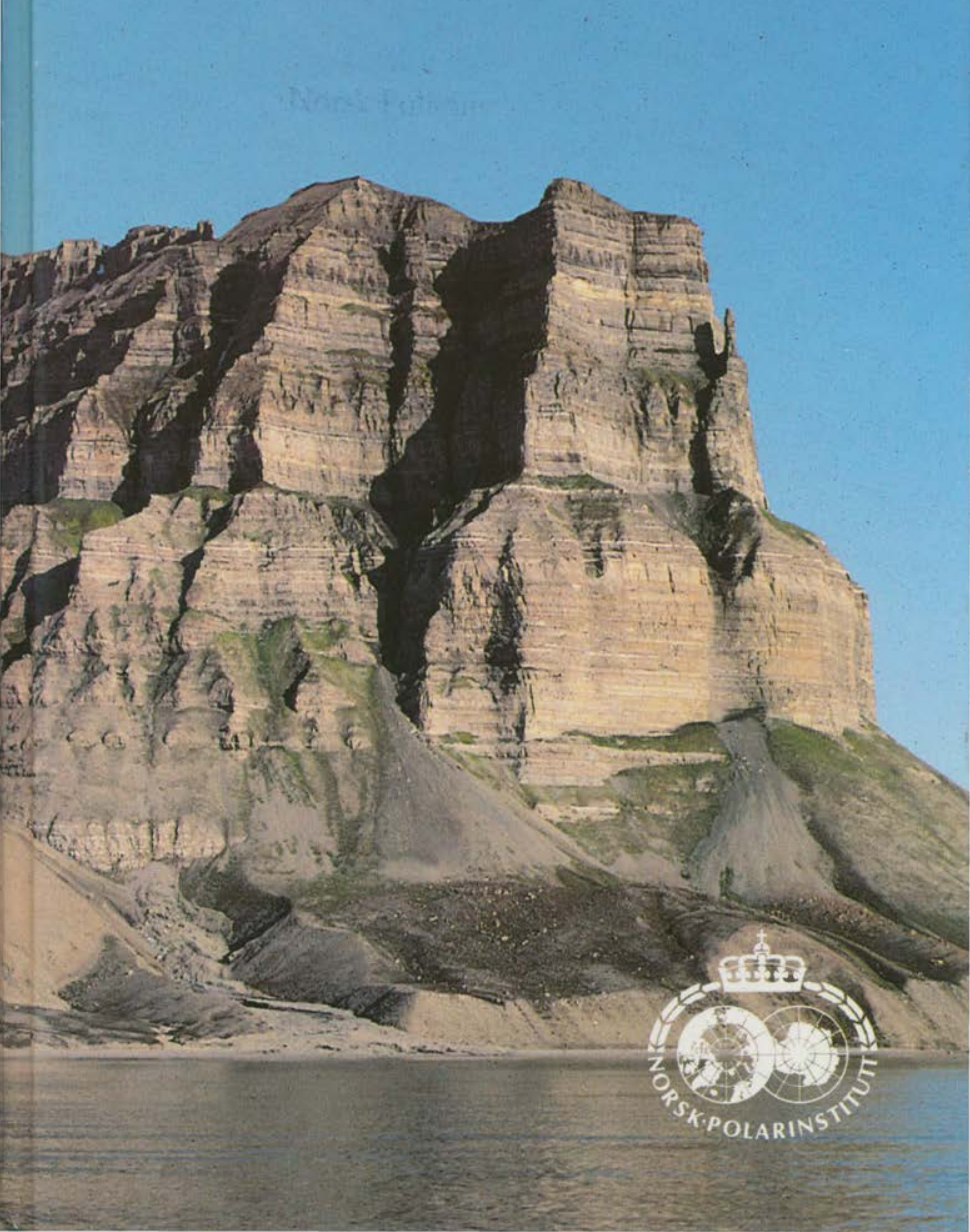
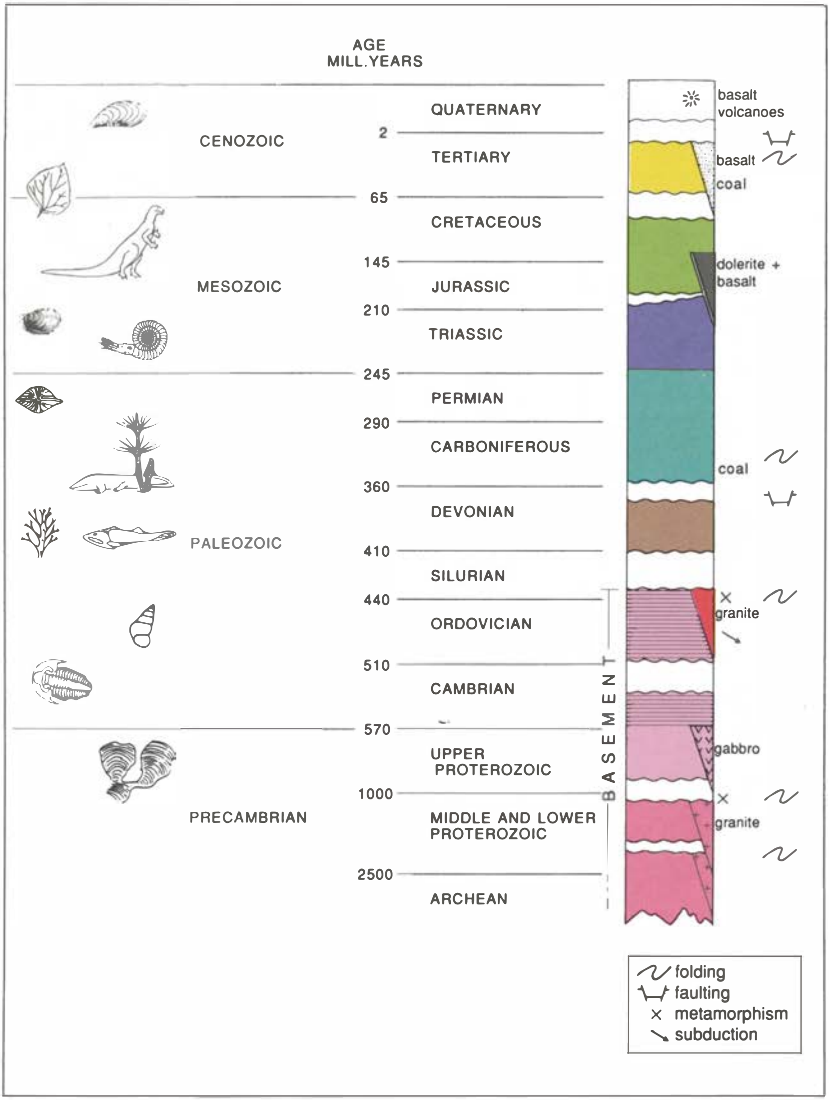
AUDUN HJELLE

# GEOLOGY OF SVALBARD

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CENOZOIC
QUATERNARY
2
TERTIARY
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MESOZOIC
JURASSIC
210
TRIASSIC
245
PERMIAN
290
CARBONIFEROUS
360
DEVONIAN
PALEOZOIC
410
SILURIAN
440
ORDOVICIAN
510
CAMBRIAN
570
UPPER PROTEROZOIC
1000
PRECAMBRIAN
MIDDLE AND LOWER PROTEROZOIC
2500
ARCHEAN
BASEMENT
basalt volcanoes
basalt
coal
dolerite + basalt
coal
granite
gabbro
granite
folding
faulting
metamorphism
subduction

POLARHÅNDBOK NO. 7

AUDUN HJELLE

# GEOLOGY OF SVALBARD

NORSK POLARINSTITUTT

OSLO 1993

Photographs contributed by the following:

Dallmann, Winfried: Figs. 12, 21, 24, 25, 31, 33, 35, 48
Heintz, Natascha: Figs. 15, 59
Hisdal, Vidar: Figs. 40, 42, 47, 49
Hjelle, Audun: Figs. 3, 10, 11, 18 , 23, 28, 29, 30, 32, 36, 43, 45, 46, 50, 51, 52, 53, 54, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 71, 72, 75
Larsen, Geir B.: Fig. 70
Lytskjold, Bjørn: Fig. 38
Nøttvedt, Arvid: Fig. 34
Paleontologisk Museum, Oslo: Figs. 5, 9
Salvigsen, Otto: Figs. 13, 59
Skogen, Erik: Fig. 39
Store Norske Spitsbergen Kulkompani (SNSK): Fig. 26


English translation: Richard Binns
Editor of text and illustrations: Annemor Brekke
Graphic design: Vidar Grimshei
Omslagsfoto: Erik Skogen
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## PREFACE

In an area like Svalbard with sparse vegetation and little habitation, the geological formations dominate the landscape. Those who travel here therefore often become curious and want to know more about the geology.

This handbook aims to provide a simplified introduction to the geological history of Svalbard and the main aspects of the geology. Those who would like more detailed information are referred to the 1:100,000 scale geological thematic map series published by the Norwegian Polar Institute; the maps are accompanied by more detailed descriptions and comprehensive reference lists.

This handbook is one of a series published by the Norwegian Polar Institute. Similar ones dealing with Svalbard flora, geography, animal life and history have already appeared.

I wish to thank Arild Myhrvold for preparing the maps and my present and former colleagues Winfried K. Dallmann, Tore Gjelsvik, Hilde B. Keilen, Yoshihide Ohta, Otto Salvigsen and Thore S. Winsnes in the geological section of the Norwegian Polar Institute for providing photographs and for valuable help and necessary corrections while the book was being prepared.

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*Audun Hjelle*

## INTRODUCTION

About 60 % of the 63,000 km² large land area of Svalbard is covered by glaciers. These are particularly extensive in the northeast, Austfonna on Nordaustlandet being the largest; its front is almost continuous for about 200 km. In the west, where the warm waters of the final branch of the Gulf Stream make their presence felt and mild air currents from the south meet land, there are almost ice-free areas. The fjords on the west coast are therefore open most of the year and there has been permanent settlement on the archipelago for nearly 100 years, even though with an annual precipitation of only 300 mm the Svalbard area is really a cold desert. The Gulf Stream is effective beyond Nordaustlandet in the north, and the Sjuøyane islands furthest north in Svalbard have no glaciers. In the east, on the other hand, land forming the island of Kvitøya is almost completely concealed beneath the Kvitøyjøkulen glacier, only a few small tongues being visible.

Svalbard has been called "a paradise for geologists" and "a geological picture book". When we look at the geological time- scale, we can understand better why this is so. Because Svalbard has been beneath sea level throughout the greater part of its geological history, almost unbroken deposition (sedimentation) of sand, gravel, clay, carbonate, etc. has taken place. This material has subsequently been transformed into stratified rocks. The almost complete stratigraphical column shows that Svalbard has rocks from every division of the history of the planet, and many contain well-preserved fossils of animals and plants from the past.

Svalbard has little soil and no woodlands or cultivated ground to conceal the geological formations. In this naked countryside, geological features are therefore unusually distinct. Not least, the many fjords in the west and north have large numbers of fine geological sections. Even though much of the countryside is ice covered, there are few better places in the world to study the geological history of the planet. Svalbard is therefore both a natural geological archive and a laboratory where past and present geological processes can be especially clearly demonstrated.

When you are walking in the countryside, questions can crop up in your mind. Why are some mountains higher than others? Why do rivers and fjords run in certain directions? How is it that fossils of warmth-loving plants and animals are to be found in frozen Svalbard rock, or remains of marine animals on high mountaintops? The landscape may sometimes seem to be a fortuitous mixture of mountains, valleys, plateaus and lakes. However, not much basic geological knowledge is required before we can begin to look at the landscape and countryside with different eyes. He or she who realises how things hang together will discover that what may seem dead and static is really a living landscape undergoing continuous evolution. Where Svalbard now stands, sea has alternated with land, huge upheavals in the Earth's crust have created mountain chains that have subsequently been worn down and levelled off by running water and glaciers. The material resulting from this erosion was deposited as clay, sand, gravel, and limey mud, which themselves gave rise to new mountains.

This handbook briefly summarises the geological history of Svalbard and some of the geological events that have resulted in the Svalbard we see today. Its geological construction is dealt with areawise, and fairly detailed descriptions and maps on a scale of 1:250,000 (Fig. 1) have been included for the most easily accessible and often visited areas. The colours on these maps, the 1:2 million map, and the geological time-scale on the cover indicate the age of the rocks. The local maps also have shading or symbols distinguishing rock types.

Explanations of some words and expressions are given in separate shaded sections in the text.

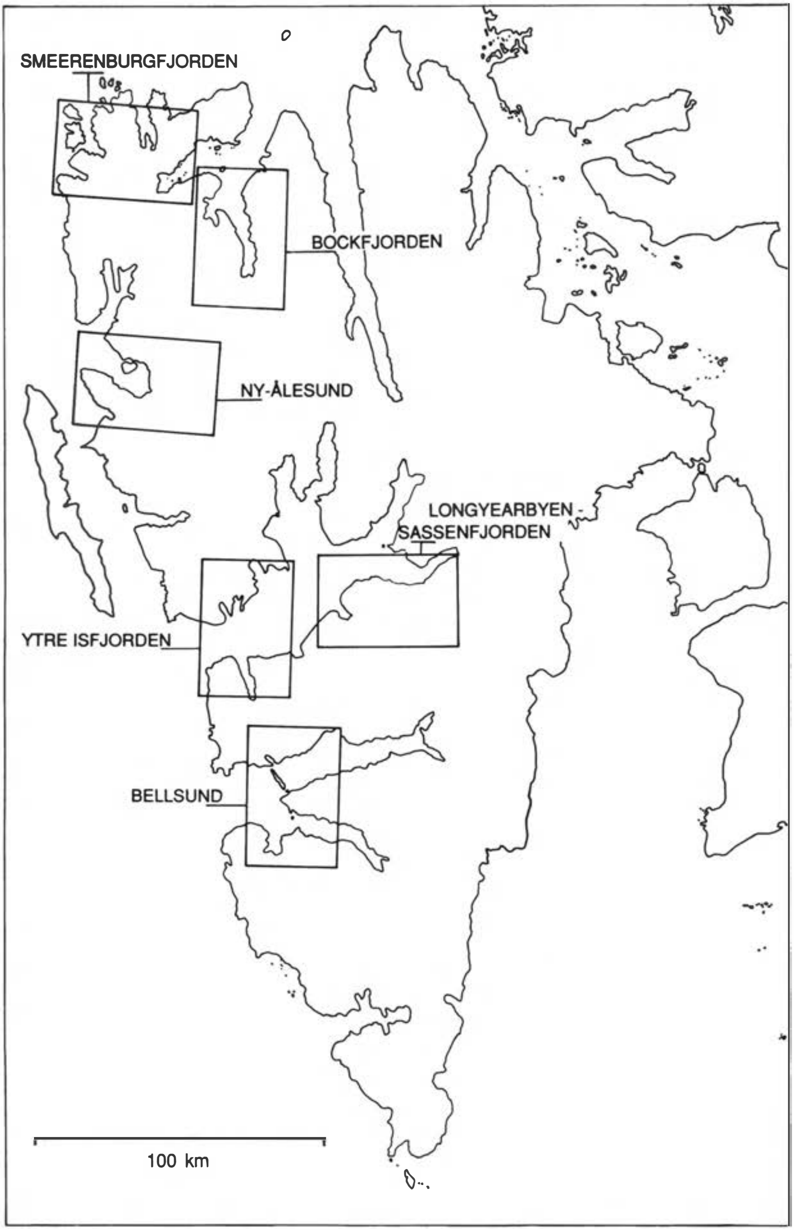



*Fig. 1 Key map showing the 1:250,000 scale coloured geological maps in the book.*

# THE GEOLOGICAL EXPLORATION OF SVALBARD

Even though Svalbard was re-discovered by Willem Barents as long ago as 1596, more than 200 years passed before geologists visited the islands. Explorers such as Poole, Martens, Scoresby and Parry admittedly made some random notes about the geology, but like most remote parts of Europe, its geological exploration did not begin before the 19th century. The Norwegian geologist, Professor Baltazar Mathias Keilhau, who visited Bjørnøya (Bear Island) and the eastern part of Svalbard in 1827, was one of the first scientists to work in Svalbard. One of his discoveries on Bjørnøya was a new species of brachiopod that has been named after him *(Spirifer keilhavii)*.

Interest for Svalbard geology gradually increased with the realisation that here in the north it was possible to study bed upon bed containing well-preserved fossils in sequences that are absent or rarely found in northern Europe.

The important French "Recherche" expedition visited Svalbard in 1838, returning with much new information about the natural environment in Svalbard, including its geology. From about 1860, Swedish expeditions put a great deal of effort into obtaining a general idea of the topography and geology of Svalbard, and the first geological maps were prepared. Adolf Erik Nordenskiöld and A.G. Nathorst were particularly active in this work.

The geological exploration of Svalbard has increased during the present century, often motivated by hopes of economic gain. As early as just after the turn of the century, a great deal of effort was put into finding workable deposits of coal and several minerals, chiefly around Isfjorden, Bellsund and Kongsfjorden, and along the west coast between Kongsfjorden and Hornsund.

Through De Norske Statsunderstøttede Spitsbergenekspeditioner and later Norges Svalbard- og Ishavs-undersøkelser, Norway began modern, systematic exploration of the archipelago. From the first decades, such geological names as the pioneers Adolf Hoel, Olaf Holtedahl, Gunnar Holmsen, Anatol Heintz and A.K. Orvin may be mentioned. Much laborious work lies behind the collecting and studying of rocks, fossils and observations carried out by these and others. By degrees, the results came; like a jigsaw puzzle, the picture of the geological history of Svalbard was gradually put together. The main features of the geology are now known, and effort is being concentrated on obtaining as precise and detailed knowledge as possible, to substantiate theories on how Svalbard and the Barents Sea evolved.

