsen, og de tok en rekke snøprøver ned til 15 m dyp.

Geologi

Hjelle sammen med Harald Furnes, Universitetet i Bergen, studerte de vulkanske lagrekkene i den vestlige delen av Vestfjella. Reidar Løvlie, også Universitetet i Bergen, tok kjerneprøver for paleomagnetiske målinger fra de samme områdene. Hovedsiktemålet med alle undersøkelsene var å få bedre forståelse for Vestfjellas geologiske plassering i Antarktis og innenfor rekonstruksjonen av Gondwanaland.

Biologi

Lauritz S. Sømme, Universitetet i Oslo, studerte kuldetilpassingen hos midd og tok med prøver av disse og av snøpetrell, de siste for miljøgiftundersøkelser. Han fikk økonomisk støtte fra Miljøverndepartementet.

Båtprogrammet

Geofysikk

Orheim målte isbarrierens posisjon og høyde fra 9° til 44°V, og han satte ut massebalansestaker på Filchnerisen ved 39°V.

Arne Foldvik, Herman Gade og Reidar Bø, alle fra Universitetet i Bergen, foretok studier av vannmassene under hele toktet. De satte ut ti strømmålere og to tidevannsmålere på omkring 500 m vanndyp i området rundt 74°S og mellom 34° og 40°V. Dette prosjektet var en fortsettelse av et samarbeidsprosjekt med USA for å studere dannelsen av Det Antarktiske Bunnvann, og fire av strømmålerne var anskaffet av USA. De tre foretok også detaljerte studier av vannmassene ved Filchnerisens barriere.

Kristen Haugland og Fridtjof Veim, Universitetet i Bergen, gjennomførte vel 1000 km refleksjons- og refraksjonsseismiske studier av jordskorpen, ved hjelp av et 16 kanals registreringsutstyr, et 20-tall sonarbøyer og luftkanoner. De foretok målinger med et sjøgravimeter utlånt fra en fransk institusjon.

Hans Olav Torsen, Bjørn A. Fossum og Per A. Østerholt, alle fra Institutt for Kontinentalsokkelundersøkelser (IKU), studerte de øvrige jordskorpelag ved hjelp av «sparker». De brukte sidesøkende sonar til å avbilde havbunnen ved hjelp av lydbølger og foretok konvensjonell fotografering av havbunnen, som viste omfattende pløyemerker fra isfjell. De foretok også magnetometriske registreringer under hele toktet. De to sistnevnte var også ansvarlig for posisjoneringen ombord, som foregikk ved hjelp av et integrert satellittnavigasjonssystem.

Geologi

George H. Maisey, IKU, tok havbunnsprøver ved hjelp av grabb, skrape og kjerneprøvetaker.

Biologi

Svein E. Fevolden, Sentralinstitutt for industriell forskning (SI), og Trond E. Ellingsen, NTH, studerte først og fremst krillforekomstene i Weddellhavet, med finansiell støtte fra Fiskeridirektoratet og Norges Fiskeriforskningsråd. Fevolden foretok også generelle biologiske observasjoner, inkludert hvalregistreringer.

Etter at landpartiet ble hentet 17. februar, foretok ekspedisjonen undersøkelser nordover langs kysten av Dronning Maud Land, inntil kontinentet ble forlatt to døgn etterpå. Deretter fortsatte ekspedisjonen til Bouvetøya, med ankomst 23. februar i pent vær. To gummibåter ble satt på vannet, og i alt 11 ekspedisjonsdeltagere gikk iland på Nyrøysa. Det viktigste enkeltarbeidet var å sette opp en automatisk værstasjon, som over Nimbus-satellitten skulle sende tilbake informasjon om lufttrykk, vindstyrke og temperatur. Denne har nå virket perfekt i 1½ år. Samtidig studerte biologene pingvin- og selkoloniene, og de samlet inn prøver av pingvin og evertebrater. Geologene tok prøver av Nyrøysa for ytterligere å klarlegge dannelsesmåten av dette landområdet.

Neste dag ble øya posisjonsberegnet ved hjelp av satellittmålinger, og det viste seg at den gamle posisjon var noen kilometer feil, videre ble en del krillprøver innsamlet. En tidevannsregistrator ble operert i vel ett døgn, og øyas østside ble besøkt av i alt 22 mann.

Den tredje dagen ved Bouvetøya forverret været seg, og ingen landgang ble forsøkt. Men dyrekoloniene rundt øya ble fotografert på nært hold før kursen ble satt mot Cape Town. Ekspedisjonen ankom her 2. mars, og ekspedisjonsdeltagerne fløy tilbake til Norge, mens M/V «Polarsirkel» ankom Bergen og ble losset 28. mars.

Arbeid ved avdelingene

(Se også under Publikasjoner)

Hydrografi

Avdelingen fullførte redaksjonelt arbeid etter årets loddinger på de nye sjøkartene 506 og 523 og påbegynte redaksjon av ny utgave av sjøkart 510. Videre utførte avdelingen beregninger i forbindelse med automatiske uttegninger av hydrografiske originaler.

Geodesi-topografi

Det ble utført arbeid på et turkart over Nordenskiöld Land i målestokk 1:200 000. Kystområder på Barentsøya med nærmeste innland er konstruert i målestokk 1:100 000. Videre er det utført billedtriangulering og konstruert fem kart i målestokk 1:10 000 av Brøggerhalvøya for MAB-prosjektet. Det er også utført beregninger bl.a. av geodetisk-topografiske observasjoner fra feltsesongen.

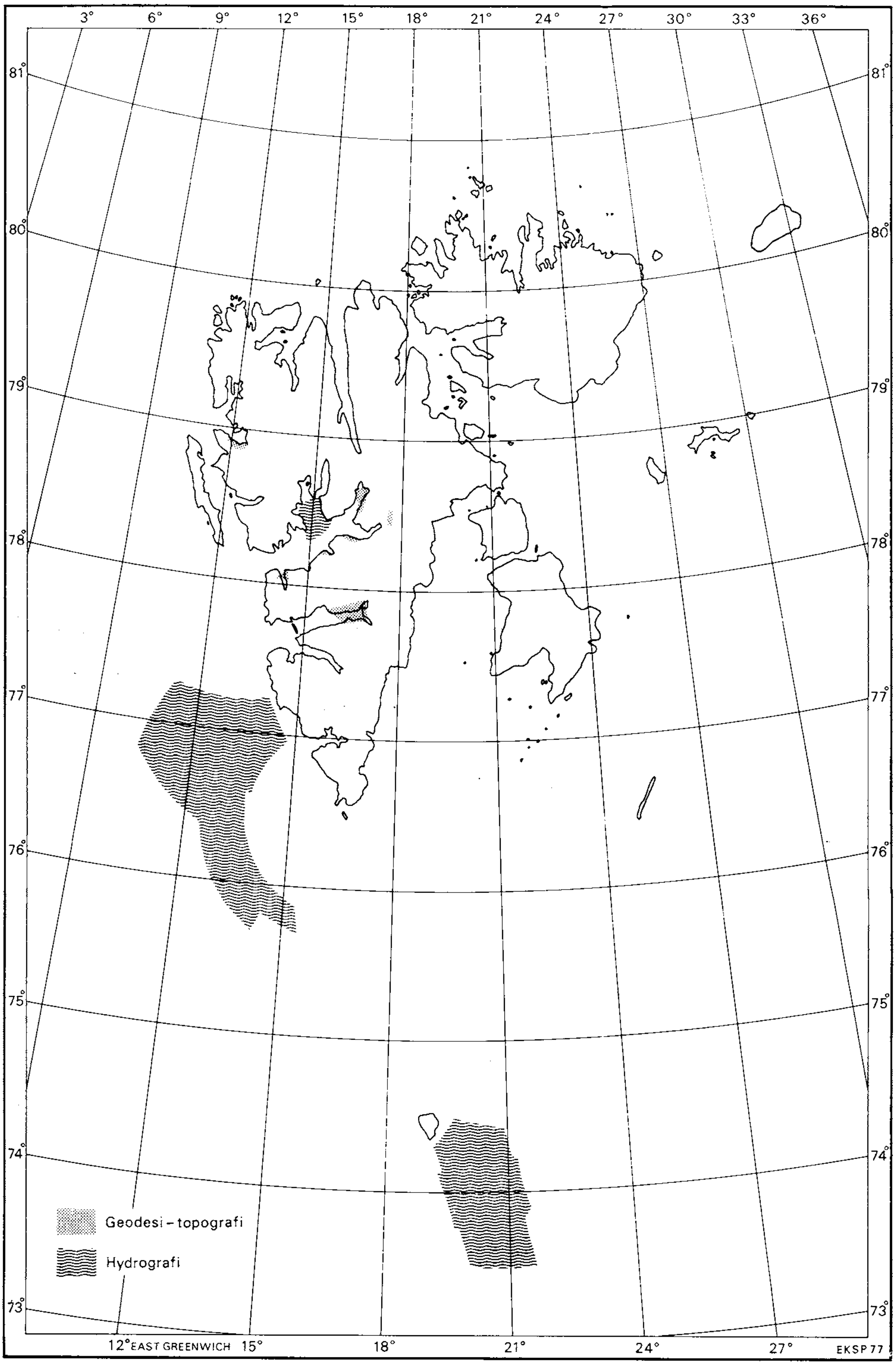


Fig. 1. *Geodetiske, topografiske og hydrografiske arbeidsområder i 1977. Maringeofysiske undersøkelser ble foretatt innenfor hydrograferingsområdene i havet.*

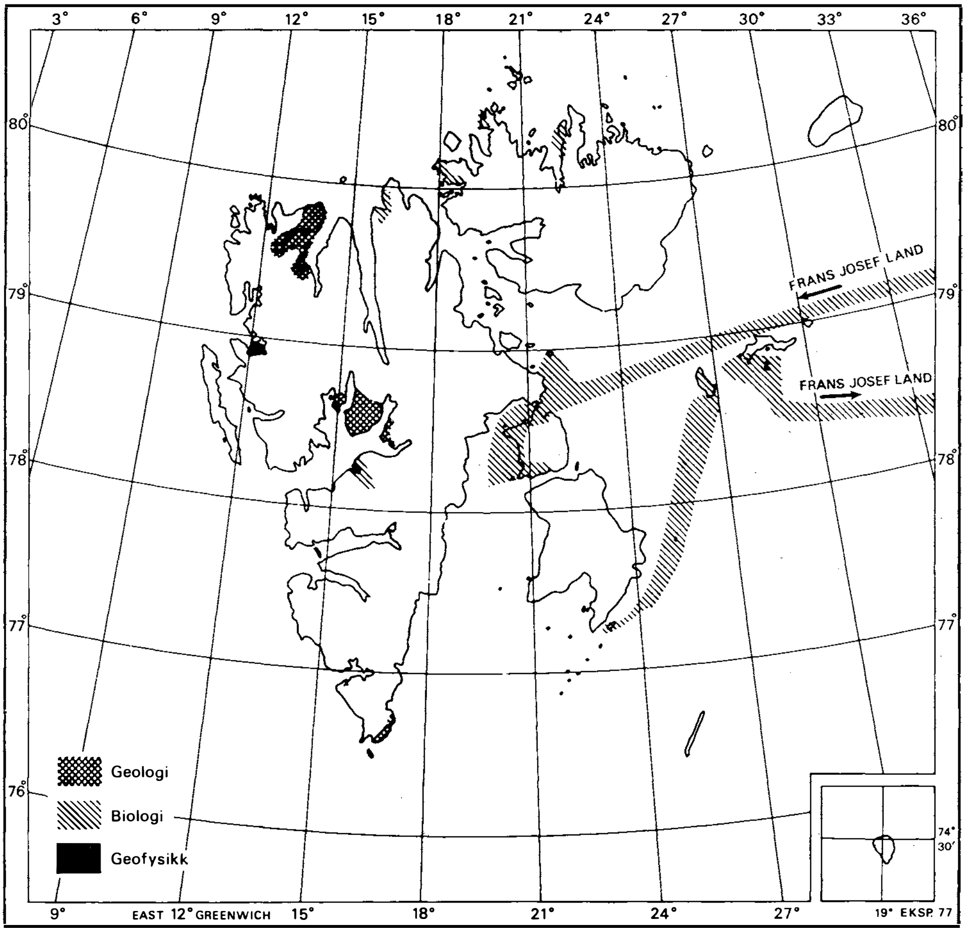


Fig. 2. *Geologiske, biologiske og geofysiske arbeidsområder i 1977.*

Teknisk avdeling

Avdelingen har utført rettelser og tillegg på sjøkartene 501, 502, 503 og 505, og besørget trykt ny utgave av sjøkart 501 og nye opplag av 514C, 515 og 515C. Topografisk kart B10 er under arbeid. Geologiske kart og andre illustrasjoner til publikasjoner er besørget.

Geologi

Kullpetrografiske arbeider er blitt fortsatt. Harald Major har i samarbeid med dosent Manum ved Universitetets institutt for geologi bidratt med materiale og opplegg for hovedfagsoppgave på målinger av reflektiviteten hos kullpartikler.

Sammen med geolog ved SNSK, Alv Orheim, har Major behandlet utviklingen av kullfeltet ved Sveagruva, Longyear gruver og særlig fløts-identiteten i gamle Gruve 3, og videre lokaliseringen av nye diamantborhull ved Gruve 7.

Hjelle bearbeidet materiale fra Antarktis og fra Nordaustlandet, og Lauritzen bearbeidet materiale fra indre Isfjorden med henblikk på gips/anhydrittforekomstene der.

Salvigsen bearbeidet feltmateriale samlet i 1975 og 1976 fra nordvestre delen av Svalbard og sørkysten av Nordaustlandet.

Winsnes har i vesentlig grad vært engasjert med administrativt arbeid som leder for den geologiske avdeling, med Barentshavprosjektet, faglig gjennomgåelse av manuskripter, budsjetteringsspørsmål og uttalelser til myndighetene. Han bearbeidet også en del materiale fra Svalbard og Antarktis.

Kristoffersen har foretatt sammenstilling av tilgjengelige maringeofysiske data fra Barentshavet, forberedt instrumentering og planlagt det geofysiske tokt. Videre har han bearbeidet registreringer fra sommerens feltarbeid.

Elverhøi deltok i planleggingen av det maringeologiske tokt og bearbeidet grabb- og kjerneprøver fra farvannene rundt Bjørnøya.

Geofysikk

For National Aeronautics and Space Administration (NASA) har Vinje sammen med O. Bremnes, Meteorologisk Institutt, og Ø. Finnekåsa, Norsk Polarinstitutt, gjort ferdig rapporten om «Sea Ice Studies in the Spitsbergen-Greenland Area», basert på ca. 500 LANDSAT-bilder tatt i 1976. Likeledes har han sammen med Steinbakke ved Institutt for Kontinentalsokkelundersøkelser gjort ferdig en artikkel: «Some observations from Nimbus-6 data collecting platforms in polar areas».

Hisdal fortsatte bearbeidelsen av lys- og strålingsmålingene fra Svalbard, foretok sammenlignende målinger i Oslo-området og kalibrerte apparaturen. Han skrev i løpet av året flere artikler om forholdene i polarområdene.

Liestøl har bearbeidet og klargjort for publikasjon innsamlet glasiologisk materiale fra Norge og Svalbard. Vinternedbøren var mindre enn normal og sommertemperaturen høyere i Norge i 1977, hvilket resulterte i et stort underskudd på alle breene i Sør-Norge. Breene ved Ny-Ålesund viste seg i 1977 å være nærmest i likevekt, i motsetning til de foregående ti år med sammenhengende negativ balanse. Dette skyldtes dels større vinternedbør dels kortere smeltesesong.

Biologi

Datasenteret ved Norges Landbrukshøyskole har fullført program for faunistiske registreringer på Svalbard. Tilretteleggelse og overføring av faunaobservasjoner til datamaskinlagring er overtatt av hovedfagsstudent Jørn Thomassen på engasjementsbasis.

Avdelingen har arbeidet med tilretteleggelse av en marinbiologisk/hydrografisk undersøkelse i Van Mijenfjorden og bistått Miljøverndepartementets ressursavdeling med en oversikt over betinget fornybare ressurser i Arktis og Antarktis.

Larsen har sluttarbeidet det serologiske materiale fra isbjørnundersøkelsene, og resultatene ble presentert på et internasjonalt møte i USA. Annet materiale er under bearbeidelse. Larsen har hatt betydelig arbeid med å planlegge og tilrettelegge annen biologisk virksomhet på Svalbard.

Biblioteket

I 1977 ble det registrert 368 titler hvorav 42 innkjøpte bøker, 50 av gammel bestand, 66 særtrykk og småskrifter, 23 bøker fra bytteforbindelser og 4 gaver. Særtrykksamlingen har nå ca. 6200 stk.

Konsulent og informasjonsvirksomhet

Instituttet har i stigende grad vært konsultert om polare spørsmål av norske myndigheter og firmaer, institutter og enkeltpersoner i inn- og utland.

Gjelsvik har som president i Den vitenskapelige samarbeidsorganisasjon for Antarktis (SCAR) og som medlem av Den norske delegasjon til de konsultative møter under Antarktistraktaten, vært meget beskjeftiget med Antarktisspørsmål i 1977. Under Antarktisekspedisjonen opprettholdt han kontakten med skipet og formidlet beskjeder og informasjon til massemedia.

Det har også vært mange utenlandske forskere på besøk ved instituttet for å drøfte samarbeidsprosjekter på Svalbard. Både fra vestlig og sovjetrussisk side vises stigende interesse for forskning på Svalbard, og for samarbeid med Norsk Polarinstitutt eller andre norske institusjoner.

I anledning Norsk Polarinstitutts 50-årsjubileum ble det blant annet bestemt å gi ut et jubileumsskrift. En komité med Gjelsvik som formann, og Siggerud, Orheim og Annemor Brekke sto for redigeringen av dette.

Flere av instituttets ansatte har blant annet fungert som konsulenter for leksika og andre bokverk, veiledet hovedfagsstudenter og lagt opp og deltatt i undervisning.

Lundquist og forskerne besvarte innenfor sine respektive fagområder henvendelser fra massemedia vedrørende instituttets arbeidsoppgaver og virksomhet i polarstrøkene.

Reiser, møter, kursvirksomhet

Instituttets medarbeidere har i 1977 deltatt på en rekke reiser, møter og kurs:

BJØRN EGIL ARNESEN — «Kartdagene 1977», Lillehammer, i april, kurs.
- — Kurs i kartografi og reproduksjonsteknikk i oktober.
- — Innføring i EDB, Norges geografiske oppmåling, i november, kurs.

TORE GJELSVIK — Besøkte sammen med flere forskere Statoil i Stavanger og Institutt for Kontinentalsokkelundersøkelser (IKU) i Trondheim, for drøftelser av samarbeidsforhold.
- — Forberedende møte til 9. konsultative møte under Antarktistraktaten i London i mars.
- — Det 9. konsultative møte under Antarktistraktaten i London i september og oktober.
- — Antarktissymposium i Punta Arenas i Chile i april.

THOR LARSEN — «Fourth International Conference Bear Biology» i Montana, USA, i februar.
REIDAR TORGILS MANDT — Kurs i kartografi och reproduktionsteknik, Tekniske Högskolan, Stockholm, i februar og mars.
ØIVIND MEHLUM — Grunnkurs i reprofotografering, Statens teknologiske institutt, i januar.
ERIK MOEN og JOHN SUNDSBY — 2nd Seminar on Satellite-Doppler Positioning and its Application to Surveying, University of Nottingham, England, i januar.
HARALD MAJOR — SINTEF-møte om kullforskning i Norge, Trondheim, i november.
OLAV ORHEIM — Norsk representant ved Weddell Gyre Workshop, Boulder, Colorado, USA, i juni.
THOR SIGGERUD — International Atomic Energy Agency Symposium, Wien, 5.—12. mars.
— Forbruker og Administrasjonsdepartementets kurs som studieleder for opplæring om Arbeidsmiljøloven 21. oktober — 4. november.
TORGNY VINJE — POLEX- og AIDJEX-møter, Seattle, USA, i september.
THORE S. WINSNES, AUDUN HJELLE og YOSHIHIDE OHTA — Geologisk/geofysisk Antarktissymposium i Madison, USA, i august.
VIDAR HISDAL — Besøkte i oktober Geofysisk Institutt ved Universitetet i Bergen for å diskutere kalibrering av vanndamppyrheliometre.

Forelesnings- og foredragsvirksomhet

Instituttets medarbeidere har i 1977 bl.a. holdt følgende foredrag:
GJELSVIK: «Svalbards geologi, malm- og mineralforekomster», Økologikurset i Ny-Ålesund, 17. juli.
— «The work of SCAR for conservation of nature in the Antarctic», Punta Arenas Symposium, Chile, april.
— «Norwegian activity in Antarctica». Anglo Norse Society, London, 6. oktober.
— «Norske økonomiske interesser i Arktis og Antarktis». Fellesrådet for parlamentarikere og vitenskapsmenn. Stortinget, 19. oktober.
KRISTOFFERSEN: «Late Cretaceous sea floor spreading and the early opening of the North Atlantic». Norsk Petroleumsforenings Mesozoic Northern North Sea Symposium, Oslo, 17.—18. oktober.
— «Åpningen av det nordlige Atlanterhav». Geologisk institutt, Oslo, 11. oktober.
LARSEN: «Studies of blood proteins in polar bears». Fourth International Conference Bear Biology, Montana, 18.—27. februar.
— «Drivisens økologi». Nordland Distriktshøgskole, 7. mars.
— «Levende hav». World Wildlife Fund, Norge. Aulaen, Oslo, 8. mars.
— «Svalbards natur». Norsk ornitologisk og Norsk Zoologisk forening, Blindern, Oslo, 11. mars.

— «Reduced economic growth and ecological necessity». Sommerskolen, Blindern, Oslo, 20. juni.
— «Aldersbestemmelse isbjørn/populasjonsdynamikk». Marinbiologisk institutt, Oslo, 20. september.

LIESTØL: «Permafrost på Svalbard». SNSK og Utvalg for permafrost, Bergen, 13. januar.
— «Brevariasjoner og klima». Den Norske Turistforening, Oslo, 18. oktober.
— «Hydrologi og permafrost». Naturgeografien, 22. november.

ORHEIM: «Om Antarktisekspedisjonen 1976/77». Polarrådet, Stavanger, 25. april.
— «Isfjell, pingviner og forskning i Antarktis». Svenska Polarklubben, Stockholm, 28. april.
— «Med Polarsirkel til Antarktis og Bouvetøya». Skipsgruppen av NIF, Bergen, 11. mai.
— «Results of the Norwegian Antarctic Research Expedition 1976/77, and plans for 1978/79». Weddell Gyre Workshop, Boulder, Colorado, 16. juni.
— «Geofysiske undersøkelser ved Antarktisekspedisjonen 1976/77». Oslo Geofysikeres Forening, Oslo, 20. september.
— «Norge brøyter nye veier i Antarktisforskningen». Det Norske Geografiske Selskap, Oslo, 21. september.
— «Om ekspedisjonslivet i Antarktis». Norges Handelshøyskole, Bergen, 19. oktober.
— «Med ekspedisjoner til Antarktis». Bergen Katedralskole, Bergen, 16. november.
— «Norsk Antarktisekspedisjon 1976/77». Norsk Polarklubb, Oslo, 30. november.
— «Geofysisk forskning på Den Norske Antarktisekspedisjonen 1976/77». Bergen Geofysikeres Forening, 9. desember.

OHTA: «Geology and petrology of S. Heritage Range Ellsworth Mountains». Madison III. Symposium on Antarctic Geology and Geophysics, 24. august.

SIGGERUD: En rekke foredrag om Svalbard og Svalbards geologi i amatørgeologiske foreninger, folkeakademier, etc.

VINJE: «Havisen i nord». Bergen Geofysikerforening, Bergen, 11. oktober.
— «Havisundersøkelser ved Norsk Polarinstitutt». Seminar i teknologi for arktiske strøk, Norges Tekniske Høgskole, Trondheim, 29 mars.
— «Norsk Antarktisekspedisjon 1976/77, aktiviteter på land». Norsk Polarklubb, Oslo, 30. november.

Liestøl har i vårsemesteret forelest i glasiologi ved Universitetet i Oslo og Orheim i høstsemesteret ved Universitetet i Bergen.

Flere av instituttets medarbeidere har holdt foredrag på skoler, i Rotaryklubber, etc.

Publikasjoner

Skrifter:

Nr. 165 — TOR BJÆRKE and SVEIN B. MANUM: Mesozoic palynology of Svalbard — I. The Rhaetian of Hopen, with a preliminary report on the Rhaetian and Jurassic of Kong Karls Land.

Nr. 166 — D. M. LAVIGNE, N. A. ØRITSLAND and A. FALCONER: Remote Sensing and Ecosystem Management.

Meddelelser:

Nr. 104 — MAGNAR NORDERHAUG, EINAR BRUN og GUNSTEIN ULEBERG MØLLEN: Barentshavets sjøfuglressurser. Forhold i tilknytning til status, miljøproblemer og forskningsoppgaver.

Årbok 1975:

LIESTØL, OLAV: Pingos, springs and permafrost in Spitsbergen.

— Setevatnet, a glacier dammed lake in Spitsbergen.

SØRNES, ANDERS and TORSTEIN NAVRESTAD: Seismic survey of Jan Mayen.

HOWELLS, K., D. MASSON SMITH and P. I. MATON: Some rock and formation densities from Svalbard.

LØFALDLI, MAGNE and BINDRA THUSU: Microfossils from the Janusfjellet Subgroup (Jurassic — Lower Cretaceous) at Agardhfjellet and Keilhaufjellet, Spitsbergen.

MALKOWSKI, KRZYSZTOF and HUBERT SZANIAWSKI: Permian conodonts from Spitsbergen and their stratigraphic significance; a preliminary note.

CALAS, GEORGES, MIREILLE MALOD-POLVÉ, YVES MOËLO et CATHERINE VIAUX: Observations minéralogiques, pétrographiques et géochimiques sur des roches du Woodfjorden, Spitsbergen.

BUROV, JU. P., A. A. KRASIL'SCIKOV, L. V. FIRSOV and B. A. KLUBOV: The age of Spitsbergen dolerites (from isotopic dating).

VINJE, TORGNY E. and PER STEINBAKKE: Nimbus-6 located automatic stations in the Svalbard waters in 1975.