In 1948, Norges Svalbard- og Ishavs-undersøkelser was re-organised and expanded, and given the name Norsk Polarinstitutt (the Norwegian Polar Institute), having responsiblity for working in both the Arctic and Antarctic. In recent decades, geologists from the institute, along with some from Norwegian and foreign universities, oil companies and other institutions, have worked over almost the whole of Svalbard. Helicopters, now one of the most valuable tools of the geologists, have made field work more efficient, and computers have been introduced to process the information gathered by the geologists. The Norwegian Polar Institute is responsible for mapping land areas in Svalbard, and has now completed the general geological mapping. The whole of Svalbard is covered by four map sheets on a scale of 1:500,000. Work on a new series of more detailed geological maps on a scale of 1:100,000 has started. These maps are initially being published for areas where most activity is going on - the southern and western parts of Spitsbergen and its central fjord districts (Fig. 77 ). The Norwegian Polar Institute has a research station at Ny-Ålesund and a research division and field equipment store in Longyearbyen.

The geological research environment in Svalbard has always been noted for its internationalism. In recent years, co-operation with geologists from a variety of nations has been increasingly more wide-ranging and geologists from several nations now often work on joint research projects.

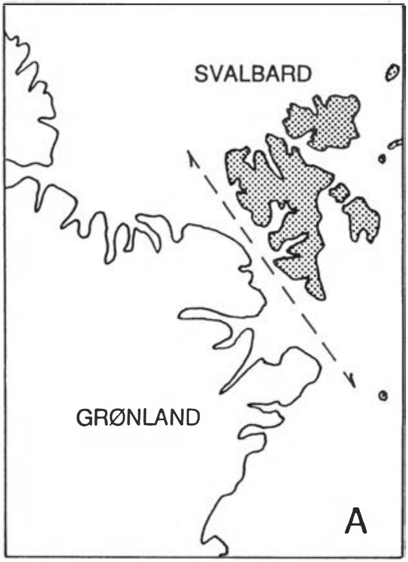
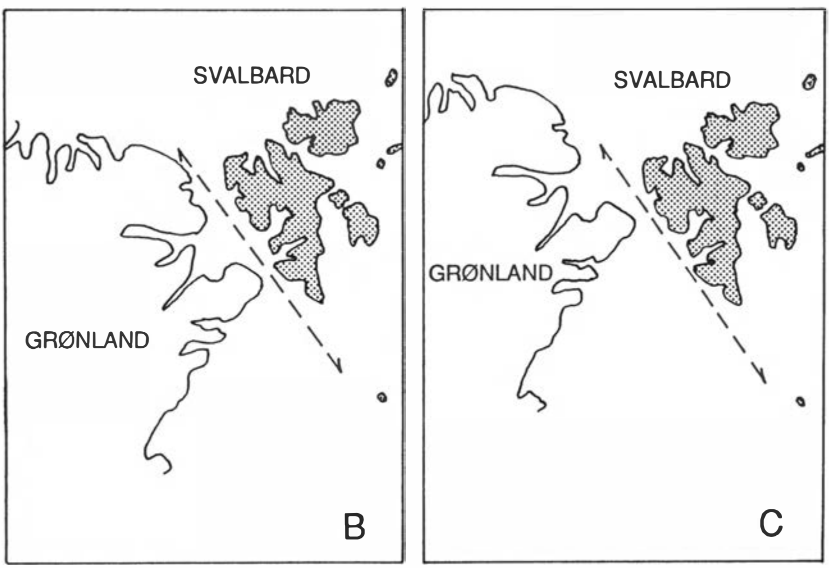



***Fig. 2 Simplified presentation of how the Svalbard and Greenland continental plates were pushed obliquely against each other during the Tertiary. A: about 56 million years ago, B: about 49 million years ago, C: about 40 million years ago. Partly after Vågsnes, Reksnes, Faleide and Gudlaugson. Norsk Polarinstitutt Rapport No. 46.***

## SVALBARD, PART OF THE NORTHERN POLAR REGION

Svalbard has not always had the shape and size it has today. The distribution of sea and land has varied through the ages, some areas sank while others rose. The land areas of Svalbard which we see today are really elevated portions of the Norwegian continental shelf in the Barents Sea, the Svalbard Platform. In the west and north, the platform falls abruptly to the deep ocean, but in the east it continues as a submarine plateau as far as Franz Joseph Land and Novaya Zemlya. Oceanographical investigations of the Barents Sea carried out by Fridtjof Nansen showed that large parts of the region have been dry land during the Quaternary.

The geographical location of Svalbard has not been constant either. The Caledonian mountain chain, segments of which can now be seen in the British Isles, along the west coast of Norway, on Spitsbergen, and along the east coast of Greenland, was formed about 400 million years ago when an easterly continental plate collided with a westerly one. Since then, the part of the European Plate on which Svalbard stands has mostly drifted northwards. This movement from south to north through tropical and desert regions to the Arctic is an important reason for the great diversity of life forms displayed by Svalbard fossils.



Some major horizontal movements took place at the close of the Devonian period, after the Caledonian folding episode. One theory maintains that Spitsbergen is composed of several segments that have drifted for long distances, one moving from an area in northern Canada. After these movements, conditions were quiet until the transition between the Cretaceous and Tertiary when segments of the European Plate began drifting independently of one another. First Norway drifted away from Greenland, forming the Norwegian Sea. In the north, compression and thrusting initially took place resulting in the belt of Tertiary folding and faulting now seen along the west side of Spitsbergen (Fig. 2). Later, around mid-Tertiary time, approximately 40 million years ago, a period of north-south rifting was initiated and Svalbard began drifting away from Greenland; the Greenland Sea opened. In response to these huge plate movements in what is now the North Atlantic region, tremendous volumes of lava poured out of fractures to build up the Mid-Atlantic Ridge. The islands of Jan Mayen and Iceland are parts of this ridge which project above sea level and consist almost entirely of volcanic rocks which have forced their way up along the spreading margins. Ocean spreading and volcanic activity are still going on today.

**Continental drift (plate tectonics)**

The outer "shell" of the planet has two layers. The upper one consists mostly of granites and is the building material of the continents where the Earth's crust may reach a thickness of 70 km. The lower layer, which borders against the underlying mantle, consists of basalt and is common beneath the deep oceans where the crust is mostly less than 10 km thick. Studies of the crust show that the continents, or parts of them, are moving slowly (usually a few cm a year) as stiff plates on a floating substrate. Where the plates are pushed against each other, fold belts, volcanoes and earthquake zones develop along the collision margin. Old ocean floor is pressed down and mountain chains are folded up.

An example of the result of colliding plates is the Caledonian mountain chain in Scotland, Norway and Svalbard that originated in Silurian times when Greenland and Europe were pushed against each other. If plates drift apart, a rift is formed and molten rock (magma) from the mantle is able to force its way upwards as lava. Norway and Greenland are now moving apart, the crust beneath the Norwegian Sea has fractured and lava is pushing up along the Mid-Atlantic Ridge, e.g. on Jan Mayen and Iceland. Ocean-floor spreading has taken place in the North Atlantic since the Tertiary, with repeated rifting and extrusion of lava. Hence, there are numerous parallel ridges of solidified lava on the sea floor.

# WHAT TOOK PLACE IN SVALBARD - WHEN?

This brief account of the geological history of Svalbard begins more than 1000 million years ago in the oldest geological era, the Precambrian, and ends in our own time, the Quaternary period. A table summarising the various geological periods can be found on the inside cover of the book and also on the enclosed 1:2 million map.

The map shows that Svalbard has been greatly affected by crustal movements along north-south trending lines where rising, sinking, thrusting, and folding of crustal blocks have taken place over a long period of time.

Fossils are found in numerous deposits, ranging from simple organisms in the oldest horizons to dinosaurs in the Mesozoic and flowering plants in the Tertiary. The variation in life forms is vast, testifying to the evolution of life on the Earth and how the natural environment in the Svalbard region has changed over several hundred million years.

**The geology of Svalbard can be separated into three broad divisions:**

1. *The basement, comprising the deepest and oldest material.* It consists of igneous and metamorphic rocks which, following erosion, were covered by horizontal, sedimentary strata. What is hereafter referred to as the Svalbard basement was formed during Precambrian to Silurian times, and is thus older than about 400 million years. The rocks forming the basement differ from Devonian and younger strata by being metamorphosed (altered by heat and/or pressure) and more strongly folded. Some basement rocks lay so deep in the crust that they were exposed to high pressures and temperatures and therefore became particularly strongly metamorphosed. New minerals crystallised and some bedrock was wholly or partially melted, and igneous rocks were intruded. The most strongly metamorphosed bedrock is found in northwestern Spitsbergen and the northern part of Nordaustlandet.

Because of its great age, the basement has undergone several periods of folding and metamorphism, and traces of the oldest ones have been partially erased by later ones. The last large-scale folding and metamorphism took place in the Silurian (the Caledonian Orogeny - or mountain-range building episode). When that ended, rivers, glaciers, rain and wind began eroding the mountains that had formed.

2. *Unaltered sedimentary rocks.* The eroded bedrock became huge quantities of sand, gravel and mud deposited on alluvial plains, in lakes and in the sea during the Devonian period. New episodes of erosion and deposition followed from Carboniferous to Tertiary times. Some of these sediments, such as conglomerates, were deposited rapidly, others slowly; some carbonate strata accumulated at a rate of less than 1 mm per century. The strata on Spitsbergen

form a huge trough-shaped structure stretching from the Isfjorden district southwards, with the youngest and uppermost beds in the middle as a core and older ones on the margins. Altogether, strata amounting to a thickness of more than 15,000 m were deposited on the basement. Not all these are preserved everywhere; some were eroded and removed before new ones were added. The thickness of an individual bed may also vary from one place to another, depending on conditions during its deposition. Apart from gentle folding during the Devonian and Carboniferous, and renewed folding and faulting in the west in the Tertiary, these younger strata have mostly remained undisturbed. The result is well preserved and for the most part gently folded or horizontal beds forming the characteristic plateau-topped mountains that are particularly common in central and eastern Spitsbergen and on the islands to the east.

Strongly altered bedrock from the time after the Silurian does not occur, but igneous rocks were intruded during the Devonian and Carboniferous, around the transition from Jurassic to Cretaceous and during the Tertiary. The most widespread igneous rocks date from Jurassic-Cretaceous time.

3. *Superficial (unconsolidated) deposits.* Uppermost and most recent are deposits from the Quaternary period, which are still forming today. These are mostly unconsolidated deposits formed during and after the last Ice Age - moraines, fluvial deposits, littoral deposits, talus (screes), and block fields. There have also been active volcanoes in northwestern Spitsbergen during the Quaternary.

## PRECAMBRIAN TO LOWER SILURIAN - FROM ALGAE TO TRILOBITES

These time periods are being dealt with together here, because in Svalbard they comprise more or less altered (metamorphosed) and folded rocks. They have often been called the Hecla Hoek series, rocks or formation after the mountain Heclahuken, furthest northeast on Spitsbergen, the geology of which was described by A.E. Nordenskiöld in 1863. These relatively old, metamorphosed rocks are found on Bjørnøya, western and northern Spitsbergen, and Nordaustlandet and the islands to the north and east of there. All these areas are situated in the Caledonian fold belt, where bedrock thousands of metres thick was compressed, folded, heated, and metamorphosed. The belt stretches from Scotland taking in Norway, eastern Greenland and Svalbard. Caledonian folds in Svalbard mostly trend around north-south, and on the west coast of Spitsbergen it is often difficult to distinguish them from later folds with the same direction.

Because of weathering and erosion, only the eroded remnants of the ancient, folded and metamorphosed basement can be seen today. In Svalbard, it now forms the substrate for much younger beds deposited from Devonian to Tertiary times.

*Precambrian*
This bedrock is more than 570 million years old. The Precambrian era lasted for several billion years, a time space that is too long for us to comprehend. It is divided into two periods, the Archaean which is older than about 2.5 billion years, and the younger Proterozoic. Radiometric methods are used extensively to determine the age of minerals and rocks (page 114), and most age determinations of Precambrian rocks in Svalbard have given Proterozoic ages. Evidence for several mountain building and metamorphic episodes (orogenies) has now been found in Svalbard, dating from approximately 1700, 1000 and 600 million years ago. These mountain chains have long since been eroded away and the rocks we now see are from their deeper, inner parts. Because the oldest rocks will usually have suffered several periods of folding and recrystallisation, it is difficult to determine when they were first formed. Some minerals, such as zircon, are, however, extremely resistant to external influences, and zircon giving an age of 3.2 billion years has been found in northwestern Spitsbergen. Other definitely Archaean minerals or rocks are not yet known from Svalbard. The far northeast probably offers the greatest chance for finding extremely ancient rocks. Some workers believe that the bedrock here may have belonged to the westernmost part of the vast Precambrian Fennoscandian Shield.

Proterozoic volcanic rocks are found in several places, and are particularly beautifully developed on Botniahalvøya, a peninsula on the north coast of Nordaustlandet. On Spitsbergen, volcanic rocks occur, among elsewhere, in Chamberlindalen, a valley south of Bellsund, and on both sides of Forlandsundet.

The best preserved Proterozoic sedimentary rocks are found astride Hinlopenstretet. Their good state of preservation has allowed a relatively detailed description of the succession and fossils to be prepared.

On the west side of Spitsbergen, the Proterozoic strata are often more irregular. The difference partly results from them having been compressed, folded and disrupted into faulted blocks during the Tertiary disturbance. Long before then, right from the time the beds were deposited, there were differences between western Spitsbergen and northeastern Spitsbergen and Nordaustlandet. In the west, for example, there are more and thicker beds of conglomerate, and the thickness of beds varies substantially. This may indicate unstable conditions here already in Precambrian time.

But there are not only dissimilarities. Tillites are found both on northeastern Spitsbergen, westernmost Nordaustlandet and the west coast of Spitsbergen. These were originally moraines, glaciofluvial deposits and drop deposits from melting icebergs deriving from glaciers which covered Svalbard around 600 million years ago. These beds are the youngest Proterozoic strata, immediately underlying the Cambrian, and form an import-


***Fig.3 Proterozoic tillite from Prins Heinrichfjella, east of Forlandsundet.***

ant key horizon for age determination. Proterozoic tillites are also found in Finnmark (mainland northern Norway) and northeastern Greenland. Beneath the tillites are beds of limestone or dolostone containing stromatolites, which are fossil algae colonies that grew in shallow water. These are among the oldest fossils found in Svalbard.

On northwestern Spitsbergen and the northern part of Nordaustlandet, along with the smaller islands of Sjuøyane, Storøya and Kvitøya, the Precambrian rocks are generally strongly metamorphosed. The lowermost beds here have once been so deep in the crust that high pressures and temperatures caused them to be partially melted and recrystallised transforming sedimentary rocks and volcanics into mica schist, gneiss and migmatite; disrupted remnants of marble and amphibolite beds can often also be seen.

## The most common rock-forming minerals

QUARTZ consists of silica (silicon oxide) and occurs in most rocks. It is the chief mineral in quartzite and sandstone, and also occurs as rock crystal, rose quartz, smoky quartz and amethyst. Agate, flint and opal also consist of silica.

FELDSPAR is a collective name for an important group of light-coloured, rock-forming minerals. The most important feldspars are alkali-feldspars, containing potassium, sodium and aluminium, and plagioclases, containing sodium, calcium and aluminium. Alkali-feldspars are common in, for example, granite, and plagioclases in diorite and gabbro.

CALCITE is composed of calcium carbonate and is the main mineral in limestone and calcareous marble.

DOLOMITE is composed of calcium-magnesium carbonate and is the chief mineral in dolostone and dolomitic marble. It is frequently light coloured.

BIOTITE Dark mica. A common silicate mineral containing among other things, potassium, iron and magnesium.

MUSCOVITE Light-coloured mica. A common silicate mineral containing among other things, potassium and aluminium.

AMPHIBOLE An important group of rock-forming silicate minerals, common in amphibolite and gabbro. Often prismatic or needle-shaped and dark coloured. The most common amphiboles, such as hornblende, are dark and contain large quantities of iron, magnesium and calcium.

PYROXENE An important group of rock-forming silicate minerals found in many gabbros. Many types, the most common of which contain much iron, magnesium and calcium. Often greenish or brownish.

GARNET A group of silicate minerals with varying composition, often occurring in metamorphic rocks, e.g. almandine in gneiss, pyrope in eclogite, grossular and andradite in metamorphosed carbonate-rich rocks.

CHLORITE Greenish, mica-like, silicate mineral containing iron, magnesium and aluminium. Often a replacement product of biotite, amphibole or pyroxene.

OLIVINE A magnesium- and iron-bearing silicate mineral, often green or brown. Common in many gabbroic rocks.

*Cambrian and Ordovician*

In contrast to the Proterozoic bedrock, these strata more often contain fossils, mostly in beds of calcareous and dolomitic limestone. This is the Age of Invertebrates. The most common faunal groups were trilobites, brachiopods, cephalopods and graptolites. The Cambrian has been called the Age of Trilobites. All Cambrian and Ordovician fossils derive from marine creatures living in the Iapetus Ocean. This ocean opened in the early Cambrian when a westerly Canadian-Greenland Continental Plate (Laurentia) began drifting away from the easterly Fennoscandian Plate. Because animal and plant life had still not evolved sufficiently to survive out of water, the land was barren and without life at this time. In Svalbard, fossils from these two periods are often somewhat deformed because of subsequent folding, but they are nonetheless better preserved than those found in Proterozoic rocks. Ordovician fossils were first found on southeastern Bjørnøya. Along the west coast of Spitsbergen, fossils were first found in Cambrian and Ordovician beds in Sørkapp Land. Ordovician fossils have subsequently also been found on the east side of Forlandsundet, near St. Jonsfjorden. In northeastern Svalbard, Cambrian and Ordovician fossils are found immediately above the late-Proterozoic tillites in Olav V Land, Ny Friesland and western parts of Nordaustlandet.

Many of the Cambrian and Ordovician fossils found in Svalbard are more closely related to species from North America and Greenland than those found to the east, e.g. in the Oslo Region. At any rate parts of Svalbard were therefore more closely linked to the westerly than the easterly continental plate.