EBBINGE, BARWOLT and DOROTHEA EBBINGE-DALLMEJER: Barnacle Geese *(Branta leucopsis)* in the Arctic summer.

WINSNES, THORE S.: Anatol Heintz.

SIGGERUD, THOR: Olav Holtedahl.

LIESTØL, OLAV: Glaciological work in 1975.

HISDAL, VIDAR: The weather in Svalbard in 1975.

VINJE, TORGNY E.: Sea ice conditions in the European sector of the marginal seas of the Arctic, 1966—1975.

— Radiation conditions in Spitsbergen in 1975.

LARSEN, THOR: Observations of animal life in Svalbard in 1975.

LUNDQUIST, KAARE Z.: Norsk Polarinstitutts virksomhet i 1975.

— The activities of Norsk Polarinstitutt in 1975.

— Main field work of scientific and economic interest carried out in Svalbard in 1975.

Notiser:

VINJE, TORGNY: Drift av Trolltunga in Weddellhavet.

BOCKELIE, T., D. L. BRUTON and R. A. FORTEY: Research on the Ordovician Rocks of North Ny Friesland, Spitsbergen.

HÅGVAR, SIGMUND and ARVID HEGSTAD: A sample of spiders (Araneida) from Svalbard.

Årbok 1976:

LAURITZEN, ØRNULF: Development patterns of gypsum/anhydrite in Lower Permian sediments of central Spitsbergen — a suggested classification.

NYSÆTHER, EIGILL: Investigations on the Carboniferous and Permian stratigraphy of the Torell Land area, Spitsbergen.

STEEL, RONALD J.: Observations on some Cretaceous and Tertiary sandstone bodies in Nordenskiöld Land, Svalbard.

WORSLEY, DAVID and NATASCHA HEINTZ: The stratigraphical significance of a marine vertebrate fauna of Rhaetian age, Kong Karls Land.

BJÆRKE, TOR: Mesozoic palynology of Svalbard —II. Palynomorphs from the Mesozoic sequence of Kong Karls Land.

MANUM, S. B., T. BJÆRKE, T. THRONDSEN, and M. EIEN: Preservation and abundance of palynomorphs, and observations on thermal alteration in Svalbard.

BJÆRKE, TOR and HENNING DYPVIK: Sedimentological and palynological studies of Upper Triassic — Lower Jurassic sediments in Sassenfjorden, Spitsbergen.

DALLAND, ARNE: Erratic clasts in the Lower Tertiary deposits of Svalbard — evidence of transport by winter ice.

BIRKENMAJER, KRZYSZTOF and STANISLAW ORLOWSKI: Olenellid fauna from the base of Lower Cambrian sequence in south Spitsbergen.

BIRKENMAJER, KRZYSZTOF: Trace fossil evidence for predation on trilobites from Lower Cambrian of south Spitsbergen.

ELDHOLM, OLAV and ANNIK M. MYHRE: Hovgaard Fracture Zone.

SALVIGSEN, OTTO: Radiocarbon datings and the extension of the Weichselian icesheet in Svalbard.

TVEDE, ARVE M. and OLAV LIESTØL: Blomsterskardbreen, Folgefonni, mass balance and recent fluctuations.

ØRITSLAND, NILS A.: A model of energy balance in Arctic mammals.

LARSEN, THOR: Counts and population estimates of Svalbard reindeer *(Rangifer tarandus platyrhynchus)* in Nordaustlandet, Svalbard, 1974 and 1976.

DE BIE, STEVEN: Survivorship in the Svalbard reindeer *(Rangifer tarandus platyrhynchus Vrolic)* on Edgeøya, Svalbard.

NORDERHAUG, MAGNAR: Undersøkelser av praktærfuglen *(Somateria spectabilis)* på Svalbard.

SØMME, LAURITZ: Observations on the snow petrel *(Pagodroma nivea)* in Vestfjella, Dronning Maud Land.

LIESTØL, OLAV: Gunnar Holmsen.

— Glaciological work in 1976.

HISDAL, VIDAR: The weather in Svalbard in 1976.

VINJE, TORGNY E.: Sea ice conditions in 1976.

— Radiation conditions in Spitsbergen in 1976.

LARSEN, THOR: Observations of animal life in Svalbard in 1976.

ORHEIM, OLAV: Preliminary report of the 1976/77 Norwegian Antarctic Research Expedition.

GJELSVIK, TORE: Norsk Polarinstitutts virksomhet i 1976.

— The activities of Norsk Polarinstitutt in 1976.

— Main field work of scientific and economic interest carried out in Svalbard in 1976.

Notiser:

LIESTØL, OLAV: Årsmorener foran Nathorstbreen?

SALVIGSEN, OTTO: An observation of palsa-like forms in Nordaustlandet, Svalbard.

FEVOLDEN, SVEIN E. and LAURITZ SØMME: Observations on birds and seals at Bouvetøya.

GULLESTAD, NILS: Observasjoner av tyvjo *(Stercorarius parasiticus)* i Hornsund, Spitsbergen, 1963 og 1964.

VINJE, TORGNY E.: M/S «Fortuna» beset and wrecked in the East Greenland Sea.

Annen publisering:

THOR LARSEN: Studies of polar bear blood proteins. *Proceedings 4th International Conference Bear Biology.* (Under trykking).

ØRNULF LAURITZEN: Intrusivganger i den sydlige delen av Hadelands kambro-silurområde. *Nytt fra Oslofeltgruppen* Nr. 4.

— Conservation of geological localities within the Oslo region, Norway. *Geology and Physiography section Nature Conservancy Council, Information Circular* No. 13, September 1977.

TORE GJELSVIK, EIGILL FARETH og INGVAR LINDAHL: Cier'te. Beskrivelse til det berggrunnsgeologiske kart 1733 II — 1:50 000 (med fargetrykt kart). *NGU Nr. 331, Skrifter 20.*

YNGVE KRISTOFFERSEN and MANIK TALWANI: Extinct triple junction south of Greenland and the Tertiary motion of Greenland relative to North America. *Geol. Soc. of America, Bull.* 88:1037—1049.

YNGVE KRISTOFFERSEN and STEVE CANDE: Late Cretaceous magnetic anomalies in the North Atlantic. *Earth and Planetary Science Letters 35* (1977): 215—224.

OLAV LIESTØL: Glasiologiske undersøkelser i Norge. Bidrag til N.V.E.

OLAV ORHEIM: Antarktis-ekspedisjonen 1976/77: Glade forskere tilbake med lovende resultater. *Forskningsnytt* Nr. 4 (1977): 2—9.

— Glaciological and marine geological studies at perimeter of Dronning Maud Land, Antarctica. *Final report of investigation* Nr. 28550 to NASA 1977. 17 pp.

— Med Polarsirkel i isen. *Aftenpostens A-magasin* Nr. 43.

— Med Polarsirkel til Antarktis. *Rieco-Nytt* 8. Årg. nr. 4: 4—9.

— Global Glacier Mass Balance Variations during the past 300 years. *Polar Oceans, Proceedings of the Polar Oceans Conference, Montreal.* Antarctic Institute of North America 1977: 667—680.

— Norwegian Antarctic Research, past and present. *El desarrollo de la Antártica.* Instituto de estudios internacionales de la Universidad de Chile: 154—160.

Forskningsstasjonen på Svalbard

Oversikt og drift av de forskjellige faste forskningsprosjektene

1. *Strålingsmålinger:*
   Norsk Polarinstitutt, Oslo. Det har i perioder fremkommet en del feil ved utstyret p.g.a. tekniske problemer i Ny-Ålesund. Dette gjelder både datalogger og strålingsmålere. Registreringene er dog tilfredsstillende.
2. *Tidevannsmåleren:*
   Norsk Polarinstitutt, Oslo. Registreringene ble foretatt hver halve time med tape og batterikapasitet for seks måneder. Test på utskrift av dataene blir foretatt ca. to ganger pr. måned. Kontroll av data viser at registreringene går tilfredsstillende. Varmekabler er montert.
3. *Oseanografi:*
   Havforskningsinstituttet, Bergen. Sjøprøver ble tatt opp i juli og august fra stasjon A og B. Utstyret er mangelfullt.

4. *Luftforurensning:*
Norsk institutt for luftforskning, Kjeller. Det har vært en del problemer med utstyret som er plassert i luftskipsmasten et stykke vekk fra Forskningsstasjonen. I juli ble derfor utstyret flyttet til den gamle telemetristasjonen.
5. *Meteorologi:*
Det Norske Meteorologiske Institutt, Blindern. Observasjonene er tatt etter det oppsatte programmet. Utstyret fungerer tilfredsstillende.
6. *Glasiologi:*
Norsk Polarinstitutt, Oslo. Massebalansemålinger har vært utført ved de to breene Austre Brøggerbreen og Midre Lovénbreen. I forbindelse med disse målingene ble vannføring, slamtransport og oppløste stoffer målt i bre-elvene.
7. *Seismisk stasjon:*
Jordskjelvstasjonen, Universitetet i Bergen. Stasjonen fungerer meget godt og kun små korrigeringer har vært nødvendige. Bygningstekniske arbeider har vært utført for å holde jevnere temperatur. Stasjonen har ikke vært kalibrert fra Bergen.
8. *Ionosfærefysikk:*
Universitetet i Tromsø. Den vitenskapelige assistent ved Forskningsstasjonen hadde avtale med Nordlysobservatoriet om driftsmålinger i forbindelse med Nordlysobservatoriets pågående eksperiment. På grunn av forsinkelser i leveringer av instrumenter, har ikke Nordlysobservatoriet kunnet sende opp utstyr. Vit. ass. har derfor arbeidet med teoretisk ionosfærefysikk denne perioden.
Riometrene:
Nordlysobservatoriet, Universitetet i Tromsø i samarbeid med Danmarks Tekniske Højskole. Alle riometre har denne perioden fungert, men det opptrer endel forstyrrelser. Noen små feil har vært reparert av teknikeren på FST.
9. *Magnetometer:*
Nordlysobservatoriet, Universitetet i Tromsø.
Registreringene gikk normalt.
10. *All-sky-camera:*
Nordlysobservatoriet, Universitetet i Tromsø. Kameraet var montert klart for registreringer 11. oktober. En del problemer ble løst og utstyret har siden fungert tilfredsstillende.
11. *VLF målinger:*
Universitetet i Oslo. Utstyr montert sommeren 1977 og har fungert tilfredsstillende.
12. *Pulsasjonsmagnetometre:*
Universitetet i Oslo, i samarbeid med Institutt for Terrestriell Fysikk, Moskva. Sommeren 1977 ble innstallert instrumenter for registrering av dette i forbindelse med IMS programmet. Utstyret fungerer tilfredsstillende.

Diverse

1. *Aurora, 25 fot plastsjark:*
   Etter istandsetting i Norge ble båten satt på vannet i midten av juli. Båten ble delvis brukt til å hente sjøprøver, samt en rekke turer i forbindelse med biologisk virksomhet.
2. *Småbåter:*
   FST disponerer en 14 fots Ranabåt i plast, en 16 fots Mørebas i plast, en 8 fots plastjolle og en gummibåt. Til båtene finnes påhengsmotorer.
3. *Snøscootere:*
   Stasjonen disponerer tre snøscootere.
4. *Annet utstyr, arbeidsrom, etc.:*
   Det er en del generelt utstyr ved Forskningsstasjonen til utlån til gjestende forskere og til bruk for det faste personell.

Bruk av stasjonen, gjestende forskere

1. Det blir etter hvert flere brukere ved stasjonen. Ca. 30 forskere fra følgende institusjoner har arbeidet ved eller ut fra stasjonen i perioder fra en uke til tre måneder:
   Universitetet i Bergen, Jordskjelvstasjonen
   Universitetet i Tromsø, Nordlysobservatoriet
   Universitetet i Oslo, Fysisk institutt
   Norsk Polarinstitutt
   Man and the Biosphere prosjektet, Norsk Polarinstitutt
   Stipendiater, Norsk Polarinstitutt
   I samarbeid med forskere fra disse ansvarlige institusjoner har det også vært endel utenlandske forskere.
2. Videre har det vært en rekke besøk ved stasjonen av representanter for myndigheter og almenheten, med utenriksminister Frydenlund i spissen. Det har også vært en rekke besøk av folk fra presse, kringkasting og TV.

Personale

1. *Første halvår:*
   Stasjonssjef Kjell Glorvigen (sammen med Kings Bay Kull Comp.)
   Vitenskapelig assistent Monica Kristensen
   Ingeniør Birger Amundsen
2. *Annet halvår*
   Stasjonssjef Einar Ellingsen (sammen med KBKC)
   Vitenskapelig assistent Monica Kristensen
   Ingeniør Torfinn Roaldsen

The activities of Norsk Polarinstitutt in 1977

Extract of the annual report

By TORE GJELSVIK

Field work

NORWAY

Glaciology

Glacier mass balance measurements at Storbreen, Hardangerjøkulen, and Blomsterskardbreen were conducted by O. Liestøl. Changes in frontal positions were measured for eleven glaciers, of which five were advancing and the remaining were retreating. Briksdalsbreen advanced 23 m to a position not exceeded since 1948.

SVALBARD

The expedition activity started in March with polar bear investigations north and west of Svalbard and on Kong Karls Land, and later in the spring followed geophysical work in the Ny-Ålesund area.

The summer expedition to Svalbard, headed by T. Siggerud, was carried out with two ships, M/S «Olav Scheel» and M/S «Polarstar», and a smaller vessel, «Svalis». The former sailed from Bodø on 13 June and returned to Bodø on 1 September. M/S «Polarstar» left about one month later and returned on 7 September.

The field parties which did geological, biological, geodetic-topographical, and hydrographical work, were put ashore and supported by the vessel. Of a total of 56 expedition members, seventeen were from the staff of Norsk Polarinstitutt, four from other institutes, and the remainder engaged for shorter or longer periods. During the summer M/S «Polarstar» sailed around Svalbard and eastwads to the Soviet territorial border off Frans Josef Land.

Offshore hydrographic surveying was carried out southwest of Spitsbergen and from and southeast of Bjørnøya from M/S «Olaf Scheel», which also supported marine-geophysical and geological work in the same areas. Hydrographical surveying inshore was carried out in Isfjorden from «Svalis». In addition to ship crew, the expedition counted 47 participants and was carried out under mostly favourable ice conditions and with no accidents of any kind.

The expedition cooperated with and supported several institutions, including the Ministry of the Environment, the University of Wisconsin, the University of St. Louis, the Norwegian Agricultural University, the MAB-project, the University of Oslo, and the Governor (Sysselmann) of Svalbard.

Geophysics

O. Liestøl, based at Ny-Ålesund one month from the end of May, measured accumulation on Midre Lovénbreen and Austre Brøggerbreen, and followed the development of superimposed ice on the surface of the glacier.

K. Repp measured meltwater flow and suspended material in the Brøggerbreen drainage system.

V. Hisdal resumed measurements of the intensity of daylight and the attenuation of solar radiation by the atmosphere. A series of observations of the total water vapour content in the atmosphere over the station was initiated with a new spectropyrheliometre.

T. Vinje prepared four NIMBUS satellite stations for ice drift measurements. Two stations were deployed between Nordaustlandet and Frans Josef Land (the Barents Sea Project), and the two other between Greenland and Svalbard (the GARP Project).

Hydrography

Favourable ice and weather conditions permitted extensive use of the Motorola navigation system to a distance of 35 kilometres. Approximately 600 km² were sounded from «Svalis» by H. Hornbæk and L. Nordli.

E. Moen, J. Fjørtoft, and E. Mørk utilized the Hi-Fix positioning system with M/S «Olaf Scheel» and 4,380 miles of track were run on Hornsundbanken and southeast of Bjørnøya.

Geodesy — topography

O. Steine worked on a tourist map (1:200,000) of the inner Isfjorden area, measured trigonometric grids at Brøggerbreen and Sveagruva, and mounted a tide gauge in Sveagruva.

J. Sundsby made precision nivellement and gravimetre measurements across the fault zone in Flowerdalen near Longyearbyen.

On contract, Fjellanger Widerøe A/S carried out vertical photography of Kvitøya, Storøya, Nordaustlandet, Tusenøyane, and Brøggerhalvøya, the eastern part of Nordenskiöld Land and the western parts of Sabine Land and Heer Land. A detailed air photographic survey was carried out near Longyearbyen.

Geology

Due to extensive field work in the previous Austral summer in Antarctica and the presence of a number of staff geologists at a symposium on Antarctic geology and geophysics in the United States in August, the terrestrial field work in Svalbard was less than usual. However, studies in marine geology and geophysics under the Barents Sea Project were increased.

Y. Ohta studied basic rocks in northeast Svalbard, Ø. Lauritzen Devonian, Permo-Carboniferous and younger beds in the Isfjorden area, and O. Salvigsen together with H. Østerholm (Finland), Quaternary deposits around Woodfjorden. Terrestrial geological studies related to the Barents Sea Project was carried out by A. Elverhøi in Sørkapp Land. The marine geological studies were conducted during a one week cruise with M/S «Olaf Scheel» southeast of Bjørnøya. A marine geophysical survey was carried out southeast of Spitsbergen and around Bjørnøya in conjunction with the hydrographical work of M/S «Olaf Scheel». The geophysical program consisted of magnetic and sparker profiling and sonorbuoy refraction measurements and was conducted by Y. Kristoffersen. A bathymetric rise in Bjørnøyrenna was found to be associated with a diapir structure, and a large moraine was discovered, on the slope of the Spitsbergen Bank towards Leirdjupet in 300 m water depth.

A cooperative project was established between Norsk Polarinstitutt, NORSAR, Store Norske Spitsbergen Kulkompani A/S, and the Soviet mining company Arktikugol. The project was planned by Kristoffersen and E. Huseby (NORSAR), and includes mapping of the micro earthquake activity in order to evaluate the risk of damage to mine installations and dwellings in Spitsbergen.

Seismic equipment has been installed in Pyramiden, Barentsburg and in Longyearbyen.

Biology

T. Larsen surveyed polar bear dens in Kong Karls Land. In April an aerial survey of the distribution of polar bear tracks took place in the Fram Strait as part of a joint, long-term polar bear program between the University of Montana, the Zoological Museum, Copenhagen, and Norsk Polarinstitutt. Observers in the aircraft were B. O'Gara and C. Vibe. P. Wegge substituted for Larsen until he returned from his field work in Kong Karls Land.

During the summer season, limnological studies in the western part of Ny Friesland, and reindeer studies and botanical investigations on Barentsøya, were supported by the institute. In August, Larsen undertook live trapping, tagging and population estimates of polar bears between Svalbard and Frans Josef Land from M/S «Polarstar».

JAN MAYEN

Three persons from the Geological Institute, University of Bergen, carried out glaciological, meteorological, and geological investigations on the island in cooperation with Norsk Polarinstitutt.

ANTARCTICA

The 24 participants in the Norwegian Antarctic Research Expedition 1976/77 left Port Stanley on board M/V «Polarsirkel» on 3 January after flying from Oslo via Buenos Aires. The expedition leader was O. Orheim with T. Vinje second in command. Two land bases with nine men altogether were established: «Camp Norway 3» on Riiser-Larsenisen, and «Camp Norway 4» 160 kilometres inland, in the Vestfjella mountains. The group of nine worked ashore until 17 February when they were picked up by M/S «Polarsirkel». While the land parties worked ashore, the ship travelled a distance of 8,000 kilometres in the central and southern Weddell Sea carrying out a wide spectrum of geophysical investigations.

The terrestrial program

Geophysics

Vinje, Y. Gjessing, University of Bergen, and J. Snuggerud, Teledirektoratet, studied the air circulation close to the snow surface.

Gjessing, K. Repp, and B. Wold established movement and accumulation stakes at different locations on Riiser-Larsenisen. Snow samples were taken down to 15 m depths.

Geology

A. Hjelle and H. Furnes, University of Bergen, studied the volcanic rocks in the western part of Vestfjella, while R. Løvlie, also from the University of Bergen, obtained core samples for paleomagnetic measurements.

Biology

L. S. Sømme, University of Oslo, studied cold adaption in mites and sampled birds for pollution measurements.

The marine program

Geophysics

Orheim measured the position and elevation of the ice shelf barrier from 9° to 44°W, and he emplaced mass balance stakes at the Filchner Ice Shelf.

A. Foldvik, H. Gade, and R. Bø from the University of Bergen, conducted oceanographic measurements during the whole cruise. Ten current metres and two tidal gauges were moored near the sea bed in about 500 m of water. The team also carried out detailed physical oceanographic measurements near the Filchner Ice Shelf.

K. Haugland and F. Veim, University of Bergen, carried out multichannel seismic reflection and refraction measurements over a distance of more than

1,000 kilometres. Gravity was also recorded during the whole cruise. H. O. Torsen, B. A. Fossum, and P. A. Østerholt from the Continental Shelf Institute, studied the upper sedimentary layers by shallow seismic reflection (sparker) profiling. Side-scan sonar was utilized in addition to conventional photography. A marine magnetometer was operated during the entire cruise.

Geology

G. H. Maisey, the Continental Shelf Institute, carried out marine geological sampling by corers, grabs, and dredges.

Biology

S. E. Fevolden, Sentralinstitutt for industriell forskning, and T. E. Ellingsen, University of Trondheim, studied krill distribution in the Weddell Sea. They also conducted general biological observations including whale registrations.

BOUVETØYA

The expedition reached Bouvetøya on 23 February. An automatic weather station was established at Nyrøysa. Air pressure, wind strength, and temperature data are transmitted via NIMBUS satellite, and the station has now operated perfectly for 1½ year. Other work done on the island included biology, geology, and tide measurements. The expedition left Bouvetøya after three days and arrived in Cape Town on 2 March.

Preparation of data

Hydrography

Work on charts 506 and 523 was completed and editorial revision of chart 510 initiated. Charts 501, 502, 514, and 515 were reprinted.

Geodesy — topography

Construction and edition of the inner Isfjorden tourist map and construction of map of the coastal areas on Bouvetøya were undertaken. Work on a new edition of map B10 Van Mijenfjorden was done. Five maps at a scale of 1:10,000 of Brøggerhalvøya was constructed for the MAB-program.

Geology

Winsnes was occupied with administrative duties particularly related to the Barents Sea project. Major continued coal-petrographical studies while Hjelle, Lauritzen, and Salvigsen prepared for publication data from previous expeditions. Kristoffersen and Elverhøi compiled background data, prepared instrumentation for the field work, and worked on data from the summer expedition.

Geophysics

Vinje has completed manuscripts on sea ice and radiation conditions in Svalbard.

Hisdal continued his work on the radiation and illuminance data from Ny-Ålesund. In the course of the year he wrote several articles on the weather in polar areas.

Liestøl prepared glaciological data from Norway and Svalbard for publication.

Biology

The computer centre at Norges Landbrukshøgskole has completed a data logging program for fauna registrations in Svalbard, has prepared a plan for marine biological/hydrographical investigation in Van Mijenfjorden, and supplied the Ministry of the Environment with a survey of renewable resources in the Arctic and the Antarctic. Larsen completed preparation of serological data on polar bears.

Main field work of scientific and economic interest carried out in Svalbard in 1977

By TORE GJELSVIK

Nationality	Institution or company (residence) Name of expedition	Name (s) of leader (s) No. of participants	Area of investigation Period	Work
Norwegian	Norsk Polarinstitutt	THOR SIGGERUD 53 (+ transport crew, 2 ships, 1 boat)	Svalbard and surrounding waters and waters between Svalbard and Frans Josef Land. March–September	Hydrography, topography, geology, geophysics, and biology. See pp. 306–313
	MAB- (Man and the Biosphere) Program	NILS A. ØRITSLAND 15	Brøggerhalvøya, Reinsdyrflya, Nordenskiöld Land January–December	Evertebrate zoology, vegetation mapping, reindeer biology
	University of Oslo	GISLE GRØNLIE 4	Sørkapp Land 30 June–12 August	Geology
	«	PÅL PRESTERUD 2	Ny-Ålesund 1 July–9 August	Biology
	«	JOHN KROG 5	Sassendalen 24 March–5 April	Biology
	University of Bergen	JENS EVANGER 2	Area around Svea 1 July–2 September	Geology
	«	EIRIK SUNDVOR 6	Coast of northwest and north Svalbard 28 August–28 September	Geophysics
	University of Tromsø	ANDERS KLEMMETSEN 4	Bjørnøya 24 August–1 September	Biology
	«	JOHAN B. STEEN 2	Adventdalen, Nordenskiöld Land 1 July–12 July	Biology
	«	PER KYRRE REYMERT 3	Bjørnøya and northwest Spitsbergen 8 July–2 September	Registration of relics of ancient culture
	University of Trondheim	AA. T. EKKER 2	Bellsund 15 May–15 August	Biology
	Oil Directorate	ERIK TALLERAAS 5	Isfjorden 12 August–19 August	Geology

	STATOIL	J. Bleie & H. E. Kellogg 13	South Spitsbergen	Geological mapping
	Nordland Distrikthøyskole	Nils Gullestad 3	Kapp Mitra 10 July–1 September	Biology
Norwegian/ Polish/Ame- rican/German	University of St. Louis/ University of Hamburg	Brian Mitchell 12	Edgeøya, Barentsøya, Hornsund, Longyearbyen 19 July–23 August	Seismological investigations
British	University of Cambridge	W. B. Harland 14	Western coast of Spitsbergen 21 May–6 September	Geology
British/Dutch	The Wildfowl Trust	R. H. Drent & M. Owen 11	Nordenskiöld Land 30 May–1 September	Biology
Dutch	University of Amsterdam	P. Oosterveld 20	Edgeøya 17 July–15 September	Biology
	Natuurhistorische Vereinigung	H. V. Bohemen 6	Brøggerhalvøya 28 June–19 July	Biology
	University of Amsterdam	E. M. Binsbergen 2	15 June–15 September	Biology
Polish	University Gedansk	S. Scauomil 6	Hornsund 10 June–15 August	Oceanography
	Polish Geographical Society, Warsaw	W. Gebriel 7	Area south of Sarstangen 19 July–3 September	Glaciology, hydrology, meteorology
Russian	Sevmorgeo	D. V. Semevskij 30	Woodfjorden, Hornsund, Nordaustlandet, Bohemanflya May–September	Geology
	Academy of Sciences USSR	Evgenij Zinger 18	Barentsburg, Pyramiden, Ny-Ålesund, Svea, Longyearbyen, Nordaustlandet, Ekmanfjorden, Lomfjorden, Wijdefjorden, Agardh, Kapp Millar May–September	Glaciology
Swiss	University of Bern	Edi Festel 12	Ymerbukta, Borebukta 23 June–9 July	Geology, glaciology, biology

Notiser

A preliminary report on the geology of Sjuøyane

Abstract. — Migmatites and granites of Sjuøyane are briefly described. The migmatite paleosomes are assumed to be of late Precambrian age; the time of migmatization is uncertain, possibly Caledonian. A sillimanite-cordierite-almandine paragenesis of paleosomes indicates conditions of high temperature — low pressure type of amphibolite facies prior to migmatization. Structural evidences suggest the main NNE-SSW structures to be refolded along E-W axes.