## SILURIAN AND DEVONIAN - FOLDING AND PRIMITIVE FISH

Two continental plates, the Canadian-Greenland Plate (Laurentia) and the Fennoscandian Plate, collided with each other at this time, causing large-scale folding and faulting (the Caledonian Orogeny) throughout what is now the North Atlantic region and forming the long-since eroded away Caledonian mountain chain. Rocks comprising the roots of this chain are easily visible in the British Isles, western Scandinavia, eastern Greenland and Svalbard. In Svalbard, this Caledonian Orogeny, named after Caledonia, an old name for Scotland, was most intense during the Silurian. All rocks older than late-Silurian are therefore folded and metamorphosed to varying degrees. Investigations of fossil magnetism (palaeomagnetism) show that Svalbard was close to the equator just after this folding episode. Granites intruded the old rocks during the late Silurian and early Devonian. Both Newtontoppen, east of Wijdefjord, the highest mountain in Svalbard, and Hornemantoppen, east of Magdalenefjorden, consist of such granites.

When the main Caledonian Orogeny ended at the transition from Siluri-

## Altered (metamorphosed) rocks

These are igneous or sedimentary rocks that have been altered by heat and/or high pressure, often with the additional influence of chemically active solutions. The result is recrystallisation, often accompanied by development of schistosity. For example, limestone can be altered to marble, basalt to amphibolite.

AMPHIBOLITE Greyish-black or black rock carrying amphibole as its main mineral; usually formed from gabbro or basalt.

BLUE SCHIST Schist metamorphosed under high pressure; a constituent mineral is blue sodium amphibole (glaucophane).

ECLOGITE Crystallised under high pressure and consists chiefly of red garnet and green pyroxene.

PHYLLITE Fine grained cleaved rock, usually formed from shale. Cleavage surfaces have a silky sheen produced by small flakes of muscovite and chlorite.

MICA SCHIST Schistose rock of varying grain size, containing quartz, mica and small amounts of feldspar. Usually formed from shale, but more strongly altered than phyllite.

GNEISS Medium to coarse grained rock formed from mica schist, impure sandstones or granitic rocks. Contains alternating light-coloured stripes, lenses and layers rich in quartz and feldspar and dark-coloured ones containing mostly mica and/or amphibole. Has more feldspar and is often coarser and more irregularly schistose than mica schist.

HECLA HOEK A previously much used term to describe the ancient basement of metamorphosed and folded rocks older than late Silurian in Svalbard. The term basement is used on modern Norwegian Polar Institute maps and in this book.

QUARTZITE Quartz-rich rock, usually metamorphosed sandstone.

MARBLE Metamorphosed limestone. Heat and/or pressure recrystallises limestone to the more coarse grained and generally purer marble. Dolomitic marble is altered dolostone.

MIGMATITE A mixed rock in which fragments of metamorphosed rocks "float" in a granitic groundmass.

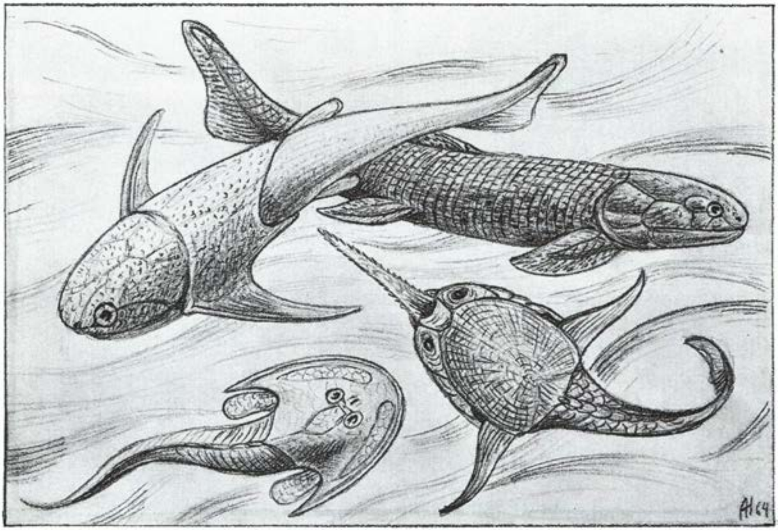


***Fig.4 Reconstruction of the four most important types of fish in the Devonian rocks of Svalbard. Lowermost, two primeval fish - a Pteraspid on the right and a Cephalaspid on the left. Uppermost, two true fish - a tassle-finned fish on the right and an armour-plated shark on the left. Drawn by Anatol Heintz.***

an to Devonian, northern Spitsbergen began sinking at the same time as rivers swept vast quantities of gravel and sand into the developing basin depositing thick layers of sediment. In the west, where the land was highest and steepest, erosion was particularly active and rivers excavated and planed down the old mountains. The Devonian beds formed from the material deriving from the eroding mountains were deposited on the old, planed-off surface of the Caledonian mountain chain from Silurian time. Transport of material in northwestern Spitsbergen was mostly from west to east, and the sediment produced a total thickness of around 8000 m of sandstones, conglomerates and shales. These were mostly deposited in brackish or fresh water, often in river deltas and shallow lakes. The lower part of the succession contains some beds of volcanic rock. Sedimentary rocks from the very uppermost Devonian are lacking in Svalbard. The Devonian is called the Age of Fishes, and fossils of primitive fish, the first-known vertebrates, and primitive plants have been found in Svalbard. The first terrestrial plants evolved at this time. The Devonian beds, which often consist of characteristic red sandstones, correspond to what is called the Old Red Sandstone in the British Isles. The colour implies periods of dry, desert-like climate, with rare, but heavy, showers which could give rise to rivers and lakes.

## Folding and faulting

ANTICLINE The upper, upwards curved, part of a fold. The oldest beds are in the core.

SYNCLINE The lower, downwards curved, part of a fold. The youngest beds are in the core.

ANTIFORM & SYNFORM Like syncline and anticline, but the relative age of the rocks remains uncertain.

FOLDING Beds may be folded when exposed to pressure, i.e. they are bent and become tilted to a greater or lesser degree.

FOLD AXIS An imaginary line around which beds have been folded.

FAULT A displacement in the Earth's crust along vertical or oblique fractures in the rock. By studying the rock on either side of a fault it is often possible to determine the direction and amount of displacement. In an oblique fault where the upper part is pushed upwards the displacement surface is called a thrust plane and the fault may be an overthrust. A longitudinal depression is called a graben.

The bedrock along a fault is more or less crushed and disintegrated (brecciated), and the erosive power of glaciers and rivers will readily excavate a trough-like hollow. Wijdefjorden, which is 120 km long, has been excavated along such a fault.

CALEDONIAN OROGENY Crustal movements in Silurian-Devonian time resulting in folding, metamorphism and intrusion of igneous rock. Areas affected by the Caledonian Orogeny (the Caledonides) are found around the North Atlantic: Scotland, western Scandinavia, Svalbard and eastern Greenland. Named after Caledonia (Scotland).

RIFT Long fracture or depression in the crust.

TECTONICS The study of the structures of the Earth's crust and the forces that cause them.

The Devonian rocks were deposited after the Caledonian Orogeny was virtually over. They are therefore little folded and almost unaltered. Some weak after-effects of the Caledonian folding have nonetheless left their mark on the strata. This folding episode took place late in Devonian time or in the early Carboniferous, and the result is now seen as gentle folds in the Devonian beds. Faulting took place again at this time, chiefly along the old fault lines, and northern Spitsbergen subsided. Graben faults were formed, between which the Devonian beds have been partially protected from erosion right to the present day. Some folding of the Devonian strata is a result of this faulting. It seems likely that the area in which Devonian beds were deposited may also have extended east of Wijdefjord, but that a lateral fault along the fjord has moved this easterly portion northwards. Following these movements there was a period in Carboniferous time when the Devonian strata were eroded and new deposition took place. These new deposits remained in a horizontal position on top of the gently folded Devonian beds. Where Devonian beds are absent, either because they were never deposited or because they have been removed by erosion, the Carboniferous rocks lie directly on the basement.

## CARBONIFEROUS AND PERMIAN - SWAMPS AND SHALLOW SEAS

The total thickness of Carboniferous-Permian deposits rarely exceeds 1500 m, but at the head of Isfjorden it reaches 2900 m in places. As was the case with the Devonian, earth movements influenced deposition, and faulting and basin development determined where sediments were deposited, especially the lower beds. The result is an alternation of beds deposited on land and in the sea, and shallow water areas repeatedly alternated with low-lying plains.

During the first part of the Carboniferous, Svalbard was still a relatively flat land area with lakes, lagoons and alluvial plains. The lowermost Carboniferous beds are therefore fluvial or deltaic deposits which strongly resemble the Upper Devonian beds. However, the Svalbard Plate gradually drifted to wetter, more tropical areas and whereas the Devonian sandstones were deposited in a dry climate and are therefore often reddish, the Lower Carboniferous sandstones are light grey, suggesting a damper climate. The lower part also has coal seams containing plant fossils, showing that there must have been a fairly luxuriant swamp vegetation in Svalbard at that time. They were mostly spore plants (cryptogams) that resembled horsetails, ferns and other plants found today, but these were much larger; heights of 10-30 m were not unusual. This was the Age of Amphibians, animals which thrived both in water and on land. In the swamps, toads and other amphibians were the commonest animals, but fish, insects and scorpions were also numerous. The rich plant life in the swamps gave rise

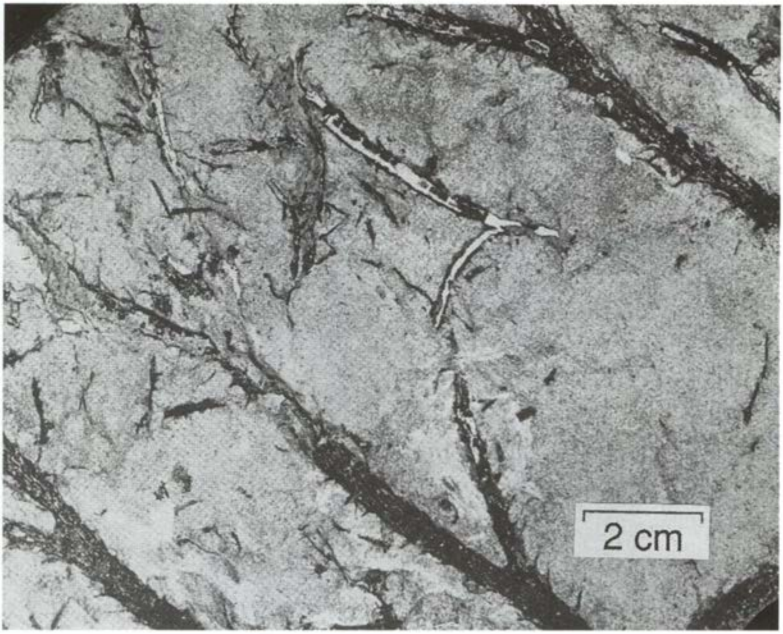



***Fig. 5 Primitive spore plants from Devonian rocks in northern Spitsbergen.***

to organic material which over time led to formation of coal, particularly in central parts of Spitsbergen. The lowermost, coal-rich, Carboniferous beds are lacking in western Spitsbergen, where sandstone and conglomerate dominate.

The sea began flooding over the land in the middle of the Carboniferous, and the Upper Carboniferous mostly consists of marine deposits. Repeated faulting along north-south lines produced differences in height and there was an alternation between deposition on land and in shallow marine areas. The salt water which periodically flooded the land reacted with calcareous beds and when the sea retreated again and evaporation set in, gypsum, anhydrite and dolomite were formed. Typical rocks are breccias (consisting of angular rock fragments), limestone and dolostone containing fossil bivalves (mussels) and gastropods (snails), and beds of gypsum or anhydrite. The climate changed at this time from wet to desert-like, perhaps because Svalbard rapidly drifted from a damp, sub-tropical area to a dry, temperate one further north. Brachiopods (lamp-shells) were among the most common creatures in the Carboniferous seas, sometimes occurring in such vast numbers that pure shellbanks were formed on the sea floor from the shells of dead in-

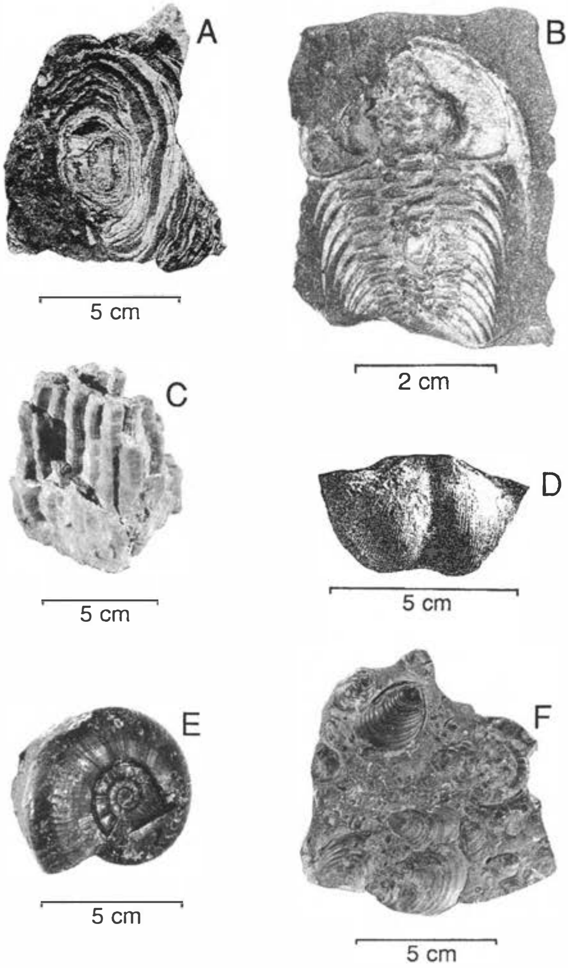



***Fig. 6 Some Svalbard fossils.***
***A. Proterozoic algal structure (stromatolite), Olav V Land. B. The Cambrian trilobite Holmia, from Sofiekammen, north of Hornsund. C. Carboniferous coral from Sassenfjorden. D. Productus, a brachiopod from the Permian on Kapp Starostin in the Festningen section. E. A Triassic ammonite from inner Isfjorden. F. Aucella, a bivalve, in Jurassic shale from the south side of Sassenfjorden.***

## Sedimentary rocks

are formed from layers of gravel, sand, mud, volcanic material and remains of animals and plants deposited in water or on land. Sandstone and conglomerate are generally deposited on or close to land (continental deposits). Limestone, dolostone and dark shales are common marine deposits. Following cementation and subsequent compaction, these deposits become stratified, solid rocks.

LIMESTONE consists chiefly of calcium carbonate (calcite), and is formed by deposition and precipitation of carbonate in water, the carbonate being mostly derived from shells and skeletons of small animals and plants.

DOLOSTONE is a light-coloured rock comprised of calcium- magnesium carbonate (dolomite).

CONGLOMERATE consists of more or less well-rounded fragments measuring from a few millimetres to several metres in diameter enclosed in a groundmass of finer material. Conglomerates were originally shore gravel, river gravel, etc. Coarse conglomerate generally implies large height differences during deposition, as a result of rapid land uplift.

SANDSTONE is formed of cemented sand, mostly quartz sand.

SILTSTONE resembles sandstone, but is more fine grained.

CLAYSTONE is a massive rock formed from clay deposited in water.

SHALE is like claystone, but has a parting.

TILLITE is a morainic conglomerate, a consolidated moraine, containing stones of varying size in a more fine-grained groundmass. As in present-day moraines, the stones are only slightly rounded. In well-preserved tillites, the stones often have grooves formed during movement of the ice.

TUFF is a rock formed of consolidated ash from volcanoes.

dividuals. Many limestone beds were formed from such shellbanks. Tiny calcareous shells belonging to foraminifera are also often found in the same beds. Some beds formed on land have traces of plant roots.

The Lower Permian beds greatly resemble the uppermost Carboniferous. A reliable indication that the Permian has started is what is called the Brucebyen Beds (named after Brucebyen, Billefjorden). These are characteristic, dark-coloured limestones situated about 10 m above the Carboniferous-Permian boundary. Following land uplift at the beginning of the Permian, the sea again flooded the land in the Middle Permian forming shallow-water marine deposits in areas which periodically became dry, giving rise to renewed formation of gypsum, anhydrite and dolomite. There was an abundance of various shellfish in the warm, clear sea water. Hard, richly fossiliferous, Upper Permian flint layers formed from these deposits are easily seen. They largely consist of siliceous sponges, brachiopods and bryozoans (moss-animals), and are resistant to erosion. They therefore stand up as north-south ridges in places where they have been pushed into a vertical position in the Tertiary fold belt. Examples are Kapp Starostin and Vermlandsryggen in the outer part of Isfjorden, Akseløya in Bellsund, and Treskelen in Hornsund.

## TRIASSIC, JURASSIC AND CRETACEOUS - SQUIDS AND REPTILES

During the Mesozoic, the portion of the crust that is now the Svalbard region drifted from about 45°N to 60°N, and the climate was largely temperate and damp. Marine deposits are most widespread, but as in the Carboniferous and Permian, marine and terrestrial deposition alternated, depending on whether the land sank or rose. Many features demonstrate a marked distinction between the Palaeozoic and Mesozoic, and many forms of life died out, including trilobites. The rocks from this period are mostly shales, siltstones and sandstones, seldom limestones. The shift from the often pure, light-coloured, frequently hard, Permian limestones to the dark, softer Triassic beds is therefore extremely distinct. (Fig. 12) The land surface had largely been levelled and conditions were more stable than in Carboniferous and Permian times. Faulting was almost confined to the transition from Jurassic to Cretaceous. The maximum thickness of strata is around 2600 m. There was a rich animal and plant life during the Mesozoic, reptiles being particularly abundant, and this period is often called the Age of Reptiles.

### *Triassic and Lower Jurassic*

The Lower and Middle Triassic rocks in Svalbard were mainly deposited in shelf areas, and characteristic rocks are grey and black shales with beds of sandstone and siltstone. The Middle Triassic shales often contain phosphatic layers rich in hydrocarbons - oil shale. There are scattered plant remains and several thin coal seams in the Upper Triassic. Common fossils in the Triassic

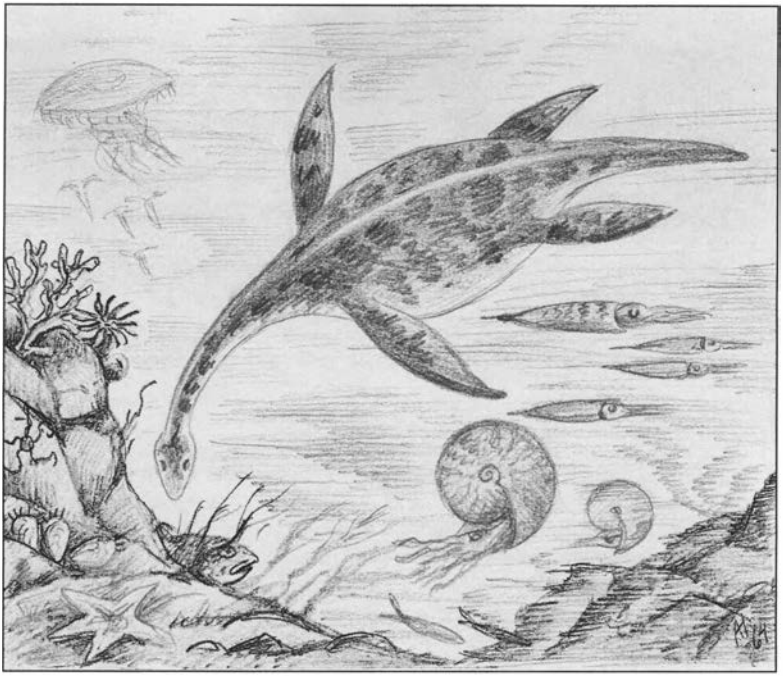


***Fig. 7 Reconstruction of the swan-necked reptile, Tricleidus Svalbardensis, found in Jurassic beds south of the entrance to Sassenfjorden. The total length of this reptile may have been 5-6 m. Bullet-shaped belemnites and spiral ammonites are swimming to the lower right. Drawn by Anatol Heintz.***

deposits in Svalbard are bivalves and ammonites. The bivalves lived on the sea floor, whereas the ammonites swam freely, hunting prey. Fossils of vertebrates, such as reptiles, are also found, especially in the Lower Triassic. Some reddish, iron-rich, claystone beds are found in the Upper Triassic and Lower Jurassic, before the strata become dominated by sandstone deposited in deltaic areas close to a shallow sea. Some beds are missing locally where land uplift was sufficient to cause breaks in sedimentation.

*Jurassic and lowermost Cretaceous*

In this period, most of what is now Svalbard was covered by sea. At the base of the succession is a characteristic, metre-thick conglomerate, the clasts of which vary in size and often consist of phosphatic nodules. The deposition of this conglomerate may suggest that the sea encroached upon the land for a short period, or the bed may have been formed during storms in a shallow

## Some Svalbard fossils

Fossils are tracks, remains or impressions of animals and plants that lived in former periods in the history of the Earth and have been preserved in sedimentary rock and unconsolidated deposits. Animals and plants were buried by gravel, sand and mud which subsequently became transformed into rocks. Fossils provide evidence of changes in climate and habitats, and by studying them we can see that evolution has taken place; the oldest plants and animals are more primitive than present-day ones. Fossils that characterise particular horizons are called index fossils.

AMMONITES An extinct group of squids with spirally shaped shells, particularly numerous in the Mesozoic, especially in the Jurassic and Cretaceous.

BELEMNITES An extinct group of squids with bullet-like shells, common in the Mesozoic, especially in the Jurassic and Cretaceous.

TRILOBITES Articulated animals which mostly lived on the sea floor, related to scorpions. Their backs were protected by shields - a head shield, an articulated body shield and a tail shield. Trilobites varied in size from a few mm to about half a metre in length. They were particularly numerous in Cambrian and Ordovician times, and became extinct in the Permian. Many species are good index fossils.

BRACHIOPODS (lamp-shells) Sedentary marine animals with shells like those of bivalves. Common in the Palaeozoic and Mesozoic, but many species are also living today.

GRAPTOLITES Colonial animals living in the sea from Cambrian to Carboniferous times. Important index fossils.

FORAMINIFERA Microscopic single-celled marine animals with shells. Known from the Cambrian to the present day.

STROMATOLITES Fossil structures derived from algal mats that grew in shallow water. In Svalbard they are, for example, found in some Upper Proterozoic dolomitic beds.

DINOSAURS Large terrestrial reptiles that lived from Triassic to Cretaceous times. Fossilised footprints of the herbivorous (plant-eating) Iguanodon and fossils of the carnivorous (meat-eating) Allosaurus have been found in Svalbard.

BRYOZOANS (moss-animals) Colony-forming marine animals, living from the Ordovician onwards. Common fossils in Permian beds in Svalbard.

PRIMITIVE FISH Lacked jaws and teeth, and had a cartilaginous (gristly) skeleton with the head and part of the body covered by bony plates. Common in the Devonian.

*Fig. 8 An artist's impression of some fossils from Svalbard. In the centre are three large footprints made by the Cretaceous dinosaur, Iguanodon. Drawn by Anatol Heintz.*

sea. The sedimentary rocks otherwise consist mostly of dark marine shales, often rich in fossil squids (ammonites and belemnites) and bivalves. Remains of Plesiosaurs, swan-necked marine reptiles which lived in the Jurassic seas, have been found near Isfjorden and on the east coast. Plesiosaurs had heavy, oval bodies, paddle-like limbs and long necks with small heads (Fig. 8). As the end of the period approached, the sea became shallower again and the deposits coarser, particularly in the south.

Towards the end of the Jurassic and at the beginning of the Cretaceous, the stable conditions in Svalbard were interrupted by a period of disturbance with volcanic activity and faulting. Magma was intruded, crystallising as dark igneous rock called dolerite. It mostly occurs as numerous 5-30 m thick sills, parallel with the sedimentary beds, but occasionally as transverse dykes. These intrusions are particularly common on northeastern Spitsbergen and Kong Karls Land. The magma probably forced its way along fissures and fractures, volcanoes as such being rare.

*Cretaceous*

Following the land uplift, Svalbard in the early Cretaceous had extensive alluvial plains, and the bedrock formed consists almost entirely of sandstone in which many terrestrial plant fossils can be found. Fossil footprints of herbivorous (plant-eating) dinosaurs at Festningen in outer Isfjord and of carnivorous (meat-eating) dinosaurs at Kvalvågen in southeastern Spitsbergen indicate a mild climate and abundant vegetation. In this period, which may be called the age of the large reptiles, the Svalbard area was situated further south than today - about 130 million years ago it was between 50° and 60° N.

The upper part of the Lower Cretaceous sees an alternation of marine and terrestrial deposits - siltstone, shale and sandstone. The beds were deposited in shallow shelf seas and deltas, and some have structures indicating that storms and surf affected them. Important fossils are bivalves, squids, snails and fragments of tree trunks. In the latter part of the Cretaceous, the Svalbard area was raised so much that instead of deposition there was erosion. The uplift of the "Svalbard block" was greatest in the north, and most of the succession is lacking there. Towards the close of the Cretaceous, several animal groups that were common in the Mesozoic seas died out, among them ammonites, belemnites and dinosaurs.

## TERTIARY - ANOTHER FOLDING EPISODE, COAL AND SANDSTONE

The disturbance at the transition between the Jurassic and Cretaceous can be looked upon as a precursor of the earth movements which began when portions of the Euro-American Continental Plate started to move relative to one another at the transition between the Cretaceous and Tertiary periods. Simultaneous with these plate movements, the land became uplifted, erosion increased and a distinct break in the succession developed. The eroded material was deposited in a long, shallow depression in the area that is now southern Spitsbergen. These Lower Tertiary beds largely consist of sandstones. Luxuriant vegetation formed the basis for several coal seams in this part of the succession and beautiful plant fossils are occasionally found when the coal is being worked. In contrast to the plant life in the Cretaceous and earlier periods, many Tertiary plants greatly resemble present-day ones (Fig. 9).

While some of the Tertiary beds now seen were being deposited, Svalbard and Greenland were being pressed obliquely against each other and Spitsbergen was exposed to pressure from the west (Fig. 2). An extensive, long, narrow syncline was formed approximately coinciding with the former shallow depression. This Central Tertiary Basin dominates the geology of the southern part of Spitsbergen, from Isfjorden to Storfjorden. The pressure from the west brought about intense folding and thrusting, especially along the west coast of Spitsbergen. The sharp, jagged peaks which Willem Barents

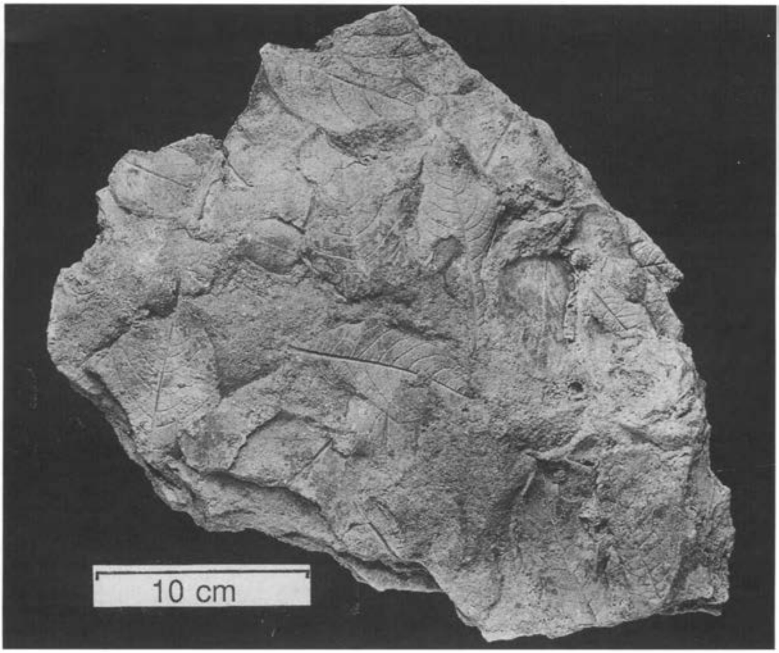



***Fig. 9 Fossil leaves from deciduous trees found in Tertiary beds near Isfjorden.***

saw when he called the land Spitsbergen in 1596 are located in this mountain chain. At the beginning of the Tertiary, Svalbard was situated at about the same northerly latitude as southern Norway is today. Despite the rich plant life, several deposits indicate that fjord and shore ice occurred locally along the coasts in winter.

The Tertiary strata in the Central Basin may once have been 4000 m thick, but erosion has removed some in the course of time and the succession is now around 2000 m thick.

In the mid-Tertiary, the plate segments which until then had been pressed against each other drifted apart again and there were several episodes of fracturing and faulting. In the Forland trough, at Forlandsundet, more than 5000 m of sand, gravel and still coarser material were deposited. The western margin of the Svalbard Plate is now situated beneath the sea about 40-80 km west of Spitsbergen where the edge of the shelf falls steeply westwards from a depth of about 200 m on the shelf to around 2000 m in the deep ocean.

The crustal movements triggered off volcanic activity in northern Spitsbergen towards the end of the Tertiary, and remains of Tertiary basalt lava flows are found over a large area.

Late in Tertiary time, Svalbard had attained more or less its present shape and size, but the sculpturing of the landscape with its mountains, valleys and fjords was largely carried out during the Quaternary.

## QUATERNARY - ICE AGES AND VOLCANOES

*Ice ages*

Periods when glaciers cover large, otherwise ice-free areas, are called ice ages. It is now thought that these major climatic variations are chiefly caused by periodical changes in the Earth's orbit and axis. The last period in the geological history of the Earth, the Quaternary, has been dominated in Svalbard by ice ages with intervening warmer episodes. Studies of glacially-transported boulders, ice striations and landscape forms suggest that the whole of Svalbard has been covered by a vast ice sheet at least once during the Quaternary. Four ice ages are known from Europe, and there are traces of several ice ages in Svalbard, too. When the Quaternary began, Svalbard and the floor of the Barents Sea were several hundred metres higher than now; the landmass stretched from Svalbard to Norway and northern Russia. The Bjørnøya Channel (Bjørnøyrenna), a large submarine valley south of Bjørnøya, is an old glacial valley.

The last Ice Age is called the Weichsel in northern Europe, and a great deal of research has been done to determine its extent and timing. Prior to the Weichsel, glaciers in Svalbard were not significantly larger than today, whereas towards its end the ice probably covered large parts of the Barents Sea and also stretched far out across the shelf west of Spitsbergen. The Barents Sea ice was probably continuous with that issuing from the Scandinavian ice sheet. Though the period with ice cover in the last Ice Age was shorter on Svalbard than in Scandinavia, the glacial erosion has removed most deposits and other traces of former ice ages.

The ice sheet during the last Ice Age was thickest in eastern Svalbard, near Kong Karls Land. As on the Scandinavian peninsula, the land was depressed by the ice, most where this was thickest. When the climate became milder and the ice melted, the land rose again. Kong Karls Land, for instance, has risen approximately 130 m relative to the sea during the last 10,000 years, since the ice sheet disappeared. Since it takes time to recover from the pressure of the ice, the land is still rising slightly, even though the heavy ice cap disappeared long ago.

A series of raised strandlines formed during this period can be seen along most of the Svalbard coast. Because vegetation is sparse, the strandlines are often easy to see. In marginal parts of the glaciated area, such as Bjørnøya and the northwestern corner of Spitsbergen, there was much less weight of ice than in central districts and there seems to have been no relative land uplift during the last part of the Quaternary.

## The geological work of the sea, rivers and glaciers

EROSION The wearing away of soils or bedrock. The rock is worn down, smoothed and scraped away by water and ice to end up as deposits on the floor of seas and lakes. Over millions of years, these sediments are transformed back into solid rock, and where land uplift takes place erosion will start its work once more. Rivers are only able to erode down to sea level. If the land rises rapidly, river valleys may become narrow and deep. Stones and gravel dragged along at the base of moving glaciers eat away particularly strongly at the bedrock beneath and may also excavate channels or hollows below sea level. The fjords are a good example of glacial erosion. Whereas the profile across a valley eroded by a river has a V shape, glaciers, which also excavate laterally, form U-shaped valleys with broader floors. The latter are most common in Svalbard.

STRANDFLAT Extensive, level coastal area just above and below sea level, thought to be formed by a combination of the excavating force of the sea and frost weathering.

RAISED STRANDLINES Shore ridges and terraces now situated higher than the sea and constructed when the land stood lower relative to the sea than it does now. They provide evidence of land uplift and former sea levels. Remains of marine animals can provide information about previous climates and when the strandlines were formed.

MARINE LIMIT The highest former sea level in an area, in Svalbard generally after the last Ice Age. Because of differing rates of land uplift, traces of former sea levels are now at different heights.

ICE STRIATIONS Grooves and furrows on rock surfaces over which a glacier has moved and on stones transported by the glacier. Their trend shows the direction taken by the glacier.

MORAINE A glacier excavates and breaks off material from the bedrock beneath it and along its sides, and stones fall onto it from mountainsides above. This material accompanies the glacier as it moves down, much of it being deposited as ridges at the glacier snout (a terminal moraine), or along its sides (lateral moraines). Where two glaciers meet, a medial moraine often forms. If the glacier melts, material lying beneath it, within it, or on its surface will remain as a layer of stony earth, called ground moraine, till or boulder clay.

ERRATICS Boulders transported from their original site, usually by glaciers.

KARST LANDSCAPE A type of landscape formed in limestone areas, water having dissolved the rock to form caves, dolines, etc.

Even though a thick ice sheet covered large parts of the Svalbard area, leaving its mark on the landscape, the quantity of ground moraine (till) and other glacial deposits is less than in Scandinavia. This is probably because part of the glaciers were cold based in Svalbard and therefore eroded less. After the ice sheet melted, the glaciation has continued on a smaller scale, and local glaciers, together with rivers, have gradually removed some of the moraines and glaciofluvial deposits formed by the ice sheet, and deposited new ones. Terminal and lateral moraines in Svalbard frequently have an ice core that partially melts in summer. These moraines were left by a glacial advance only a few hundred years ago.

A few strandline terraces contain shells deriving from creatures such as common mussels that required warmer water than is found around Svalbard today. Together with studies of pollen found in lake deposits and peat, these show that the climate after the Ice Age was periodically warmer than now and there was less ice in the form of glaciers. Radiometric dating of organic material such as shells, whalebone and driftwood is now mostly used for determining the age of former shorelines. Several hundreds of these datings have been carried out and the history of land uplift is now quite well known. 50,000-year-old strandlines have been found preserved in a few places, but mostly only strandlines younger than 12,000 years are found. Pumice, a porous volcanic rock, has drifted ashore on several occasions to accumulate on strandlines at different heights, showing that there were many volcanic eruptions during the period when these strandlines formed. However, the origin of the pumice is uncertain; perhaps it derives from submarine volcanic eruptions, or volcanoes on Iceland or Jan Mayen? One pumice accumulation on an approximately 6500-year-old strandline has a very wide distribution. A particularly distinct and large accumulation occurs about 11 m above sea level on Blomesletta on the east coast of Ekmanfjorden, a branch of Nordfjorden in Isfjorden.

There are still many glaciers in Svalbard and conditions today are in many ways like those in much of Norway towards the end of the last Ice Age, 8-10,000 years ago. Much valuable information helping to explain how the landscape in Scandinavia was sculptured during the Ice Age has been obtained by studying the glaciers, glacial erosion and glacial deposits in Svalbard.

*Landscape*

The landscape in Svalbard, as we see it today, has largely been formed during the Quaternary, and glaciers and rivers are still shaping it. The landforms depend on the nature of the bedrock as well as on how strongly rivers and glaciers have eroded. The mountains we see today are mere remnants of what were previously almost unbroken massifs. The material removed when the valleys, fjords and mountains were formed now occurs as a layer of sand, gravel, stones and mud on the floor of the fjords and sea around Svalbard.

***Fig. 10 Rounded hills formed by glacial erosion. Hytteberget on Phippsøya, Sjuøyane, viewed towards the west.***

This process is taking place in the same manner as in previous geological peiods and, just like deposits then, in a few million years the sand will become transformed into sandstone, and the clay into shale, etc.