Introduction

Sjuøyane is a group of islands positioned about 15—30 km off Nordkapp, NE Svalbard; the islands extend from about 80° 37' to 80° 50' N. The geology is little known and the main contributions date back to the last century (Nordenskiöld 1863). The present paper is based on brief helicopter surveys in 1965 and 1976: A. Hjelle, 31 July 1965 and A. Hjelle, Y. Ohta, and T. S. Winsnes 20 and 21 August 1976. The rocks are entirely of metamorphic or igneous origin (migmatites, granites).

Migmatites

These are by far the most common rocks in the islands. According to texture, composition and distribution they are tentatively divided into a western and an eastern type. The western migmatites which are relatively homogeneous, coarse-grained with development of 2—10 cm K-feldspar porphyroblasts, occur in Parryøya, Nelsonøya, Tavleøya, Vesle Tavleøya, Rossøya, and probably in the northernmost part of Phippsøya. Dark siliceous mica schist paleosomes are commonly present, however in Parryøya and Nelsonøya the paleosomes are scarce and the migmatite locally grade into coarse-grained gneissose granite. Binocular observations of the northern parts of Tavleøya and Phippsøya suggest layers of marble and/or quartzite in a coarse-grained migmatite. Average modal composition of neubulitic migmatite is (%, from five thin sections): Quartz 32, K-feldspar 26, oligoclase 29, biotite 8, muscovite 2, almandine 1, chlorite 1, sillimanite and cordierite tr.

The eastern migmatites occur mainly in the eastern part of Phippsøya and the western part of Martensøya. This rock seems to be more fine-grained and of more varying texture, and to contain a greater amount of paleosomes than the western migmatite. Characteristic paleosomes are relatively pure grey to greenish grey quartzitic sandstones. Mica schist lenses and layers also occur commonly, and minor layers, lenses and blocks of calcareous and amphibolitic rocks were recorded.

Granites

Between the two migmatite zones and in the eastern part of Martensøya a granite occurs, which in texture and composition is easily distinguishable

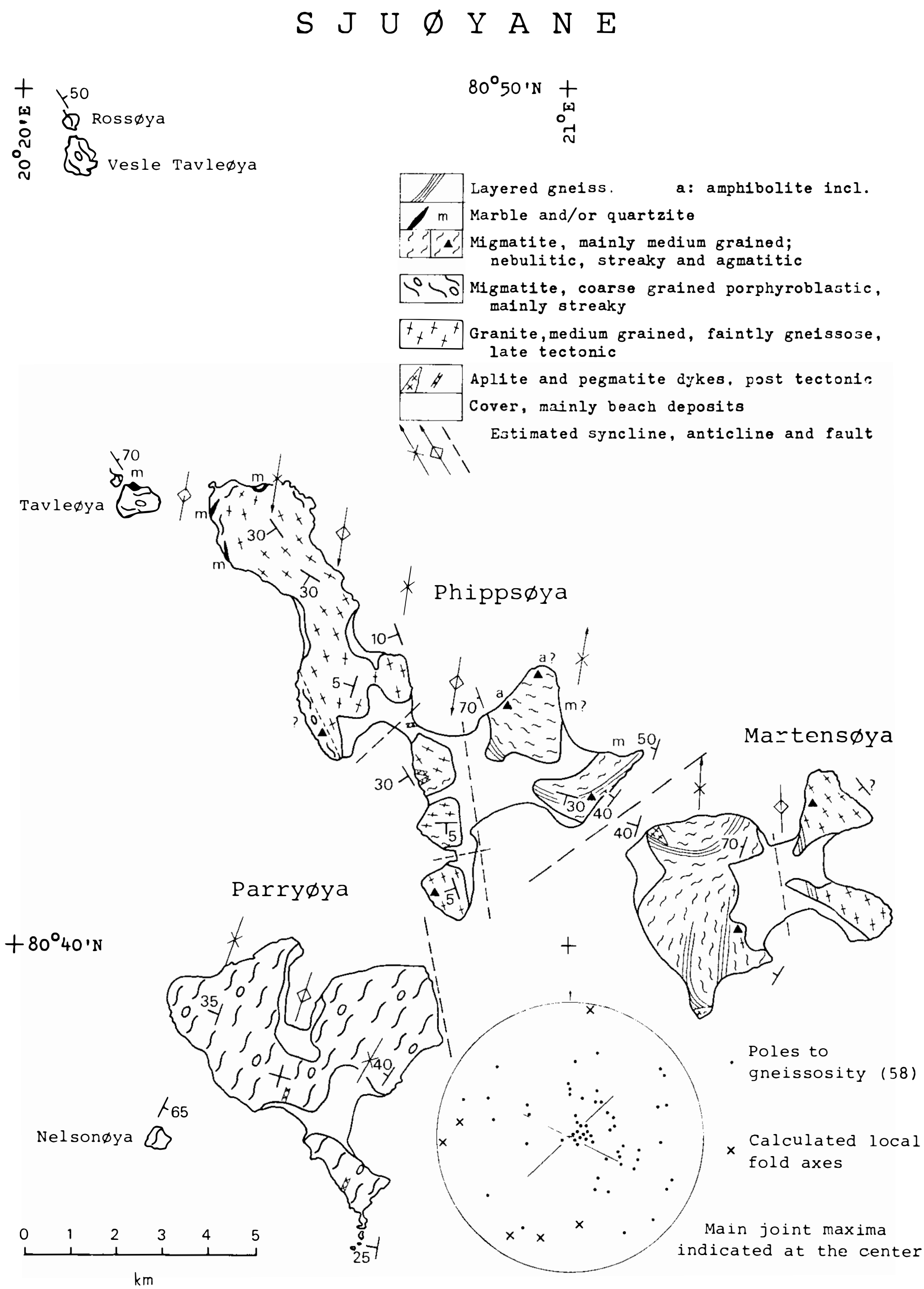


Fig. 1. *Geological map of Sjuøyane.*

from the migmatites. The granite is homogeneous grey medium grained, massive, or with a faint gneissosity. A somewhat cataclastic texture is evident in thin sections, with bent twin lamellae of plagioclase and strongly undulating quartz; biotite is mostly decomposed into chlorite. Muscovite commonly exceeds biotite. Garnet, sillimanite or cordierite is not recorded. An average modal composition is (%, from four thin sections): quartz 32, K-feldspar 30, oligoclase 28, muscovite 5, biotite 2, chlorite 3. Inclusions of migmatite, mica schist and amphibolite have been observed. Taking into account the weak gneissosity and the inclusions of gneissic rocks, the granite is considered as late tectonic.

Aplite and pegmatite dykes of a few to more than one hundred metres size, cut all rocks mentioned above. The dykes are unfoliated, of muscovite granite composition and of pinkish colour. Their cross-cutting nature and lack of gneissosity suggest a post-tectonic origin.

Structure

The general strike of gneissositities has a Caledonian trend, around NNE-SSW with westerly dips; however, great local variations exist and a set of synclines and anticlines is estimated. Calculated local fold axes are of shallow plunges and concentrate in two directions: NNE-SSW and E- W.The latter probably represents a refolding of the NNE-SSW structures.

Faults are not observed, but air photos of the southern part of Phippsøya show a distinct lineament which may represent a fault along the eastern side of the main granite.

Stratigraphy

The lowest established stratigraphical unit in Nordaustlandet, the late Precambrian Botniahalvøya Group, contains abundant and characteristic volcanic rocks; no paleosomes or layers of these rocks are recorded in the Sjuøyane migmatite. The regional structure of the Precambrian to lower Paleozoic rocks of the western half of Nordaustlandet suggests a main anticlinorium of NNE-SSW trend with increasing stratigraphical depth towards Sjuøyane (Flood et al. 1969, Fig. 48), thus the stratigraphical position of the Sjuøyane supracrustal rocks is assumed to be lower than t he Botniahalvøya Group.

Metamorphism

The sillimanite-cordierite-almandine-biotite paragenesis of the mica schist paleosomes in the migmatites indicates the amphibolite facies of high temperature-low pressure facies series. Retrogressive metamorphism is evident, especially in the cataclastic late tectonic granite, where biotite is largely replaced by chlorite.

Correlation, age

The nearest area at the mainland, around Nordkapp-Ekstremfjorden, is to a great extent built of rocks closely resembling those in Sjuøyane, as coarse-grained migmatites grading into gneissoze granite, and late tectonic medium-grained granites. Paleosomes and layers in the migmatites comprise dark siliceous schists and garnetiferous amphibolite. The structural trend is in the continuation of the NNE-SSW trend prevailing in Sjuøyane.

The migmatite and granite areas east of Duvefjorden consist largely of migmatites with inclusions of sillimanite-cordierite-bearing mica schist, quartzite, marble, and amphibolite (Hjelle et al., this vol.) The main submeridional structures are partly refolded along E-W axes. Both this area and the Nordkapp area is invaded by pink post-tectonic muscovite granite.

Taking into account the similarities in petrography, structure, and metamorphism, it seems evident that all the three areas mentioned belong to the same granite/migmatite complex.

K/Ar isotope dating of granitic rocks from the Brennevinsfjorden-Nordkapp area gave a minimum age of 400 m.y.; R/Sr ages of 581-636 m.y. from schists in Rijpdalen indicate a pre-Caledonian metamorphic event in Nordaustlandet, with or without Caledonian overprinting. (Gayer et al. 1966). Considering the time of migmatization and granite intrusion in Sjuøyane, a Caledonian age is possible, but decisive conclusion must wait until more radiometric evidence is available.

References

FLOOD, B., D. G. GEE, A. HJELLE, T. SIGGERUD and T. S. WINSNES, 1969: The geology of Nordaustlandet, northern and central parts. *Norsk Polarinstitutt Skrifter* Nr. 146.

GAYER, R. A., D. G. GEE, W. B. HARLAND, J. A. MILLER, H. R. SPALL, R. H. WALLIS and T. S. WINSNES, 1966: Radiometric age determinations on rocks from Spitsbergen. *Norsk Polarinstitutt Skrifter*. Nr. 137.

HJELLE, A., Y. OHTA and T. S. WINSNES, 1978: The geology of northeastern Svalbard. *Norsk Polarinstitutt Årbok* 1977: 7—24.

NORDENSKIÖLD, A. E., 1863: Geografisk och geognostisk beskrifning öfver nordöstra delarne af Spetsbergen och Hinlopen Strait. *K. svenska Vetensk. Akad. Handl.* 4 (7).

Audun Hjelle

An outcrop of the Kapp Starostin Formation at Austjøkeltinden, Sørkapplandet

Present knowledge of the geology of the central part of Sørkapplandet is based mainly on interpretations of aerial photographs. Helicopter support provided by Statoil's expedition to Hornsund in 1977 permitted us to examine Permian and Triassic exposures in this area, and a complete section through local representatives of the Treskelodden Beds and the Kapp Starostin Formation was examined on Austjøkeltinden, approximately 12 km south of Hornsund. This outcrop is of great interest as it represents the only known occurrence of rocks assignable to the Tempelfjorden Group between Treskelen and Sørkappøya. The Austjøkeltinden area was apparently situated on the eastern margins of the Hornsund-Sørkapp High in the Permian, a situation which is reflected in the complex nature of the condensed sequence exposed. Detailed palaeoecological and sedimentological interpretations of the Tempelfjorden Group of Sørkappøya, Austjøkeltinden and Treskelen will form part of a research thesis now under preparation by Hellem. In this note we will briefly describe this interesting exposure and compare its development to that seen at Treskelen.