The glaciers have been extremely active in shaping the land surface in Svalbard which has been worn down over thousands of years. Evidence of the work of ice can be seen everywhere. The glaciers operate like conveyor belts, carrying all the loose material and removing it to their outer parts. Detached rocks can be transported for long distances in this manner. Such erratics can provide a great deal of information about how the glacier moved. Where bedrock is sufficiently resistant to erosion, well-preserved ice striations can still be seen. The ice sheet was most continuous in eastern and northeastern Svalbard where it scoured and planed down the bedrock until the surface today is relatively even, with rounded hills.

Mountains built of horizontal beds are often flat-topped (e.g. Templet beside Isfjorden). If erosion proceeds far enough, pyramidal peaks may remain, such as Tre Kroner, east of Ny-Ålesund. Poorly consolidated rocks result in gently-sloping screes, and if hard layers intervene steep cliffs will form. Where the bedrock has been pressed together by folding and faulting, longitudinal ridges are often formed. On Spitsbergen, this is particularly clear along the west coast between Sørkapp and Kongsfjord, in both the basement and the younger sedimentary rocks (e.g. on Prins Karls Forland and Akseløya).

In Spitsbergen, the outer parts of the ice sheet excavated fjords and valleys along zones of weakness in the bedrock. A good example of this is the 120 km long Wijdefjorden that has been excavated along a north-south trending fault. Fjords are characteristic for coasts in formerly ice-covered regions, and are really drowned glacial valleys. That most of the fjords in Svalbard are in the north and west may signify that the ice moved from south and east, perhaps with repeated advances which increased the erosion.

Several large, ice-free valleys are found on Spitsbergen, particularly between Isfjorden and Van Mijenfjorden; most of them have previously contained valley glaciers. Meltwater rivers from glaciers further inland transport large quantities of sand, mud and gravel, especially in the flood period in spring and early summer. Quantities of mud exceeding one gram per litre are not unusual. Where the slope decreases, sand and mud are deposited on the valley floor and rivers are forced to take a new course. A great deal of material is also carried out into the fjords where it forms spits and banks close to the river mouths.

Coastal areas of Svalbard that were marginal to the ice sheet now often consist of only a low plain or strandflat. Large tracts lie approximately at sea level and the sea offshore is shallow. The strandflat is best developed on the western and northern coasts of Spitsbergen where it stretches far offshore, skerries and rocks being awash at low tide far from land. On Nordaustlandet, the strandflat is mainly developed in the northwest. It is thought that these low coastal plains were formed by a combination of frost weathering and the excavating force of the sea. In the course of the various ice ages, the land was raised and lowered several times and the strandflat could therefore be formed over a long period.

*Soils*

The soil cover in Svalbard is often thin. Almost all of it has developed during the Quaternary and it is mostly mineral soil formed through erosion and weathering. Block fields are most frequently found on ridges and nunataks, particular where there is hard bedrock such as quartzite, dolerite and granite. Shaley and schistose rocks weather more easily, producing mineral soil that can provide good growing conditions for plants. Organic soil, formed from plant remains, is much scarcer than in more temperate regions such as Scandinavia. Sand and clay are practically only found in valleys and on coastal plains.

*Permafrost*

In the ice-free areas of Svalbard, the ground is permanently frozen, i.e. there is permafrost which penetrates as far down as 100 to 460 m below the surface. In most places, only the uppermost, active, soil layer thaws in summer, down to between 1 and 1.5 m. Because soil is a poor heat conductor, the seasonal variations are retarded and at approximately 3 – 5 m depth the temperature is lowest in summer and highest in winter. Permafrost is absent beneath fjords, large lakes and glaciers. Large volumes of meltwater can therefore be formed beneath glaciers, and some of this drains into the bedrock. Since surface water is only found in the summer, such groundwater may be a useful source of water supply.

The mountains in Svalbard are severely affected by alternate freezing and thawing and often have large talus (scree) slopes. Where stones loosened by frost do not slide downhill, on gentle slopes and mountain plateaus, block fields are formed. Hard rock types produce large, sharp-edged stones, whereas soft shales, for instance, disintegrate to produce mineral soil.

Because of the permafrost, special attention has to be paid to the foundations for buildings and other constructions. Suitable foundations are a valuable investment, both from the safety viewpoint and the cost of building and upkeep.

In the lower stretches of the large valleys on Spitsbergen, rounded or conical mounds of mineral soil containing a core of ice can often be seen. These are called pingos and are formed in areas with permafrost. About 80 pingos, some up to 40 m high, have so far been registered in Svalbard.

Another landscape feature related to permafrost is patterned ground. This is a pattern on the surface of soil, sand or gravel in the form of more or less continuous rows or rings of stones, or ice-filled cracks. The rings are generally irregularly circular in shape, but distinct hexagons are sometimes seen. Patterned ground is found in nearly all ice-free areas in Svalbard.

Rock glaciers are common in areas of permafrost and usually form because stones in talus slopes slide downwards through the influence of their own weight and repeated freezing and thawing of the water in the scree. The largest rock glaciers seem to be located in areas that have been ice free for a long time.

*Volcanic activity and earthquakes*

In northwestern Spitsbergen, volcanic eruptions producing lava flows have occurred as recently as during the Quaternary. These lavas are among the youngest rocks in Svalbard. Thermal springs now occur as after-effects of this former volcanic activity. Springs of lukewarm water are also found in several other places along the west coast, even as far south as Sørkapp Land. The volcanic activity in northwestern Spitsbergen is probably related to rifting and the eruption of magma from the mantle that took place when the Atlantic Ocean opened, and still continue on Iceland and Jan Mayen.

Some scientists believe the volcanoes and thermal springs are related to a large magma chamber that has been located at depth beneath Svalbard, and that still exists. Such a mass of magma could press its way upwards forming a "bulge" on the Earth's crust. Study of the height of erosion surfaces formed during the Tertiary show that such bulging has actually taken place along a north-south trending zone from northwestern Spitsbergen towards Bjørnøya. This zone closely coincides with the areas where springs holding abnormally high temperatures have been found and with areas at sea north of Svalbard where noticeably strong heat flow has been measured.

Earthquakes on land have been particularly frequently recorded in two areas: 1. just north of Kvalvågen, on the east coast of Spitsbergen, and 2. on Nordaustlandet, south and southeast of Nordkapp. Most of them measure less than 2 on the Richter scale, i.e. they are relatively weak. Calculations indicate that the earthquakes may be caused by pressure from the west triggering off displacements along or close to existing faults. This pressure probably results from movements on the boundary between the Svalbard Continental Plate and the Atlantic Ocean basalts. The many earthquakes registered near this boundary west of Spitsbergen testify to these movements.

# SOUTHERN SPITSBERGEN

(SOUTH OF ISFJORDEN-TEMPELFJORDEN-WICHEBUKTA)

Southern Spitsbergen was one of the first parts of Svalbard to be geologically investigated, and the largest coal mines, Longyearbyen and Barentsburg, are situated here. Poland has had a research station at Isbjørnhamna in Hornsund since the Geophysical Year of 1957, and this has provided a base for geological and other research in this part of Svalbard.

*Basement*

Between Isfjorden and Sørkapp, the basement consists of folded and metamorphosed rocks ranging in age from more than 1100 to about 480 million years. Many rock types are present, the most common of which are phyllites with quartzite beds, limestones, dolstones and conglomerates. There are both ordinary conglomerates with well-rounded clasts and tillites ('fossilised' moraines). A characteristic conglomerate, marking the boundary between the Middle and Upper Proterozoic, is found, among elsewhere, in Konglomeratfjellet on the south side of Bellsund, from where it can be followed more or less continuously southwards to Slyngfjellet near Hornsund. The conglomerate was deposited about 1000 million years ago when a mountainous area was being severely eroded and peneplaned. This corresponds in time to the Grenvillian Orogeny (an episode of folding, faulting and metamorphism) known, for example, from North America. Outermost on the north side of Hornsund, volcanic rocks with an age of 1130 million years have been found underlying the conglomerate. Small occurrences of Proterozoic amphibolites are scattered along the west coast, and are probably mostly metamorphosed dolerites or basalts.

Following this period of erosion the land was gradually covered by shallow seas, and carbonate-rich beds were deposited. These dolostones and limestones now overlie the conglomerate and can be seen in good sections at Höferpynten in Hornsund, for example. Phyllites with quartzite beds occur further up the sequence, before tillite enters as the uppermost bed in the Proterozoic succession. A particularly large area of tillite is exposed south of outer Bellsund, smaller ones being found along the west coast between Bellsund and Isfjord.

In Sørkapp Land and also north of Hornsund there are large areas containing Cambrian and Ordovician strata in which fossils have been found, mostly trilobites and brachiopods of Lower Cambrian and Ordovician age (Fig. 6B). Hornsundtind, which at 1431 m is the highest mountain in southern Spitsbergen, consists of such strata. They were folded in the Silurian, perhaps also in the Carboniferous, and are steeply dipping.

In the region where basement rocks are exposed there are also some small, isolated occurrences of much younger rocks. These were either

***Fig. 11 Folded Proterozoic phyllite with thin quartzite layers on the coast between Isfjorden and Bellsund.***

down-faulted or older rocks were thrust above them, thus preserving them in protected positions. Examples can be seen, for instance, east of Kapp Martin on the north side of Bellsund where some strips of Carboniferous sandstone occur. Devonian beds have been preserved in the same manner in the inner part of Hornsund. These were deposited on an eroded basement surface and subsequently folded, probably in early Carboniferous time. At Calypsobyen in Bellsund, Middle Tertiary beds have been down-faulted, and on the east side of Sommerfeldtbukta near Sørkapp, the Lower Tertiary has been down-faulted more than 3000 m relative to the basement. A fairly large area of Carboniferous rocks on the south side of the entrance to Hornsund is also largely bounded by faults.

*The major syncline*

Southern Spitsbergen is dominated by beds of Carboniferous to Tertiary age which occupy a large trough-shaped synclinal structure. This was formed when Spitsbergen was exposed to pressure from the west in the early Tertiary. At first, this pressure was weak, but intense folding and faulting subsequently took place along the west coast, and the metamorphosed basement was uplifted. The Carboniferous beds, which previously lay horizontally on the eroded basement, were tilted and now dip eastwards. Because the folding became less severe eastwards, the younger strata (Car-

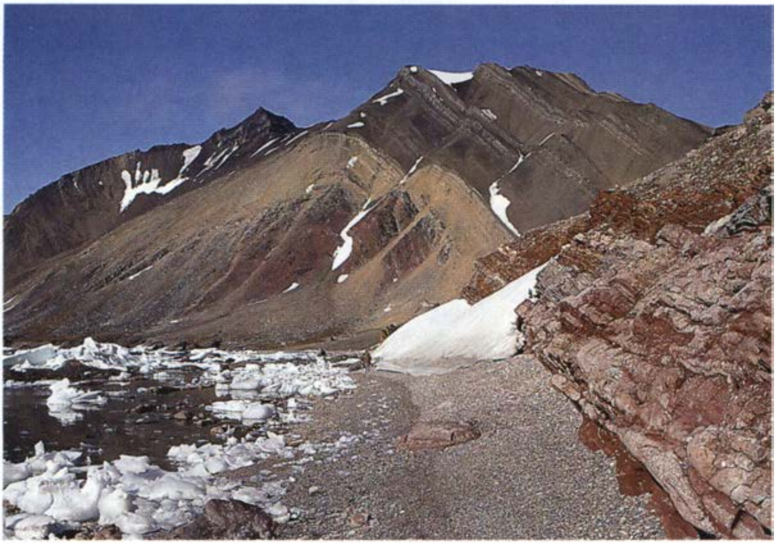


***Fig. 12 Hyrnefjellet on the north side of Hornsund, looking north. Reddish and light-coloured beds are Carboniferous and Permian in age; the dark bed uppermost is Triassic.***

boniferous-Tertiary) flatten out towards the middle of the trough, and still further east they begin to dip westwards. In the eastern part, the movements were weaker and beds are generally little folded and have only gentle dips. But overthrusting and other deformation of strata can nonetheless be found as far as the area between Agardhbukta and Lomfjorden.

Several good geological sections are to be found along the large east-west trending fjords in southern Spitsbergen, such as Van Keulenfjorden, Van Mijenfjorden and Isfjorden. The ancient folded and metamorphosed basement reaches the surface at the entrances to the fjords, whereas inwards along the fjords layer upon layer of Carboniferous to Tertiary rocks are exposed, folded and steeply dipping in the west. These beds often contain numerous fossils; plants and minor coal seams in the oldest Carboniferous rocks, shells, corals, bryozoans (moss-animals) and amphibians in younger Carboniferous and Permian beds, bivalves, squids and reptiles in Triassic and Jurassic strata, and reptiles, plants and insects in Cretaceous and Tertiary beds. Marine Plesiosaurs of Jurassic age have been found at the head of Kjellstrømdalen, footprints of plant-eating Cretaceous reptiles *(Iguanodon)* at Festningsodden south of Isfjorden, and footprints of meat-eating Cretaceous reptiles *(Allosaurus)* south of Kvalvågen on the east coast of Spitsbergen.

In the Cretaceous, Svalbard was located about 50°N and the presence of large terrestrial reptiles shows that there must then have been an extensive land area enjoying a mild climate and having luxuriant vegetation.

Uppermost and centrally located in the synclinal structure are Tertiary sandstones and shales. The largest coal deposits in Svalbard are found lowermost in the Tertiary, close to its boundary with the Cretaceous.

*Folding and faulting*

It is often difficult to distinguish which of the various fold episodes is responsible for a specific fold set. This is particularly the case in the basement rocks, which have undergone several periods of folding and faulting, in Precambrian, Silurian-Devonian and Tertiary times. However, it is sometimes possible such as south of Dunderdalen (south of Bellsund) where a conglomerate rests on an old erosion surface in previously folded basement. Clear examples of folded basement rock eroded to form an angular discordance between the basement and, for example, Carboniferous sediments are seen in many places along the western flank of the large syncline in southern Spitsbergen. At Hornsund and in Sørkapp Land, where there are deposits from many geological periods, it has been possible to distinguish several generations of crustal deformation: 1. several episodes of folding and faulting in the basement, the two clearest ones taking place at the transition from Middle to Upper Proterozoic, and in the Silurian; 2. faulting and uplift in late-Devonian time; 3. folding and faulting in the Carboniferous; 4. pressure from the west accompanied by folding and thrusting in the Lower to Middle Tertiary; 5. faulting during the opening of the North Atlantic Ocean in the latter part of the Tertiary.

The major zone of faulting and folding crossing Wijdefjorden and Billefjorden can also be traced further south on Spitsbergen, partly as anticlinal structures in the inner parts of Adventdalen and Reindalen, Kjellstrømdalen and on to Storfjorden. The structures show that displacement and folding were largely directed from southwest to northeast.

*Landforms and ice ages*

Along the west coast from Isfjord to Sørkapp, the landscape strongly reflects the NNW-SSE trending Tertiary structures. Many mountains, valleys, glaciers and inlets are orientated in this direction. Examples are Grønfjorden, Akseløya and the Recherchebreen glacier. All the largest fjords trend east-west and were excavated by glaciers that followed fracture and crush zones. The fjords and large valleys are the result of glacial erosion during several glaciations. The next largest lake in Svalbard, Linnévatnet west of Grønfjorden, was also formed by glacial erosion, and occupies a depression excavated by a valley glacier that retreated about 12,500 years ago. In the fjord districts of southern Spitsbergen, the marine limit can clearly

*Fig.13 The springs at Trollosen on the north side of Stormbukta in Sørkapp Land.*

be seen rising inwards along the fjords towards the east where the ice was thickest and subsequent land uplift greatest. The limit is situated at 89 m at Sveagruva, whereas it is 60 m at the entrance to the fjord. The Bellsund district was probably ice free as early as 13,000 years ago.

Large, open valleys are typical for the area between Isfjorden and Van Mijenfjorden. The largest are Reindalen, Sassendalen, Adventdalen and Kjellstrømdalen. Fluvial deposits from meltwater rivers cover the valley floors, and little solid rock is visible before some way up the valley slopes. Loess deposits have been seen in outer Adventdalen and are probably also present in some other large valleys. Where the bedrock includes shale and limestone, sheltered, south-facing valley slopes where rock sliding is not too pronounced may provide favourable conditions for relatively luxuriant vegetation. The vicinity of bird-cliffs is particularly favourable because a rich supply of nutrient salts from bird excrements is often present there.

Most pingos are in large valleys. An extraordinary one has been found on Kistefjellet in Sørkapp Land at a height of about 600 m. This is the highest situated pingo recorded in Svalbard and measures 150 m in diameter and approximately 10 m in height.

When southern Spitsbergen is approached from the west, the most striking features are the large strandflats backed by mountains. Such strandflats are particularly common between the entrances to Isfjorden and Bellsund, Dunderdalen and the Torellbreen glacier, and Hornsund and Sørkapp. The east coast lacks both fjords and strandflats, and is often steep with few natural harbours.

The largest spring known in Svalbard is near Trollosen, just north of Stormbukta in Sørkapp Land. A discharge of about 10,000 litres per second and a temperature of 4°C have been measured. Smaller springs are found nearby carrying water with a temperature up to 16.3°C and a salt content, mostly NaCl, of 6.8 g per litre. These springs rise in limestone and the high water temperature probably results from the water having circulated in very deep karst caves. The water smells of hydrogen sulphide, hence the names Luktvatnet (Smell Lake) and Fisnes (Wind Headland), and small quantities of the radioactive gas, radon, have been recorded. Springs have also been reported at the foot of Tsjebysjovfjellet south of Hornsund and at Sofiekammen to the north. There are two small springs at the southwest foot of Raudberget, 20 km north of Hornsund, one of which has a temperature of 12.3° C and a discharge of more than 10 litres per second. Beside Kongressvatnet, west of Grønfjorden, calcareous Carboniferous and Permian rocks have several springs that do not freeze in winter. The river draining into Grønfjorden from the lake flows all year-round and supplies Barentsburg with water.

That faults may be feeders for groundwater is well shown by an example in Agardhdalen. In the middle of the valley, where the Lomfjorden Fault (see p. 126) crosses it about 7 km from Agardhbukta, a spring issues from a pingo. Hydrogen sulphide is also given off, and sulphur is deposited round the margin of the spring.