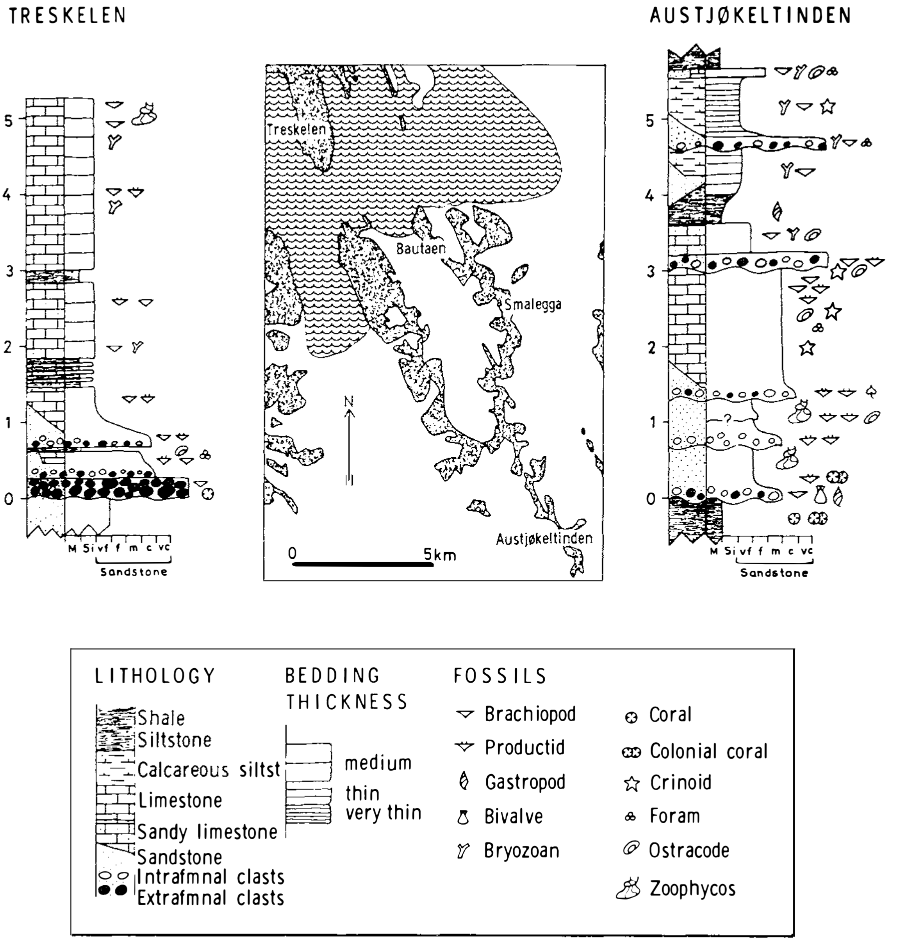


Fig. 1. *Sections through the Kapp Starostin Formation at Austjøkeltinden and Treskelen.*

The 5.5 m thick section through the Kapp Starostin Formation (Fig. 1) overlies 125 m of Treskelodden Bed equivalents which consist of conglomerates, sandstones and minor shales.

The Treskelodden Beds contain only one fossiliferous horizon, — corals occur in the uppermost shale immediately below the basal conglomerate of the overlying unit; Dr. J. Fedorowski (pers. comm.) informs us that specimens sent to him for identification all represent new taxa, so that comparison with the coral fauna of the Treskelodden Beds in Hornsund is difficult. The Kapp Starostin Formation can be divided into three general lithological units: a lower calcareous sandstone, a middle limestone, and an upper calcareous siltstone. Each of these units contains one or more conglomerates with both intra- and extraformational clasts. Glauconite occurs throughout the sequence, consituting between 2 and 20% of samples investigated.

The lower sandstone unit contains two marked conglomerates and several lag horizons marked by the accumulation of somewhat coarser material than otherwise seen in the fine to very fine sandstone matrix. The basal conglomerate contains both phosphatic and quartzitic clasts, while the upper bed contains only phosphatic clasts and bioclastic debris. The phosphatic clasts can often be shown to represent the abraded steinkerns of molluscs and brachiopods; the clasts are thought to have been formed by processes similar to those described by Kennedy and Garrison (1975) in the British Glauconitic Marl. The lower sandstones otherwise contain scattered fossils (mostly *Megousia*), gastropods and ostracodes. The trace fossil *Zoophycos* is common and specimens of *Zoophycos* are seen to have eroded tops at the junction with the basal conglomerate of the middle limestone unit.

This conglomerate (1.3 m O.D.) is dominated by phosphatic steinkerns and brachiopod debris; glauconite is concentrated in a thin veneer at the base of the bed. The conglomerate passes rapidly upwards into a pure biosparite, and phosphate is only seen higher in the section as isolated small grains. Crinoid debris constitutes the bulk of the biosparite, but ostracodes, foraminifers and partially silicified brachiopods are also common. The uppermost parts of this bed show microfissures and ?borings extending down into the limestone from the erosional contact with the overlying conglomerate; the latter is also notable for its content of the first significant amounts of extrabasinal clasts seen above the basal conglomerate of the whole sequence. A diverse brachiopod fauna is represented by transported shells preliminarily assigned to *Megousia weyprechti, Horridonia timanica, Waagenoconcha irginae, Spiriferella keilhavii,* and *Streptorhynchus kempeii.* The overlying cherty limestone has a less diverse fauna: partially silicified specimens of *Spiriferella keilhavii* and *Megousia* sp. occur together with sponge spicules, bryozoans and ostracodes.

A dark grey shale (3.6 m O.D.) passes rapidly upwards into the glauconitic calcareous siltstones typical of the uppermost unit seen. These are characterised by a prolific fauna of stenoporid and fenestellid bryozoans together with some spiriferid brachiopods *(S. keilhavii* and *Spirifer striatoplicatus)* and gastropods. A shell lag with some quartzite clasts in the middle of the unit has an undulatory loaded base, suggesting the nonconsolidated nature of the underlying silts at the time of its formation. The uppermost sandy lag contains spiriferids and some large productids: here as in many other localities on Svalbard there is no evidence of emergence of this bed prior to the deposition of the overlying Triassic shales.

Outcrops of the formation at Treskelen show a similar thickness, but somewhat different lithology. These have been described by Birkenmajer (1964) and Siedlecka (1970). The basal conglomerates here rest on different units of the Treskelodden beds, and infill karst surfaces in the underlying limestone at Creek IV. Our section was measured on the SW coast of Treskelen; the basal conglomerate here consist of extrabasinal clasts in a sandy matrix. Two thinner conglomerates are seen above this bed, and these contain a high proportion of bioclastic debris and some phosphatic lithoclasts. The remainder of the formation consists of limestones with a minor sand content and some shaly partings in the lower part of the outcrop. The limestones are fine-grained and were called calcareous spiculites by Siedlecka (1970) because of their high content of calcareous sponge spicules. Silification is widespread in the uppermost beds, decreasing downwards. The relationship between silification patterns and stylolites indicates that silification occurred prior to compaction and pressure solution.

Previous workers have described the thinning of the Kapp Starostin Formation southwards to Treskelen, and the formation has been suggested to be absent on Sørkapplandet (see e.g. Cutbill and Challinor 1965: Fig. 6). The unit *is* absent in outcrops immediately south of Hornsund, but we interpret this as a tectonic rather than a primary stratigraphical feature; the outcrops on Austjøkeltinden are important in helping to delineate the eastern margins of the Hornsund — Sørkapp High. The eastern margins of this structure were apparently the site of active faulting during deposition of the Hyrnefjellet and Treskelodden Beds, and the high seems to have been emergent until the Dienerian. The development at Austjøkeltinden indicates the proximality of this area to the high. Repeated conglomerates and lags suggest an extremely condensed sequence and the abraded phosphatic steinkerns seen in the lower part of the unit indicate a complex history of burial, exhumation and reworking of fossil shells. Of interest also is the uppermost siltstone unit which seems to represent an extremely thin representative of the Hovtinden Member equivalents described from Torell Land by Nysæther (1977).

References

BIRKENMAJER, K., 1964: Devonian, Carboniferous and Permian formations of Hornsund, Vestspitsbergen. *Studia geol. Polon.* 11.

CUTBILL, J. L. and A. CHALLINOR, 1965: Revision of the stratigraphical scheme for the Carboniferous and Permian rocks of Spitsbergen and Bjørnøya. *Geol. Mag.* 102: 418—439.

KENNEDY, W. J. and R. E. GARRISON, 1975: Morphology and genesis of nodular phosphates in the Cenomanian Glauconitic marl of south-east England. *Lethaia* 8: 339—360.

NYSÆTHER, E., 1977. Investigations on the Carboniferous and Permian stratigraphy of the Torell Land area, Spitsbergen: *Norsk Polarinst. Årbok* 1976: 22—41.

SIEDLECKA, A., 1970: Investigations of Permian cherts and associated rocks in southern Spitsbergen. *Norsk Polarinst. Skrifter* Nr. 147.

Terje Hellem
Paleontologisk Museum
Sarsgt. 1
Oslo 5

David Worsley
Paleontologisk Museum
Sarsgt. 1
Oslo 5

A regional survey of composition, provenance and diagenesis of sandstones in the Lower Cretaceous Helvetiafjellet Formation, Svalbard

Abstract. — Sandstones from widespread localities on Svalbard consist of varying proportions of these detrital grain components: monocrystalline and polycrystalline quartz, feldspars, chert and basaltic volcanic rock fragments. Quartz-rich arenites are characteristic in Spitsbergen, while mixed quartzose lithic arenites occur in southeast Spitsbergen. Volcanic arenites are dominant on Kong Karls Land. There is great variability in cementing agents. Quartz is present in proportion to the amount of detrital quartz. Chlorite and calcite are abundant in quartzose lithic arenites, while smectite and calcite, with minor zeolites are common in volcanic arenites. This suggests that detrital mineral composition strongly determines authigenic mineral composition.

Quartz rich sands were derived from a mixed sedimentary-metamorphic terrain in the west, and volcanic-rich sands were derived from contemporaneous lava flows in the east.

In order to acquire geological information of regional significance, bearing on the adjacent shelf, the Continental Shelf Institute, Trondheim, has collected samples from the major Cretaceous outcrops of Svalbard: north, east and south of the Tertiary syncline on Spitsbergen, and Kongsøya, Kong Karls Land. Mesozoic strata are widspread on the shelf (e.g. Rønnevik et al., 1975; Rokoengen, et al., 1977; Hinz & Schlüter, 1978), and probably have a high petroleum potential. The present note sums up a more detailed report published elsewhere (Edwards, 1978).

The Helvetiafjellet Formation consists of 50—100 m of largely fluvial light sandstones and dark shales deposited throughout Svalbard during the lower Cretaceous regression (Parker, 1967; Edwards, 1976; Steel, 1977). On Kong Karls Land, the Formation contains extensive basaltic lava flows (Smith et al., 1976).

Composition of detrital grains and authigenic cements was studied by thin section and scanning electron microscopy, with an energy dispersive analyser, and X-ray diffraction. Five major detrital components were identified: monocrystalline and polycrystalline quartz, feldspars, chert and volcanic (chiefly basaltic) rock fragments. On a triangular diagram, these plot into three main sandstone types: 1) quartz and quartzose arenites; quartz content usually greater than 90 per cent, 2) quartzose lithic arenites; quartz with abundant chert and volcanic rock fragments, and 3) volcanic arenites, with 50—95 percent volcanic rock fragments.

Type (1) occurs in many parts of Spitsbergen and, in light of paleocurrent evidence, appears to have been derived from a mixed sedimentary-metamorphic terrain to the west. Type (3) occurs in Kong Karls Land and was derived from contemporaneous basaltic lava flows. Occasional quartzose arenites on Kongsøya were locally derived by reworking of unconsolidated sands in the Rhaeto-Liassic Wilhelmøya Formation. Type (2) occurs around Kvalvågen, southeast Spitsbergen, and represents a mixture of quartz sands from the west and reworked volcanic sands from the east.

Authigenic cementing minerals are abundant in these sandstones.Quartz overgrowths are dominant in the quartz and quartzose arenites, and decrease with decreasing detrital quartz content. Kaolinite is observed in many feldspar-bearing quartz and quartzose arenites, while illite is scarce. Chlorite is common, along with calcite, in quartzose lithic arenites at Kvalvågen. Smectite and calcite, with minor zeolites, are abundant in the volcanic arenites on Kong Karls Land. Sandstone induration changes dramatically from very high in the west to very low in the east. Porosity is very low in the west and increases markedly to the east.

Of the many factors that may be invoked to explain the variety of mineral cements present in different areas, the above observations suggest that detrital grains composition was the major factor. Unstable detrital grains released cations to pore waters allowing clay minerals such as chlorite and smectite to form. The observed variations in induration and porosity can be explained to a certain extent by probably burial depths under younger Cretaceous and Tertiary sediments, as well as by an increasing geothermal gradient southwards in Spitsbergen during the Tertiary (Manum et al., 1977).

In view of the widespread volcanism around the Arctic during the Lower Cretaceous (Harland, 1975), it is possible that unstable volcanic detritus was supplied in varying quantities to substantial areas of the Barents Shelf. This could enable clay and calcite cements to form during diagenesis and burial, thereby adversely affecting sandstone reservoir properties.

References

EDWARDS, M. B. 1976: Depositional environments in Lower Cretaceous regressive sediments, Kikutodden, Sørkapp Land, Svalbard. *Norsk Polarinst. Årbok 1974:* 35—50.

— 1978: Composition, provenance and diagenesis of sandstones in the Lower Cretaceous Helvetiafjellet Formation, Svalbard. *Continental Shelf Inst. Trondheim, Publ.* No 98, 29 pp.

HARLAND, W. B., 1975: Phanerozoic relative motions of North Atlantic Arctic lands. In: *Can. Soc. Petrol. Geol. Mem.* 4, Canada's Continental Margins and Offshore Petroleum Exploration. 235—256. Ed. C. J. Yorath, E. R. Parker and D. J. Glass.

HINZ, K. and H.-E. SCHLÜTER, 1978: The geological structure of the western Barents Sea. *Mar. Geol.* 26: 199—230.

MANUM, S. B., T. BJÆRKE, T. THRONDSEN and M. EIEN, 1977: Preservation and abundance of palynomorphs, and observations on thermal alteration in Svalbard. *Norsk Polarinst. Årbok* 1976: 121—130.

PARKER, J. R., 1967: The Jurassic and Cretaceous sequence in Spitsbergen. *Geol. Mag.* 104: 487—505.