*Minerals and hydrocarbons*

Numerous small sulphide deposits occur in the basement in southern Spitsbergen, the most common ore minerals being iron pyrites, galena and sphalerite. Some of these deposits will be dealt with in the descriptions of local areas, so the following account only concerns those located outside these areas.

Near Höferpynten on the south coast of Hornsund, sulphides are found in fractures, dykes and dolomitic breccias. This deposit is characterised by arsenopyrite occurring along with iron pyrites and a little galena and sphalerite. In the area between austre Torellbreen and the entrance to Hornsund, the basement contains veins and dykes of siderite and iron pyrites, as well as some chalcopyrite, sphalerite and galena.

Coal is found in many places in southern Spitsbergen, and many claims were filed in this area between 1900 and 1925. Apart from near Isfjord and at Sveagruva, there has only been brief trial working. In 1918, a hunter named Gustav Adolf Lundquist found a four-foot thick coal seam at Hedgehogfjellet on the east coast of Sørkapp Land. He subsequently occupied a 6000 km$^2$ large area of southern Spitsbergen before selling it to English interests for a mere NOK 1000! The Northern Exploration Co. Ltd. (N.E.C.) had a trial working for coal at Hedgehogfjellet around 1920, but abandoned it after a short time owing to the extremely difficult harbour conditions. Coal has also been found in the area east of Van Mijenfjorden. A 1.5 m thick coal seam has been observed at Svartkuven, about 20 km northeast of Sørkapp.

On Grimfjellet, north of the head of Hornsund, Mesozoic beds occupy an anticline which may be a trap for oil and gas. The anticline has been thoroughly studied, but is situated in a difficult location in an area surrounded by glaciers inside the South Spitsbergen National Park and no exploratory drilling has been initiated. Promising structures have also been found further south, and Tundra A/S in co-operation with Polargas Prospektering AB drilled 2337 m in 1987-88 at Haketangen on the east coast of Sørkapp Land without finding commercially viable amounts of oil or gas.

## OUTER ISFJORDEN (Local map on page 54-55)

Up-faulted, folded and metamorphosed basement rocks are exposed furthest west in the area. Near this basement, overlying, younger strata (Carboniferous and younger) are approximately vertical, but a little further in along Isfjorden they dip gently eastwards. The boundary between the basement and the younger succession is at Trygghamna on the north side of Isfjorden and at Lewinodden on the south side. It is easy to see because of the contrast between the tightly folded phyllite, quartzite and marble in the west, and the more gently folded Carboniferous-Cretaceous sandstone, shale and limestone succession in the east.

### South of the fjord entrance

*Basement*

Faults divide the area between the west coast and the Carboniferous strata into several blocks which have been down-faulted towards the west. A major fault trends approximately north-south along the east side of Tunsjøen, terminating in the north at Kapp Mineral, near Isfjorden. In this area it is mainly limestone and dolostone that have been fractured and crushed along the fault, and which, at Kapp Mineral, contain galena, sphalerite and a little iron pyrites and chalcopyrite. The deposit was discovered in 1922 and Arthur Lewin, a mining engineer, had some of the best ore extracted in the following two years. Despite investigations along the continuation of the crush zone, little additional ore was found. The remains of a small building and a mine shaft can still be seen on the peninsula.

The western part of the basement area, near Kapp Linné, is mostly comprised of late Proterozoic tillite, a deposit formed during an ice age. The tillite at Kapp Linné is of a special sort, consisting of sub-rounded boulders of granite and other rocks up to 3 m in diameter in a phyllitic groundmass. This rock is thought to have originated principally as mud carried to the sea by glacial meltwater rivers, the boulders being erratics which thawed from floating, glacier-derived, icebergs to drop into the mud.

*The Festningen section*

Between Kapp Starostin and Grønfjorden, up-faulted, steeply dipping Carboniferous to Tertiary rocks form one of the most valuable geological monuments in Svalbard. This Festningen (Fortress) section derives its name from the appearance of the sandstone exposure on the promontory just west of Grønfjorden and was described in detail by Hoel and Orvin in 1937. Figure 14 shows the section in a somewhat simplified form, along with an extension westwards to the basement at Lewinodden. The steep dip of the beds means that on a 10 km long stretch of shore it is possible to walk across beds that were deposited during a span of several hundred million years. The section extends from the basement and Lower Carboniferous at Lewinodden in the west to the Tertiary at Grønfjorden in the east and presents itself as a reference book of rocks and fossils. This stretch of shore is therefore a popular target for geological excursions.

*Carboniferous and Permian* - Furthest west, Carboniferous beds directly overlie metamorphosed basement, separated by a distinct angular discordance. West of Linnéelva, the Carboniferous consists of sandstones and conglomerates which occasionally have numerous plant fossils and also some coal. The coal seams are relatively thin and impure and have no economic importance. After the sandy beds were deposited, a pause in deposition caused the absence of some Middle Carboniferous strata. After a while, the land became submerged again and Upper Carboniferous to Lower Permian beds were deposited in the sea, now appearing as carbonate-rich rocks just west of Kapp Starostin.

Marine deposition continued, and on the promontory at Kapp Starostin the strata from the upper part of the Permian are 380 m thick. They are often richly fossiliferous, including brachiopods and bryozoans (moss-animals). In common with elsewhere on Spitsbergen, the deposits from this period contain abundant silica, largely derived from siliceous sponges, leading to the formation of hard layers that are resistant to weathering and therefore form conspicuous benches here.

*Triassic* - With a total thickness of around 1000 m, the Triassic strata comprise a major part of the Festningen section. The great thickness probably results from the sequence being folded and imbricated so that some beds re-appear at several places along the section. Just east of Kapp Starostin, the bedrock consists of soft shales that weather and erode easily; hence, the

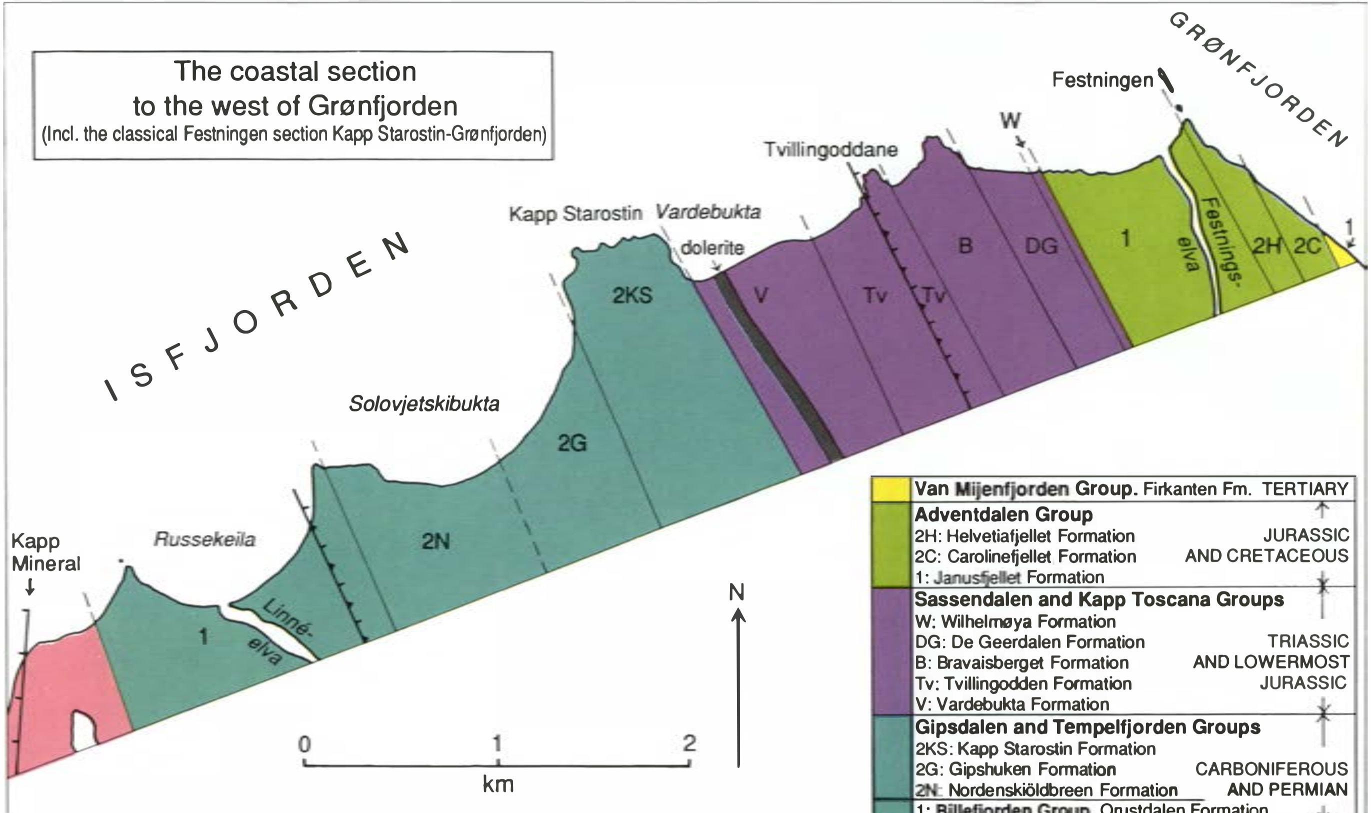



*Fig. 14 Coastal section west of Grønfjorden.*

***Fig. 15 Festningsodden showing the scaffolding used when making plaster casts of dinosaur tracks.***

presence of an inlet here. The most common fossils here are ammonites, bivalves and brachiopods. East of the inlet, the twin promontories of Tvillingoddane are composed of harder siltstone and sandstone. West of the westerly of these headlands, beds of calcareous sandstone occur. The strata in the vicinity of the easterly one are severely folded and faulted. The dark shales just east of this headland are considered to be among the best source rocks for hydrocarbons in Svalbard. They also contain phosphatic nodules. The uppermost Triassic is dominated by sandstones and siltstones.

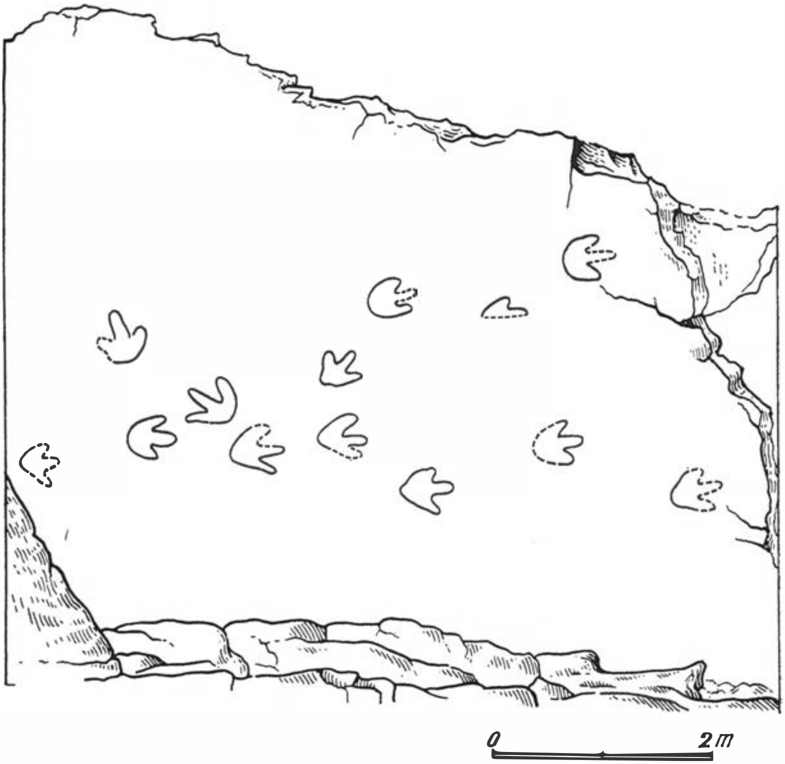
*Jurassic* - The Lower and Middle Jurassic deposits are rather thin here, only about 18 m, and conglomerates are present in both the lower and upper parts. The upper of these conglomeratic horizons is very characteristic, partly because it contains phosphatic nodules. It is overlain by dark grey and black shales. These are soft and slides and folds have easily formed making it difficult to estimate the thickness. Ammonites and bivalves are common fossils here.

*Cretaceous* - With its dark shales, the lowermost Cretaceous strongly resembles the Upper Jurassic. The combined thickness of Jurassic-Cretaceous shales straddling the Festningselva river and continuing east to Festningsodden probably reaches about 500 m. At Festningsodden there is an abrupt, marked change from dark shales deposited in open marine conditions to what is referred to as the Festningen sandstone and to siltstones, both of which were deposited on alluvial plains and in deltas near the coast. Most of the sandstone has cross bedding. Some coal seams occur, too, and fragments of fossil plants are not uncommon. The sandstone is porous and is regarded as a good reservoir rock for hydrocarbons. Fossil footprints of the plant-eating terrestrial dinosaur, Iguanodon, were found in sandstone on the east side of Festningsodden in 1960. Iguanodons were 10-12 m long and 3-5 m high. The tracks found were more than half a metre across and the stride measured about 2 m. The damp sand on which these reptiles left their footprints was covered by sand and mud which, over time, became hardened, preserving the tracks. In the Tertiary, the beds were pushed on edge, which explains why the tracks are on a vertical cliff (Figs. 15 and 16). This was the first time tracks of large terrestrial reptiles were found in Svalbard. It is also the northernmost find, more than 2500 km from the nearest ones known in Central Europe (Fig. 17). The cliff containing the footprints fell into the sea later in the 1960's.

In the Cretaceous, the forerunners of the large Tertiary earth movements began. The land was uplifted, most in the west and northwest, and the uppermost Cretaceous beds were eroded. They are therefore absent at the end of the Festningen section, at the entrance to Grønfjorden. Lower Tertiary beds appearing in a syncline 1 km southeast of Festningsodden therefore directly overlie the Lower Cretaceous.

*Quaternary and landscape features*

The extensive strandflat along Nordenskiöldkysten stretches as far as Isfjorden. Here, south and east of Kapp Linné, rivers and small lakes (e.g. Strokdammane) can often be seen to follow the trends of faults and folds. Vardeborgsletta, east of Linnéelva, is a coastal plain with fine raised strandlines. Patterned ground is beautifully developed at the north end of Linnévatnet and near Borgdammane. Some streams in the latter area behave peculiarly. They flow on the surface for a while before disappearing in holes and pools lacking visible outlets. This is not easy to explain, but probably results from the lack of permafrost in some places and by the water draining along channels formed by the partial solution of limestone (karst). Measurements of the temperature beneath the surface have in a few places given some unusual readings considering that this is Svalbard. Instead of permafrost beneath the thawed surface, the temperature actually increases downwards, at one place to as much as 10.7°C above freezing at 3.3 m depth. This may explain why the water circulates below the surface without freezing. Normally, temperatures just beneath the surface would be below freezing the whole year round. The area concerned is close to a thrust zone in the bedrock and meltwater running along this from the Vardebreen glacier above and just to the east could have penetrated deep into the ground, thereby being heated up. When the water again reaches the surface it may have a significantly higher temperature than its surroundings.




About 10 km along Grøndalen is a group of pingos near which several small springs are seen, from one of which a discharge of 3 litres per second has been measured. A little gas bubbles up from some of these springs, and the smell of hydrogen sulphide is noticeable in places. A chemical analysis of water from one spring gave 0.88 g per litre of mineral salts, mainly sodium carbonate and sodium chloride.

*Coal and oil near Grønfjorden*

The Grønfjorden area came into focus about the turn of this century when coal was found on the east side of the fjord. It first began to be worked in summer 1915 when Arthur Lewin rented an area from a Russian company called A/S De Russiske Kulfelter Green Harbour and started mining at Heerodden. Only 250 tons were produced the first year, but work continued and 40 men spent the 1918-19 winter there, when coal was also mined at Gladdalen, a valley south of Heerodden. In the summer of 1919, 12,000

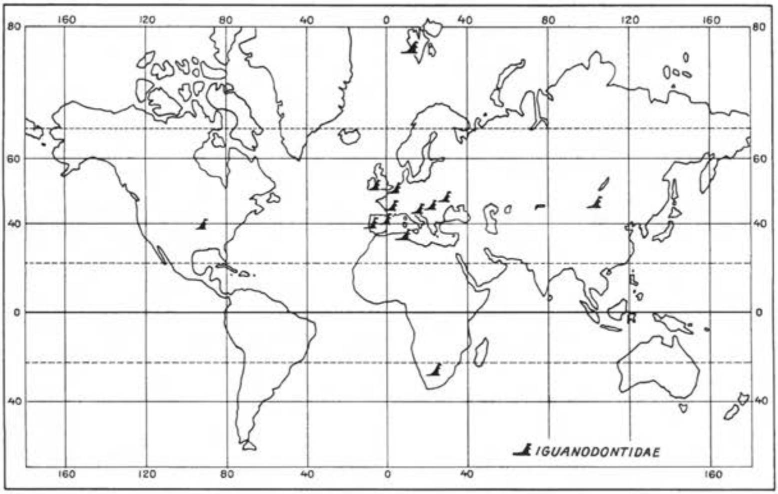



***Fig. 17 Distribution of Iguanodon dinosaurs. The northernmost discovery has been made at Festningsodden in Isfjorden. From N. Heintz (1964): Mesozoiske øglefunn fra Norge og Svalbard. Norsk Polarinstitutt Meddelelser No. 91.***

***← Fig. 16 Footprints left by a Lower Cretaceous dinosaur, Iguanodon, at Festningsodden in Isfjorden. From A.F. de Lapparent (1962): Footprints of a dinosaur in the Lower Cretaceous of Vestspitsbergen - Svalbard. Norsk Polarinstitutt Årbok 1960.***

tons were shipped out. The Russian company took over the operations itself in 1920, but later the same year sold the property to the Dutch company Nederlandsche Spitsbergen Compagnie (Nespico), which named the mining settlement in Gladdalen, Barentsburg.

Nespico started expanding and modernising the colliery, loading facilities, power station and living quarters, and built a hospital. In 1921-22, 232 people wintered there and 25,000 tons of coal were shipped out the following summer. Coal prices dropped during the slump later in the 1920's and the company got into financial difficulties. It unsuccessfully offered to sell the plant to the Norwegian government, and in 1932 the plant and coal deposits were sold to the state-owned Russian company Trust Arktikugol. Like the other collieries in Svalbard, Barentsburg was destroyed during the Second World War and coal production did not resume until 1948. In 1972, Trust Arktikugol rented 20 km$^2$ at the entrance to Grøndalen from the Norwegian company Store Norske Spitsbergen Kulkompani A/S for 25 years, and all mining has been concentrated there since 1976. The Gladdalen colliery will gradually cease to be worked and a projected

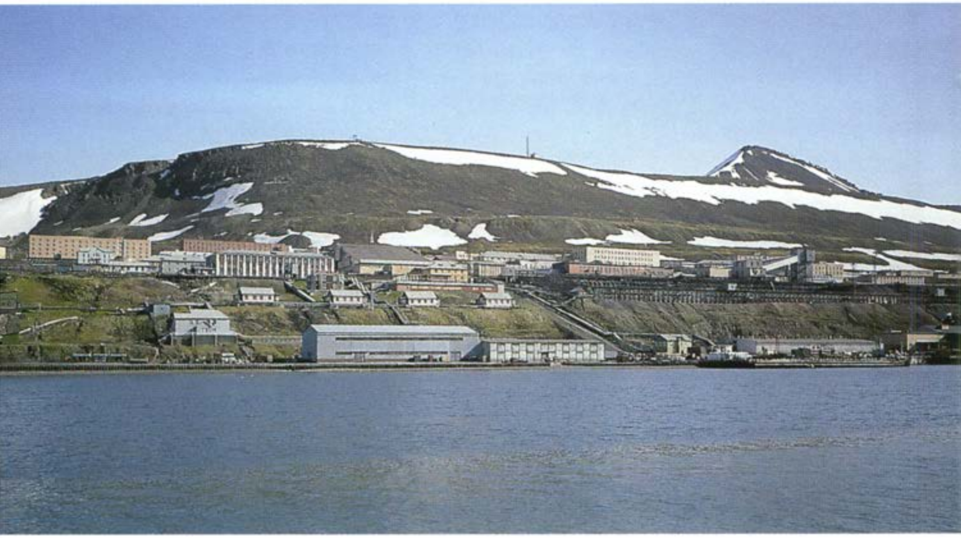


***Fig. 18 Barentsburg, looking east.***

new mine near Barentsburg will take over. Around 200,000 tons of coal a year are currently being mined.

Gas was found at Finneset on the east side of Grønfjorden in 1918. The gas source and surrounding area were occupied by Arctic Oil Company and the find was registered with the Norwegian Ministry of Foreign Affairs. Subsequent investigations showed that the gas was probably methane originating from a coal seam, and was not linked to an oil deposit. The Norwegian geologists, Gunnar Horn and Anders K. Orvin, prospected for oil at Grønfjorden in 1926 on behalf of Store Norske. They found traces of asphalt and viscous oil in a few Triassic beds, but because possible reservoir rocks were probably not particularly porous, they thought that any deposits which might be present would scarcely be large.

Attempts to locate oil and gas near Grønfjorden were not resumed before 1963-64 when Norsk Polar Navigasjon used lightweight equipment to drill near the head of Grønfjorden, with a negative result.

## North of the fjord entrance

*Basement*

A conspicuous landmark at the entrance to Isfjord is a bird-cliff called Alkhornet on the west side of Trygghamna. The cliff chiefly consists of folded and metamorphosed Proterozoic limestone and dolostone. The area west and northwest of Trygghamna otherwise mostly has phyllites with limestone beds, sometimes also remnants of dark, metamorphosed sills. An interesting feature of these sills is that they contain minerals which must have crystallised under high pressure. The basement here was probably forced downwards when continental plates collided towards the end of the Proterozoic. High pressure rocks can also be found at St. Jonsfjorden, just north of this local map (see page 94).

North of Trygghamna is a large area of metamorphosed Proterozoic basaltic lava. Flow structures and gas cavities provide clear evidence that this is a lava. Pillow structures show that the lava, at least in places, was extruded under water.

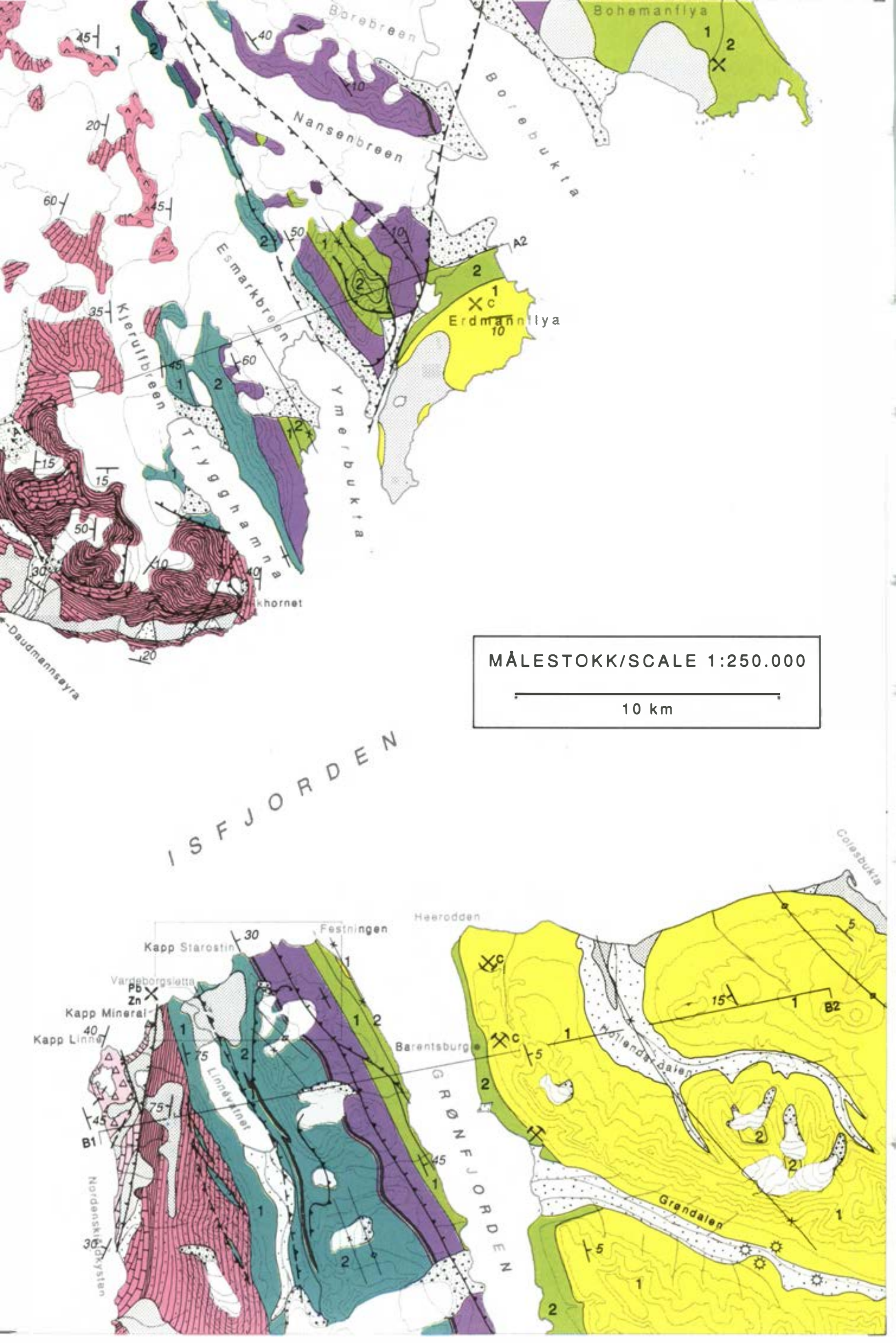
*Carboniferous to Tertiary*

Northeast of Trygghamna, non-metamorphosed Carboniferous to Tertiary strata form the northern end of the huge trough-shaped "basin" on Spitsbergen, the beds mostly dipping east or south. Just east of Trygghamna, Vermlandsryggen comprises the same strata as the Festningen section, with hard, Upper Permian, flint-bearing beds acting as as a reinforcement for the protruding headland.

The youngest and uppermost surviving beds in the central basin north of Isfjorden are exposed on the Erdmannflya peninsula; they were deposited in the Cretaceous and early Tertiary. The Cretaceous sandstone has several shaley beds with impressions of leaves and other plant remains. The Tertiary succession begins with a thin conglomerate deposited on eroded Cretaceous beds and has a total thickness of about 200 m. The lowermost Tertiary strata consist of sandstones with two coal seams, the thickest measuring about 1 m. Trust Arktikugol has drilled for coal on Erdmannflya.

The considerably larger Bohemanflya, further northeast, has Upper Triassic, Jurassic and Cretaceous beds dipping about 10-15° south. The Triassic is mostly sandstones, whereas the Jurassic consists of shale, mudstone and siltstone. Yellowish-brown weathering stone balls, 5-20 cm in diameter, occur in the Upper Jurassic beds. They were formed by chemical precipitation of carbonate and iron-bearing minerals, and beautiful fossils are sometimes concealed in their core. The first thick Cretaceous sandstone, the Festningen sandstone, is 6-7 m thick on Bohemanflya. It is overlain by a 2 m thick, shaley coal seam discovered by Søren Zachariassen as early as 1862; it was among the first to be worked in Svalbard. In 1899, about 50 tons were mined, but because the coal is impure and the sea is shallow for a long distance from the shore, resulting in poor harbour conditions, mining did not last long.

West of Bohemanflya, on the lower slopes of Sylfjellet, some metre-thick lenses of basalt have been found which some geologists think may indicate volcanic activity in Triassic times. The chemical composition of this basalt resembles that of altered lavas derived from submarine volcanic eruptions.



Borebreen
Bohemanflya
Nansenbreen
Borebukta
Esmarkbreen
Erdmannflya
Kjerulfbreen
Trygghamna
Ymerbukta
A2
Daudmannsøyra
MÅLESTOKK/SCALE 1:250.000
10 km
ISFJORDEN
Heerodden
Festningen
Kapp Starostin
Vardeborgsletta
Pb
Zn
Kapp Mineral
Kapp Linné
Barentsburg
GRØNFJORDEN
Colesbukta
Hollendardalen
Grendalen
Linnévatnet
Nordenskiöldkysten
B1
B2

## LEGEND - LOCAL MAP OUTER ISFJORDEN

Sediments, sedimentary and metamorphic rocks

- QUATERNARY, MORAINES
  - " BEACH DEPOSITS
  - " RIVER DEPOSITS AND UNDIFFERENTIATED DEP
  - " PINGO
- 2 / 1 TERTIARY
- 2 / 1 JURASSIC (1) AND CRETACEOUS (2)
- TRIASSIC AND LOWERMOST JURASSIC
- 2 / 1 CARBONIFEROUS AND PERMIAN
- UPPER PROTEROZOIC (Basement)
- MIDDLE PROTEROZOIC (Basement)

Igneous rocks

- Jurassic-Cretaceous dolerite

### Rocks symbols in the basement

- Tillite
- Limestone and dolostone
- Phyllite with carbonate beds and minor metadolerite intrusions
- Phyllite with quartzite beds
- Basic lava

**Division of the beds from Carboniferous to Tertiary:**

TERTIARY: Van Mijenfjorden Group. 1. Firkanten, Basilika, Gilsonryggen and Battfjellet Formations. 2. Aspelintoppen Formation
JURASSIC AND CRETACEOUS: Adventdalen Group. 1. Janusfjellet Formation 2. Helvetiafjellet and Carolinefjellet Formations
TRIAS AND LOWERMOST JURASSIC: Sassendalen and Kapp Toscana Groups
CARBONIFEROUS AND PERMIAN: 1. Billefjorden Gr. 2. Gipsdalen and Tempelfjorden Gr.

- Normal fault, barbs towards downthrow block.
- Thrust fault, teeth towards overthrust unit.
- Syncline/ anticline
- 15 Planar structure (bedding, schistosity, foliation), dip in degrees/ vertical/ horizontal
- Active/ abandoned mine/ test pit
  C: coal Pb: lead Zn: zinc

### GEOLOGICAL SECTIONS

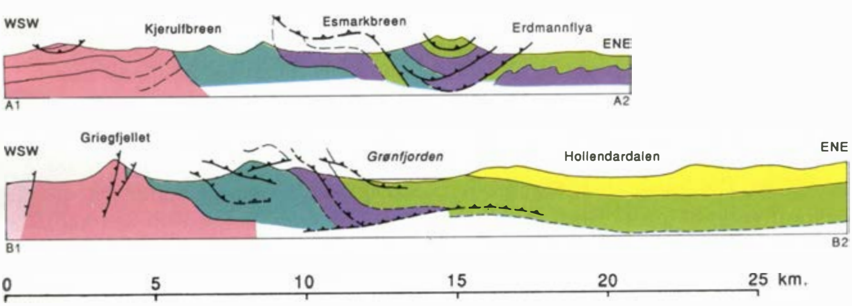



*Fig. 19 Outer Isfjorden.*

*Quaternary and landscape features*
Both Erdmannflya and Bohemanflya are strandflats, mostly reaching less than 50 m above sea level. The strandflats continue into the fjord as an approximately 1 km broad submarine platform. Both peninsulas were completely covered by ice during the last Ice Age and erratics of granite and gneiss indicate ice movement towards southwest or west. When the melting of the ice cap got properly underway around 10,000 years ago, the area rose again, at first as rapidly as about 3 m per century, later much more slowly. The highest shore deposits were formed around 10,000 years ago and are now about 60 m above sea level. A very distinct beach ridge is at a height of 11 m and can, for instance, be seen along the south side of Erdmannflya. After the ice retreated, a period ensued when it was warmer than now and common mussels lived here 5000 to 9000 years ago.

Daudmannsøyra, on the north side of the entrance to Isfjorden, is a spit forming a typical strandflat crossed by meltwater streams in summer and having many small lakes. Raised strandlines are found at several heights. Here, too, the strandflat stretches offshore as a submarine platform, and remains of wrecked ships are evidence of how difficult and treacherous these waters are.

## LONGYEARBYEN - SASSENFJORDEN (local map page 62-63)

The area covered by this local map has almost only sedimentary rocks. The total thickness of the visible succession is around 2500 m and the basement is not exposed anywhere. The area is situated just east of the axis of the major trough-shaped syncline in southern Spitsbergen and the beds are horizontal or dip gently southwest. The oldest strata, of Carboniferous age, are therefore exposed in the northeast. The youngest and uppermost ones are from the Middle Tertiary and can be seen on the summit of Nordenskiöldfjellet, near Longyearbyen.

### Sassendalen – Sassenfjorden – Tempelfjorden

*Carboniferous and Permian*
Templet, one of the most beautiful and majestic mountains in Svalbard, catches the eye at the entrance to Tempelfjorden. It consists of almost horizontal Permian strata. The lower slopes near the fjord have a variety of Lower Permian limestones alternating with white gypsum beds. Higher up is bed upon bed of Upper Permian flint and sandstone, totalling around 400 m. The lowermost 30 m are packed with fossils and are comprised almost entirely of silicified brachiopods, moss-animals and sea lily (crinoid) stems. These hard, fossiliferous beds often form steep cliffs or are covered by screes, and are therefore poorly accessible. However, they are more accessibly exposed at Sveltihel, south of Tempelfjorden.

The bedrock forming Templet fractures easily and frost weathering has excavated gullies and clefts in the upper part of the mountain. The steep cliffs here are alive with birds in the summer. Below 200 m, the material produced by weathering has collected in huge talus cones which reach down to the fjord. The Carboniferous-Permian strata in the Sassenfjorden-Tempelfjorden district were deposited in shallow marine areas boasting a rich animal and plant life. The influence of sea water on calcareous deposits, and subsequent evaporation, led to crystallisation of calcium sulphates in the form of gypsum and anhydrite beds. Attempts have been made to work gypsum in this area, e.g. at Kapp Schoultz on the south side of Tempelfjorden where remains of the mining equipment can still be seen. The Lower Permian beds are exposed at several places in the lower reaches of Sassendalen and fine examples of brachiopods (Spiriferids and Productids) are easy to find.

*Triassic to Tertiary*

The Triassic strata mostly consist of shales with some siltstones and sandstones. In the middle, several beds in the shales are studded with cm/dm-sized, greyish blue, phosphatic nodules which often contain fish fossils. Phosphate-bearing beds can also be seen south of Sassenfjorden, e.g. on the north side of Botneheia. Volcanic breccias have been found on Wimanfjellet, about 5.5 km southeast of Deltaneset, suggesting that volcanic eruptions took place during the Triassic.

Common Triassic and Jurassic fossils are ammonites, bivalves and remains of reptiles and fish. Good places to find fish and reptile fossils include exposures of Middle and Upper Triassic beds on the south side of Sassenfjorden and Sassendalen. The Jurassic and Lower Cretaceous strata consist of soft, dark shales making the Jurassic-Cretaceous boundary difficult to locate. Fossil reptiles are found in shales near the boundary between the Jurassic and Cretaceous on the south side of Sassenfjorden, both at Deltaneset and Diabasodden, and abundant fossil ammonites and bivalves are also to be found. At Diabasodden and west of Gipsvika, the igneous rock, dolerite, intruded the sedimentary strata as dark sills and dykes in Jurassic-Cretaceous time.

A traverse from Deltaneset southwards to the summit of Janusfjellet passes through an approximately 800 m thick succession extending from Triassic rocks near the fjord to Tertiary on the summit. From sea level to a height of about 50 m, the Triassic sandstone is found, partly covered by sand and gravel in which fine polygonal structures are occasionally observable. From 50 to about 475 m are the dark marine shales astride the Jurassic-Cretaceous boundary. Their lower portion contains fossil belemnites (squids) and *Aucella* (bivalves), and bones of Plesiosaurs and Icthyosaurs are found about 250 m above sea level. Measurements of part of a Plesiosaur skeleton found here suggest that the creature may have been more than 6 m long. The

Jurassic-Cretaceous boundary is located about 300 m above sea level. Near this boundary is a thin limestone bed with numerous fossil ammonites and bivalves as well as fragments of fossilised trees and vertebrates. Curious nodules are found in the shales between 300 and 400 m. These are chemical precipitates containing calcium- and iron carbonate, and occasionally fossils. The Festningen sandstone and other Cretaceous sandstones enter around 475 m. Large blocks have broken off the Festningen sandstone and slid on the soft shale down to about 250 m above sea level. The uppermost part of Janusfjellet, from about 700 m to the summit, consists of a sequence of Tertiary conglomerate, sandstone and shale.