ROKOENGEN, K., D. G. BELL, T. BUGGE, T. DEKKO, T. GUNLEIKSRUD, R. L. LIEN, M. LØFALDLI and J. O. VIGRAN, 1977: Sampling of bedrock and Quaternary deposits offshore parts of North-Norway in 1976. *Continental Shelf Inst. Publ.* 91. 65 pp. In Norwegian with English summary.

RØNNEVIK, H. E. I. BERGSAGER, A. MOE, O. ØVREBØ, T. NAVRESTAD and J. STANGNES, 1975: The geology of the Norwegian continental shelf. In: *Petroleum and the Continental Shelf of North-West Europe. Vol. 1 Geology:* 117—128. Ed. A. W. Woodland.

SMITH, D. G., W. B. HARLAND, N. F. HUGHES and C. A. G. PICKTON, 1976: The geology of Kong Karls Land, Svalbard. *Geol. Mag.* 113: 193—232.

STEEL, R. J., 1977: Observations on some Cretaceous and Tertiary sandstone bodies in Nordenskiöld Land, Svalbard. *Norsk Polarinst. Årbok* 1976: 43—68.

Marc. B. Edwards
Continental Shelf Institute
P.O. Box 1883
7000 Trondheim
Norway

Present Address:
Bureau of Economic Geology
University of Texas
University Station, Box X
Austin, Texas 78712
U.S.A.

Early Cretaceous foraminifera from the Janusfjellet Formation in Kong Karls Land, eastern Svalbard

Abstract. — Two foraminiferal assemblages are reported from the Lower Cretaceous Tordenskjoldberget Member of the Janusfjellet Formation in Kongsøya, eastern Svalbard. Calcareous species dominate the lower part of the member, whereas simple arenaceous forms characterize the upper part. These microfaunas indicate a neritic to marginal marine environment for the Tordenskjoldberget Member.

Introduction

The principal regions of Mesozoic sediments in Svalbard are the central and eastern parts of Spitsbergen and the islands of eastern Svalbard

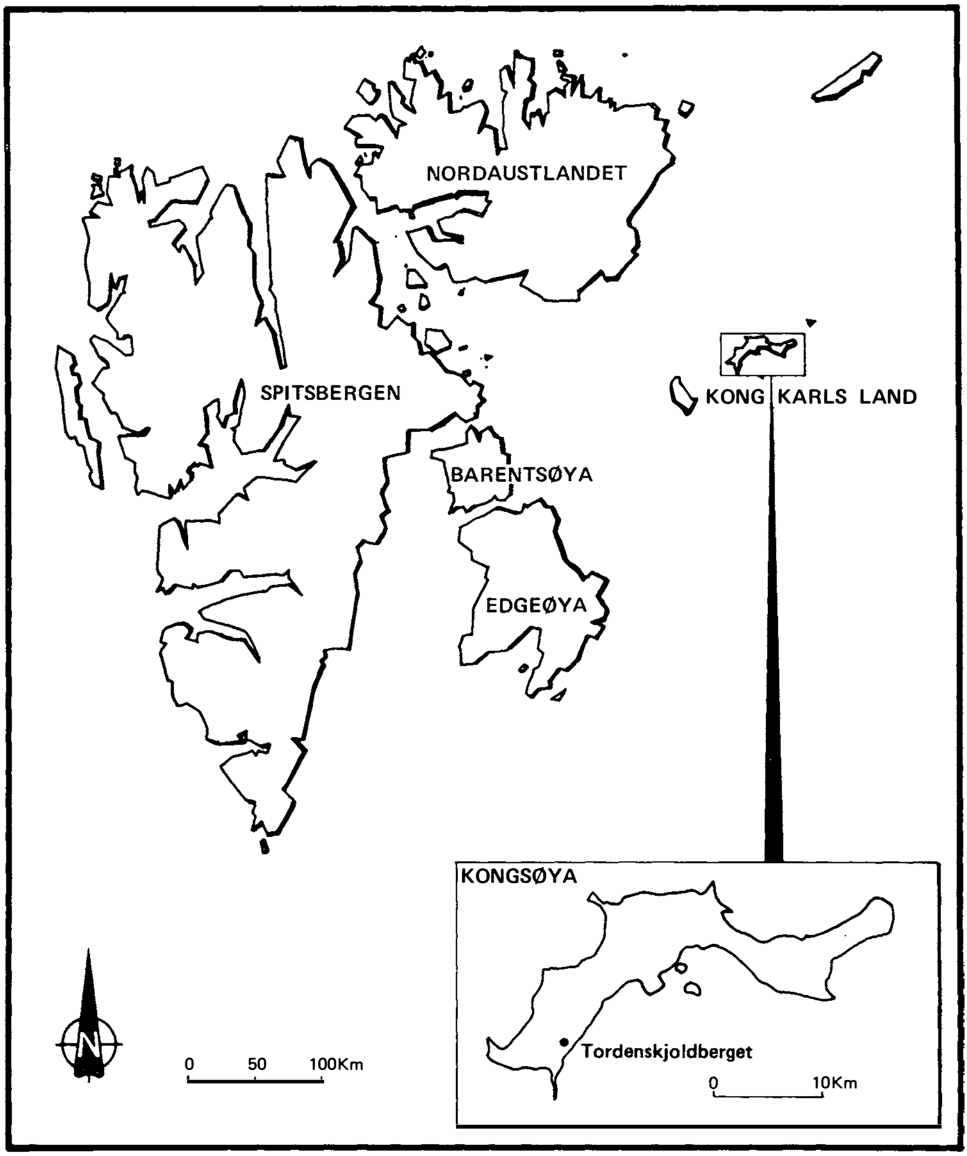


Fig. 1. *Location of Tordenskjoldberget, Kong Karls Land, Svalbard.*

(Fig. 1). These sediments are predominantly shales, siltstones, and sandstones deposited mainly under marine conditions with two periods of non-marine sedimentation marked by coals (Harland 1973; Edwards 1976; Edwards et al. in press). Biostratigraphical studies of these sediments have been done by many workers. Newer data are published by Parker (1967), Tozer and Parker (1968), Nagy (1970), and Bjærke et al. (1976). Foraminifera are earlier reported from the Mesozoic of Wilhelmøya (Klubov 1965), Agardhfjellet, and Keilhaufjellet (Løfaldli and Thusu 1976).

A detailed description of the geology of Kong Karls Land was given by Smith et al. (1976). Recently, Edwards et al. (in press) modified the stratigraphical nomenclature proposed for eastern Svalbard by Smith et al. (1976). According to Edwards et al., the Janusfjellet Formation in Kong Karls Land includes the Retziusfjellet and Tordenskjoldberget Members. The Retziusfjellet Member consists of clay and shales, the Tordenskjoldberget Member consists mostly of shale and siltstone, with limestone and marl in the basal part (Fig. 2). The new formation and member names proposed by Edwards et al. are used in this article.

Sampling of Mesozoic rocks in Kong Karls Land was carried out by the Continental Shelf Institute in the summer of 1976.

This article is concerned with the general features of the foraminifera in the Tordenskjoldberget Member of the Janusfjellet Formation.

Foraminifera

Two foraminiferal assemblages are recognized at Tordenskjoldberget (Fig. 2). Assemblage I occurs in the lower part of the Tordenskjoldberget Member, whereas Assemblage II belongs to the upper part of this member. The two assemblages are summarized below.

Assemblage I. This assemblage consists predominately of calcareous forms. The Nodosariidae, Involutinidae and Spirillinidae dominate the assemblage. The Nodosariidae are to a great extent represented by species of *Astacolus, Saracenaria, Lenticulina, Marginulina, Marginulinopsis* and *Lagena,* the Involutinidae by *Trocholina,* and the Spirillinidae by *Spirillina* and *Patellina.* A few species of the arenaceous genera *Ammodiscus, Haplophragmoides,* and *Glomospira* are present.

Assemblage II. This assemblage contains very few species and is also limited in number of specimens. The meagre fauna is composed almost entirely of arenaceous foraminifera. The families Lituolidae, Trochamminidae and Ammodiscidae are represented by a few species of *Haplophragmoides, Trochammina* and *Ammodiscus.*

Discussion

The paleoecological interpretations presented here are principally based on the diversity of the microfossils and the relative abundance of dominant genera which have been compared with the bathymetric distribution of Cretaceous and Jurassic analogues from the literature.

Assemblage I is dominated by nodosariids and species of *Trocholina* and *Spirillina.* Nodosariids occur in nearly all marine environments, but are concentrated in the neritic and in the upper bathyal zone (Sliter and Baker 1972; Chamney 1977). In Early Cretaceous time, species of *Trocholina* and *Spirillina* are known to be common in marl and calcareous shelf-sediments of France (Chevalier 1965; Guillaume 1973), Germany (Kemper 1972), and Poland (Moryc and Wasniowska 1965). This association is also common in Upper Jurassic reef-facies from various parts of Europe (Seibold and Seibold 1960; Hanzlikova 1965; Hassan El Khoufary 1974). According to Kemper (1973), *Trocholina* prefers a well aerated shallow-water environment with hard bottom.

Assemblage II is made up of foraminiferal groups that can tolerate wide environmental differences and are found in sediments of considerable depth variations. The low diversity of the assemblage, however, suggests a shallow marine environment, probably a marginal marine condition. These foraminifera could also be the result of a cool temperature or reduced oxygen supply in deeper water (Moorkens 1976).

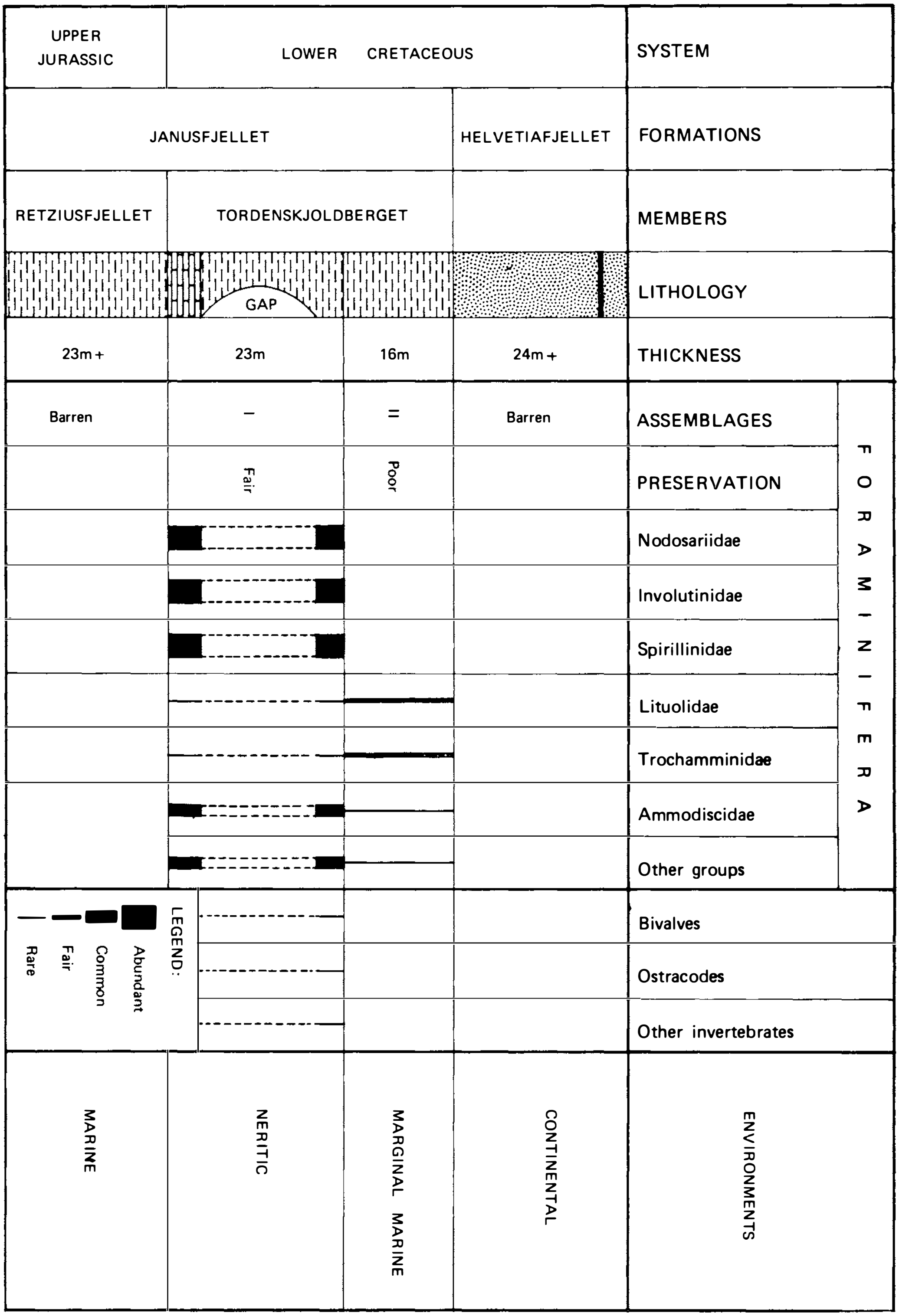


Fig. 2. *Distribution of fossils and environmental interpretations based on foraminifera in the Tordenskjoldberget Member at Tordenskjoldberget.*

Acknowledgements

The field work was carried out in the summer of 1976 by the Continental Shelf Institute. Norsk Polarinstitutt gave financial support to the field work and the Royal Norwegian Council for Scientific and Industrial Research (NTNF) to the study of the material. The present study was carried out as a part of the NTNF-financed project P-142 (Micropaleontology, Arktis). I would like to thank these institutions for their help.

A special thank is extended to Dr. Marc B. Edwards for improving the English.

References

BJÆRKE, T., M. B. EDWARDS, and B. THUSU, 1976: Microplankton from the Janusfjellet Subgroup (Jurassic — Lower Cretaceous) at Agardhfjellet, Spitsbergen. A preliminary report. *Norsk Polarinstitutt Årbok* 1974: 63—68.

CHAMNEY, T. P., 1977: Foraminiferal morphogroup symbol for paleoenvironmental interpretation of drill cutting samples: Arctic America. *Ist. Int. Symp. on Benthonic Foraminifera of Continental Margins. Part B. Paleoecology and Biostratigraphy MARITIME SEDIMENTS Spec. Pub. 1:* 585—624.

CHEVALIER, J., 1965: Contribution a l'étude stratigraphique et micropaléontologique du Crétacé inférieur du Languedoc et de la Provence occidentale. Colloque sur le Crétacé inférieur (Lyon, septembre 1963). *Mémoires du B.R.G.M.* 34: 695—709.

EDWARDS, M. 1976: Depositional environments in Lower Cretaceous regressive sediments, Kikutodden, Sørkapp Land, Svalbard. *Norsk Polarinstitutt Årbok* 1974: 35—50.

EDWARDS, M., T. BJÆRKE, J. NAGY, T. S. WINSNES, and D. WORSLEY, in press: Mesozoic Stratigraphy of Eastern Svalbard: a Discussion.

GUILLAUME, S., 1973: Les Trocholines du Crétacé inférieur du Jura. *Revue Micropaleont.* 5: 257—276.

HANZLIKOVA, E., 1965: The Foraminifera of the Klentnice Beds (Malm). *Sbornik geologickych ved,* rada *P,* 5: 39—104.

HARLAND, W. B., 1973: Mesozoic geology of Svalbard. Arctic Geology (Ed. M. G. Pitcher). *Amer. Assoc. Petroleum Geologists Memoir* 19: 135—148.

HASSAN EL KHOUFARY, R., 1974: Beiträge zur Stratigraphie und Paläontologie des Juras von Ostspanien. VI. Untersuchungen im Oberjura der südwestlichen Iberischen Kordillere unter besonderer Berücksichtigung der Mikrofauna (Provinz Teruel und Rincon de Ademuz). *N. Jb. Geol. Paläont.* 144: 296—341.

KEMPER, E., 1972: The Valanginian and Hauterivian stages in northwest Germany. In: (R. Casey and P. F. Rawson Eds.) *The Boreal Lower Cretaceous:* 327—344. Liverpool, Seel House Press.

KLUBOV, B. A., 1970: The Triassic and Jurassic deposits of Wilhelmøya. In: *Geology of Spitsbergen* 1965 transl. J. E. Bradley (ed. W. B. Harland). Boston. Spa N.L.L. 1970: 182—192 (from the Russian ed. V. N. Sokolov, Leningrad 1965).

LØFALDLI, M. and B. THUSU, 1976: Microfossils from the Janusfjellet Subgroup (Jurassic — Lower Cretaceous) at Agardhfjellet and Keilhaufjellet, Spitsbergen. *Norsk Polarinstitutt Årbok* 1975: 69—77.

MOORKENS, T. L., 1976: Palökologische Bedeutung einiger Vergesellschaftungen von sandschaligen Foraminiferen aus dem NW europäischen Alttertiär und ihre Beziehung zu Muttergesteinen. Sonderdruck aus dem COMPENDIUM 75/76. Erganzungsband der Zeitschrift *Erdöl und Kohle, Erdgas, Petrochemie:* 77—95.

MORYC, W. and J. WASNIOWSKA, 1965: Neocomian Deposits at Basznia near Lubaczów (SE Poland). *Roczn. Pol. Tow. Geol.* 35: 55—70.

NAGY, J., 1970: Ammonite faunas and stratigraphy of Lower Cretaceous (Albian) rocks in southern Spitsbergen. *Norsk Polarinstitutt Skrifter* Nr. 152: 1—58.

PARKER, J. R., 1967: The Jurassic and Cretaceous sequence in Spitsbergen. *Geol. Mag.* 104: 487—505.
SEIBOLD, E. and I. SEIBOLD, 1960: Foraminiferen der Bank- und Schwamm-Fazies im unteren Malm Süddeutschlands. *N. Jb. Geol. u. Paläont. Abh.* 109: 309—438.
SLITER, W. V. and R. A. BAKER, 1972: Cretaceous bathymetric distribution of benthic foraminifers. *Journal of Foraminiferal Research* 2: 167—183.
SMITH, D. G., W. B. HARLAND, N. F. HUGHES and C. A. G. PICKTON, 1976: The geology of Kong Karls Land, Svalbard. *Geol. Mag.* 113: 193—232.
TOZER, E. T. and J. R. PARKER, 1968: Notes on the Triassic biostratigraphy of Svalbard. *Geol. Mag.* 105: 526—542.

Magne Løfaldli
Institutt for Kontinentalsokkelundersøkelser
Håkon Magnussonsgt. 1B
7000 Trondheim

A Valanginian calcareous nannofossil association from Kong Karls Land, Eastern Svalbard

Abstract. — Samples from Kong Karls Land contain a Valanginian association of coccoliths. It is suggested that the earliest occurrence of *Tegumentum stradneri* is time-transgressive in the Valanginian — Early Barremian time span from Svalbard to southeastern France.

In the course of several expeditions the Continental Shelf Institute has sampled a number of sections in the Svalbard archipelago. Sedimentological, palynological and micropaleontological studies are currently being carried out on these samples. In a first assessment of their calcareous nannofossil content, an Early Cretaceous nannoflora was encountered in six samples from the lower, calcareous part of the Tordenskjoldberget Limestone Member, Kongsøya Formation, Kong Karls Land (Smith et al. 1976, Fig. 13-D 833, Western Kongsøya). The type section of this member was sampled in 1976 by M.B. Edwards. On a regional scale the Tordenskjoldberget Member is probably equivalent to the Rurikfjellet Member of the Janusfjellet Formation of Spitsbergen (Edwards et al. in press), where a calcareous foraminiferal fauna has been found (Løfaldli and Thusu 1976).

Early biostratigraphic work on the Tordenskjoldberget Member was based on material from the 1898 expedition of A.G. Nathorst. In a study of the molluscs of Nathorst's samples, Blüthgen 1936 (in Smith et al. 1976) concluded to a lower to Middle Valanginian age for a «Sandkalk» and an «eisenschüssige Mergel» considered equivalent to the Tordenskjoldberget Member by Smith et al. 1976, who accepted this age. Based on the palynomorphs from the section we are dealing with, T. Bjærke (Geological Institute, Oslo University), mentions a Valanginian to Barremian age in a personal communication to M.B. Edwards. B. Thusu (Continental Shelf Institute, Trondheim) considers the immediately overlying part of the Tordenskjoldberget Member of Hauterivian to Barremian age (personal communication).

Of the section studied, six samples of a marly clay contain varying amounts of nannofossils. The next lowermost sample, a hard limestone, proved to be barren. It is assumed that over this short section the presence and absence of species is function of sample richness. Therefore the pooled nannofossil content of all samples is considered as one nannoflora for stratigraphical purposes. Of the coccoliths recorded, *Watznaueria communis* is very abundant. *Watznaueria britannica, Crucirhabdus sp, Cretarhabdus conicus, Palaeopontosphaera salebrosa, Cretarhabdus crenulatus* and *Zeugrhabdotus diplogrammus* are common, and *Vekshinella stradneri, Markalius circumradiatus, Cyclagelosphaera deflandrei, Micrantholithus hoschulzii, Parhabdolithus splendens, Parhabdolithus asper, Manivitella pemmatoidea, Tegumentum stradneri, Bipodorhabdus colligatus, Stephanolithion laffittei* and *Diadozygus? sp.* are few to rare. A comparison to the range charts and type area studies of Roth and Thierstein 1972, Thierstein 1973 and 1976, and Sissingh 1977 gives a Valanginian age for this association. There are a few discrepancies however. Firstly the presence of *Tegumentum stradneri* is abberant. According to Thierstein 1973, the earliest occurrence of this species is in the Tealby Clay and Limestone, Lincolnshire, Great Britain, that is considered of Hauterivian age, and in the upper part of the sections La Charce 3 and Route d'Ages in southeastern France of Early Barremian age. Based on this and other evidence, Thierstein supposes a paleogeographical or paleo-ecological barrier between these two areas in Hauterivian — Barremian times. On Kong Karls Land however we find *Tegumentum stradneri* in a Valanginian nannoflora that lacks species of tropical affinity. So we might tentatively suggest a time-transgressive first occurrence of this species from Valanginian to Early Barremian, from Svalbard to southwest France, i.e. from a boreal to a suptropical environment. A second discrepancy is the common presence of a small form resembling a *Crucirhabdus* species and some rare fragments with affinity to *Diadozygus*. These are regarded to be reworked Jurassic forms.

The Valanginian age concluded from calcareous nannofossils is in agreement to the previous age attribution based on molluscs. A more complete taxonomic and stratigraphic treatment of calcareous nannofossils from the Svalbard archipelago will be undertaken when a representative part of the available material has been studied.

Acknowledgements. — M.B. Edwards, IKU, Trondheim, carried out the fieldwork and provided the frame of Svalbard regional lithostratigraphy. Biostratigraphy and nannofossil ranges have been discussed with M. Løfaldli, IKU, Trondheim, and with R.R. Schmidt, Utrecht University, the Netherlands. The fieldwork in the Svalbard archipelago was supported by Norsk Polarinstitutt.

References

BLÜTHGEN, J., 1936: *Die Fauna und Stratigraphie des Oberjura und der Unterkreide von König Karl Land.* Grimmen (Pomerania). 75 pp.

EDWARDS, M. B., T. BJÆRKE, J. NAGY, T. WINSNES and D. WORSLEY in press: Mesozoic stratigraphy of Eastern Svalbard. A discussion. *Geological Magazine.*

LØFALDLI, M. and B. THUSU, 1976: Microfossils from the Janusfjellet Subgroup (Jurassic-Lower Cretaceous) at Agardhfjellet and Keilhaufjellet, Spitsbergen. *Norsk Polarinstitutt Årbok* 1975: 69—77.

ROTH, P. H. and H. THIERSTEIN, 1972: Calcareous nannoplankton: leg 14 of the DSDP Project. In: (Hayes, D. E., Pimm, A. C., et al.) *Initial reports of the DSDP Project* 14: 421—485.

SISSINGH, W., 1977: Biostratigraphy of Cretaceous calcareous nannoplankton. *Geologie en Mijnbouw* 56 (1): 37—65.

SMITH, D. G., W. B. HARLAND, N. F. HUGHES and C. A. G. PICKTON, 1976: The geology of Kong Karls Land, Svalbard. *Geological Magazine* 113: (3): 193—232.

THIERSTEIN, H. R., 1973: Lower Cretaceous calcareous nannoplankton biostratigraphy. *Abh. Geol. B-A, Wien* 29: 1—52.

— 1976: Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. *Marine Micropaleontology* 1: 325—362.

Jacob G. Verdenius
IKU — Continental Shelf Institute
Håkon Magnussons gt. 1 B
7000 Trondheim — Norway

An observation of polar bear mating in Svalbard

In April 1977, in the Storfjorden area in Svalbard, I made an observation of mating polar bears *(Ursus maritimus)* on the sea ice off Mohnbukta. I was travelling in a party of five persons with snowscooters when we came upon a female polar bear, her two-year old cub, and a male bear together. The two-year old was rather active and the female chased it

Fig. 1. *The mating polar bears.*

away. Shortly afterwards she was mounted by the male. The distance between us and the mating bears was approximately 150 metres. After five minutes, I approached the two bears carefully on the snowscooter, until I was only ten metres away. Apparently my presence did not disturb them. The male's movement were rather violent, and the female apparently tried to get away from him several times. She was stopped, however, by the male holding her tight with his two forepaws. The two bears uttered no sound, but jumped around in the snow, fell down together, then got up again. The mating took approximately 40 minutes, interrupted by a few short resting periods when the bears were standing upright together. After the mating they kept at about 30 metres distance from each other.

Meanwhile, the two-year old bear had stayed 100 metres or more away from the adults, apparently ignoring the two and being occupied on its own. It was stealing up on a sea bird — probably an ivory gull *(Pagophila eburnea)* — sitting on an ice hummock. On 60 to 70 centimetres distance the young bear grabbed the bird with its forepaw and ate it immediately.

Gerd Hagen
Longyearbyen

Mating between polar bears has rarely been observed. Gerd Hagen's observation confirms some previous findings indicating that a female polar bear will accept and mate a male even if still accompanied by her two-year old offspring. The mating bears will often stay together for days, while the young bear(s) keep at some distance. The family break-up probably coincides with such mating. If so, a mature, female polar bear will mate and bring offspring every third year at most.

The observation of the young bear catching a sea bird is quite unique. Polar bears are usually not able to catch birds under such circumstances and are not considered major predators on birds in Svalbard.

Thor Larsen

Harald Lyche & Co. A.s