The areas on either side of Sassenfjorden occupy the continuation of the zone of faulting and folding that goes along Billefjorden and Wijdefjorden (the Billefjorden Fault Zone). Movement in the zone began as early as near the end of the Devonian and continued, with interruptions, for a very long time. One fault crosses Sassenfjorden from Gipsvika to the south side of the fjord, where it is visible in Marmierfjellet. The west side of this fault dropped about 500 m during the Tertiary, and on the higher east side, strata were locally removed by thrust faults. Beds from the Upper Triassic and Lower Jurassic are therefore lacking here, whereas they are preserved on the west side. South of Adventdalen, the fault is replaced by a tight fold in the Cretaceous beds.

*Quaternary and landscape features*

Sassendalen is a typical U-valley formed by glacial erosion. It is one of the largest valleys on Spitsbergen and Sassenelva is fed by meltwater from many glaciers in the interior. There is therefore a huge discharge in summer when glacier melting is at its maximum. As a result of the milling and wearing away of the bedrock by the glacier, vast quantities of sediment find their way into the river and onwards into Tempelfjorden where extensive sand and mud banks are formed off the river mouth.

Good examples of patterned ground are found in several places on the north side of Sassenelva midway along Sassendalen.

## Longyearbyen – Adventdalen

*Triassic, Jurassic and Cretaceous*

On entering Adventfjorden, mountains can be seen on either side whose lower slopes consist of Lower Cretaceous deposits overlain by Lower Tertiary. Inner Adventdalen is dominated by shallow-water and deltaic sediments of Triassic and Jurassic age. Shales and siltstones form most of the lower portion of the Triassic sequence, some of the shales being black and containing phosphatic nodules. The Jurassic consists almost entirely of black and grey shales deposited under marine conditions. Tertiary thrusting and folding were very easily transmitted in these soft shales. That they can

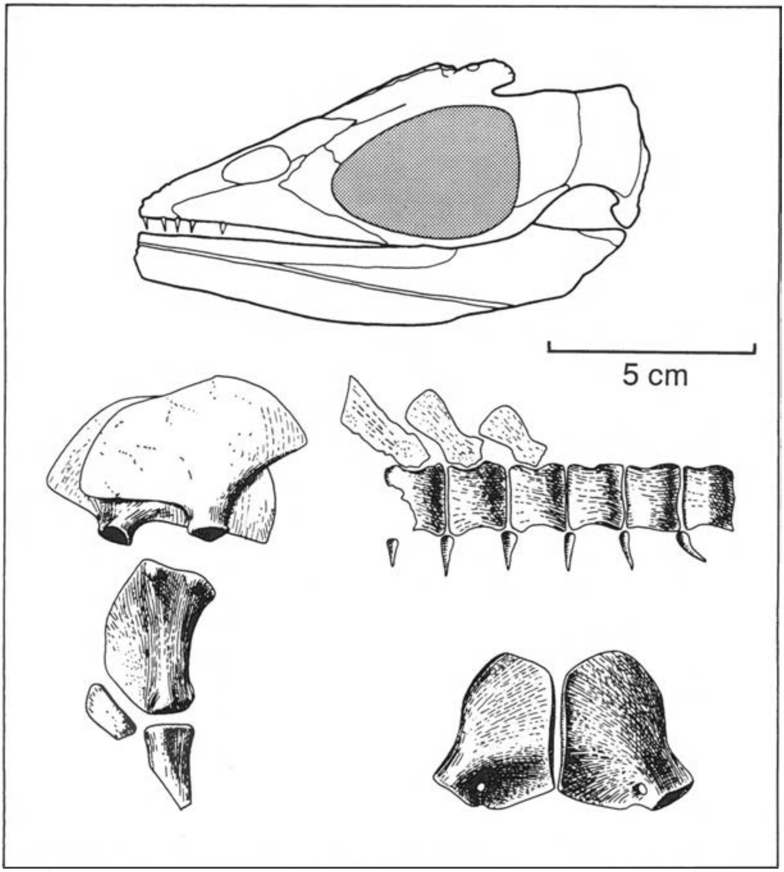



***Fig. 20** The skull and other skeletal remains of the small reptile, Grippia, found in Triassic rocks on Vikinghøgda on the south side of Sassendalen. After C. Wiman.*

serve as a lubricant is also seen by the slabs of Cretaceous sandstone, up to 1 km across, that have in the recent past slid down mountain sides on the Jurassic shales, such as, for instance, on the south and west sides of Arctowskifjellet, north of Adventdalen.

Around the end of the Jurassic and the beginning of the Cretaceous, magma intruded the sedimentary rocks to form the igneous rock called dolerite. This dark rock occasionally transects the strata as vertical dykes.

The southwesterly dip of the strata causes increasingly younger beds to be exposed in that direction so that only Cretaceous and Tertiary strata occur in the entire area around Adventfjorden and Longyearbyen. The Lower Creta-

***Fig. 21** Pilarberget, viewed towards southeast. Bjørndalen is on the left and Nordenskiöldfjellet in the background. The hill consists of Tertiary beds, except beside the fjord where some Cretaceous beds are exposed. The Longyear seam is in the Lower Tertiary, at an altitude of about 50 m.*

ceous consists of fluviatile and deltaic deposits with sandy beds, including the Festningen sandstone which is 6 to 14 m thick here. Later deposition took place in a shallow marine setting, resulting in alternating sandstone, siltstone and shale. Just over 200 m of Cretaceous beds are exposed near Longyearbyen, whereas they are 300 m thick on the north side of Adventfjorden.

*Tertiary*

Spitsbergen was uplifted during the Cretaceous, and erosion removed the Upper Cretaceous beds. Near Longyearbyen, a Tertiary conglomerate therefore lies directly upon the eroded Lower Cretaceous. The conglomerate is less than 1 m thick. The overlying Tertiary sequence largely consists of sandstones and siltstones, with some shales. The most important coal seams are found in the lower part of the Tertiary succession, which is well exposed southwest of Hotellneset in the lower slopes of the mountains along Isfjorden (Fig. 21). The total thickness of Tertiary strata from above Longyearbyen to the summit of Nordenskiöldfjellet, just southwest of the town, is nearly 1000 m. Plant fossils are found at several horizons in the succession, including fossilised trees. Well-preserved leaves and other parts of plants occur in the uppermost Tertiary strata. It is not necessary to climb to the top of Nordenskiöldfjellet to see these beds because the Longyearbreen glacier breaks off blocks of this rock and carries them down to the terminal moraine in Longyeardalen, where, with luck, beautiful fossils may be found.

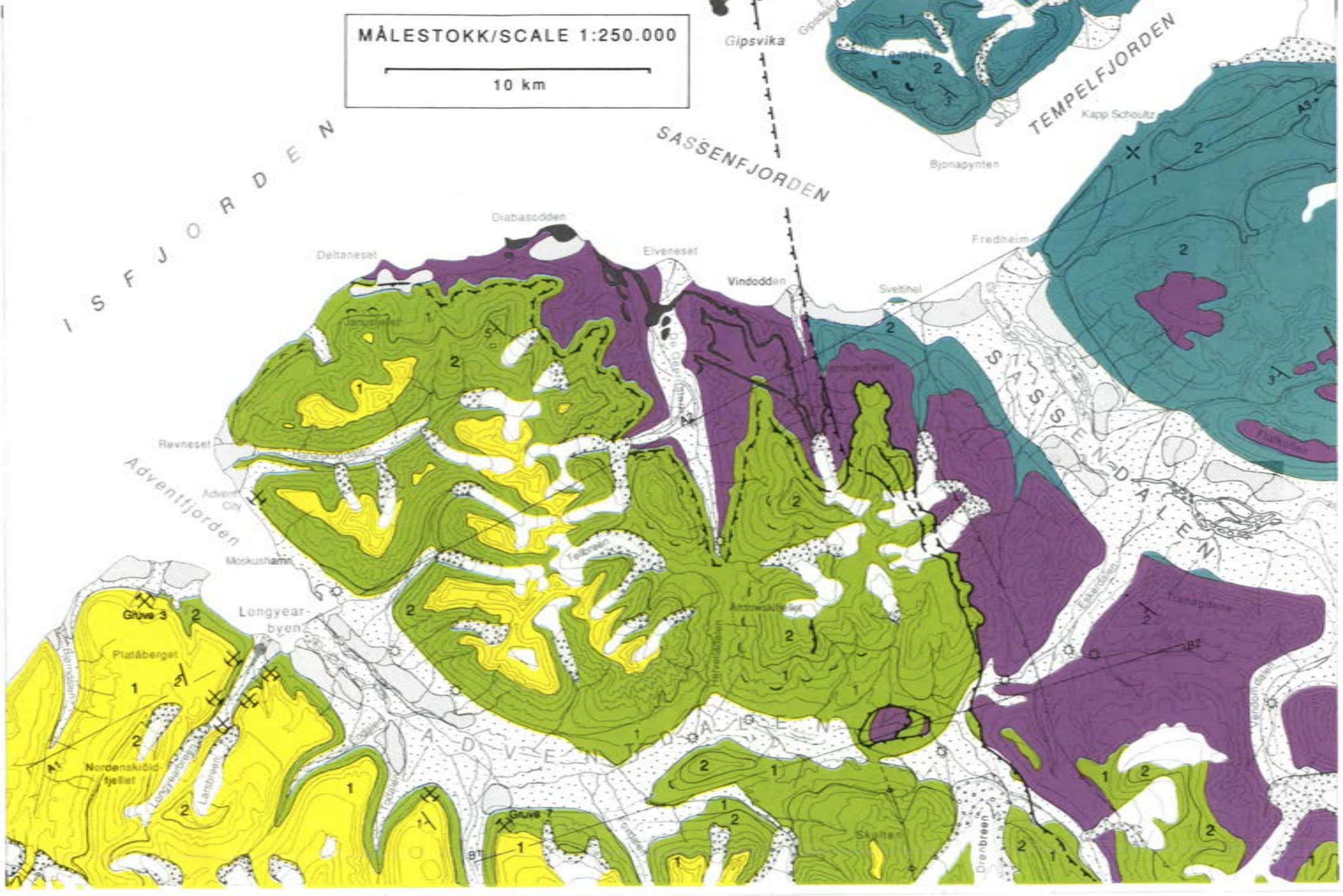
*Quaternary and landscape features*

The landscape in the area covered by this map is dominated by flat-topped and pyramidal-shaped mountains. Apart from the fjords and large valleys there are few signs of glacial erosion, perhaps because the ice sheet was frozen fast to the underlying ground here and therefore moved very little. Adventdalen is a U-shaped valley carved out by a valley glacier, the smaller valleys often having V shapes primarily produced by river erosion which takes place rapidly in the mainly friable rocks found here. Many of the smaller valleys branching off Adventdalen have been formed by rivers and lack the depressions and thresholds that are typical for glacially-formed valleys. The deposits in Adventdalen are typical for glacial meltwater rivers; sand, gravel, silt and clay are carried down the valley by the river and deposited en route alongside continuously shifting river channels. At the foot of the mountainsides, raised strandlines can be seen for about 10 km up the valley. Some loess (wind-transported deposits, mostly silt) are also found here between the flood plain and the mountain slopes. This material was originally deposited by rivers, and where these ceased to be active it was picked up by the wind and transported, mostly down-valley. Such movement still takes place, and on dry, windy summer days "clouds" of particles can be seen blowing along the valley floor. Distinct patterned ground can be found in several places, including inner Adventdalen between Foxdalen and Drønbreen.

Pingos can be seen in a number of places in Adventdalen. A hut has been built on one south of the entrance to Helvetiadalen on the north side of Adventelva; it stands 28 m above the river plain. A perennial spring containing about 5 grams of mineral salts per litre flows out just below it. Another pingo is found about 2 km SSW of Passhytta, at the head of the valley. The highest pingo in the area is located around 190 m above sea level in the pass between Helvetiadalen and De Geerdalen.

*Buildings on permafrost*

In Longyearbyen and the other Svalbard settlements, the presence of permafrost calls for special precautions when constructing building foundations. In particular, movement caused by repeated thawing and freezing of water-bearing superficial deposits has to be avoided. Stone fillings lying on bedrock result in little frost heaving. The power station at Longyearbyen has been built in such a way. It is also possible to prevent heat from the buildings thawing the ground beneath by allowing air to circulate under the buildings, as is done with the main terminal at the airport. Some buildings have had refrigerated pipes installed beneath them to prevent thawing.



MÅLESTOKK/SCALE 1:250.000
10 km
ISFJORDEN
SASSENFJORDEN
TEMPELFJORDEN
SASSENDALEN
ADVENTDALEN
Adventfjorden
Gipsvika
Kapp Schoultz
Bjonapynten
Diabasodden
Deltaneset
Elveneset
Vindodden
Fredheim
Sveltihel
Revneset
Advent City
Moskushamn
Longyearbyen
Gruve 3
Gruve 7
Platåberget
Nordenskiöld-fjellet
Tellbreen
Skolten
Drenbreen

## LEGEND - LOCAL MAP LONGYEARBYEN - SASSENFJORDEN

Sediments and sedimentary rocks

- QUATERNARY, MORAINES
- " BEACH DEPOSITS
- " RIVER DEPOSITS AND UNDIFFERENTIATED DEP.
- " PINGO
- 2 / 1 TERTIARY
- 2 / 1 JURASSIC (1) AND CRETACEOUS (2)
- TRIASSIC AND LOWERMOST JURASSIC
- 2 / 1 CARBONIFEROUS AND PERMIAN

Igneous rocks

- Jurassic-Cretaceous dolerite.

**Division of the beds from Carboniferous to Tertiary:**

TERTIARY: Van Mijenfjorden Group. 1. Firkanten, Basilika, Gilsonryggen and Battfjellet Formations. 2. Aspelintoppen Formation.
JURASSIC AND CRETACEOUS: Adventdalen Group. 1. Janusfjellet Formation. 2. Helvetiafjellet and Carolinefjellet Formations.
TRIAS AND LOWERMOST JURASSIC: Sassendalen and Kapp Toscana Groups
CARBONIFEROUS AND PERMIAN: 1. Gipsdalen Group. 2. Tempelfjorden Group

- Normal fault, barbs towards downthrow block.
- Thrust fault, teeth towards overthrust unit.
- Syncline/ anticline/ flexure.
- Cretaceous sandstone down-slided on soft Jurassic shale.
- Bedding - dip in degrees (2)

- Active/ abandoned coal mine.
- Anhydrite/gypsum - test pit.

### GEOLOGICAL SECTIONS

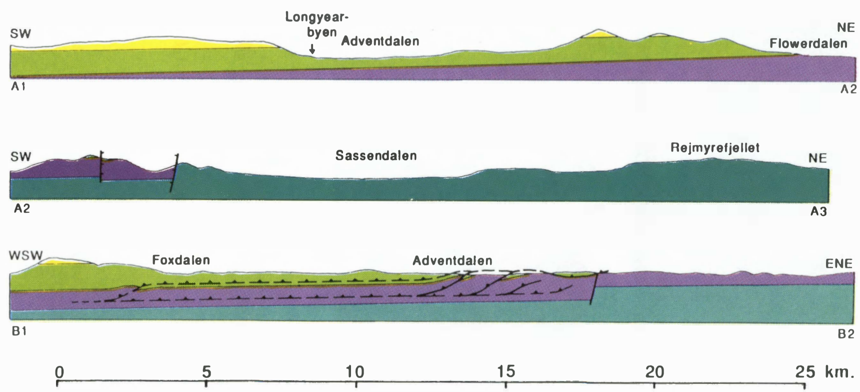



*Fig. 22 Longyearbyen-Sassenfjorden.*

*Fig. 23 View of Adventdalen looking west. The calcareous shales of Jurassic-Cretaceous age weather easily resulting in favourable conditions for mountain avens on gentle south-facing slopes.*

*Fig. 24 Longyearbyen, with Adventdalen in the background.*

### Frost in rock and earth

PERMAFROST Permanently frozen ground. The uppermost layer usually thaws in summer.

SOLIFLUCTION Slow movement of unconsolidated surface material, such as soil, gravel, etc., owing to gravity and the alternate freezing and thawing of water in the material.

PINGO Up to about 50 m high mound of mineral soil with a core of ice. Often has a crater-like hollow in the top because the ice core melts. Pingos are formed in areas with permafrost because groundwater under pressure forces its way along zones of weakness in frozen layers of earth.

TALUS CONE Cone-shaped scree of stones fallen from the mountainside above because of, for example, frost weathering. The size of the stones depends on the rock type; hard rocks, such as granite, produce large stones, friable ones, such as shale, give gravelly talus cones. The slope usually has an angle of around 30 degrees, and cannot be steeper than 45 degrees.

FROST WEATHERING The breaking down of minerals and rocks by repeated freezing and thawing of water in cracks and pores.

PATTERNED GROUND Areas with more or less continuous rows or polygons of stone, usually irregularly circular in shape, occasionally distinct hexagons, with diameters of 10 cm to 50 m. Formed in areas with permafrost and may be caused by fracturing owing to the cold and movement, and by sorting of surface layers through repeated freezing and thawing of water-bearing earth.

The permafrost has created problems for the airport runway. To hinder thawing, a stone filling was placed as a base for the runway surface. However, the filling proved to be too thin to prevent the ground beneath from thawing and causing frost heave. The runway was painted white to reduce the heat from the sun in summer, with the aim of preventing the thawing action reaching as far as the frozen, water-bearing ground beneath. Because this was still inadequate, the runway was removed in 1989 and improved drainage installed prior to the laying of new asphalt. However, subsidence is, nevertheless, still taking place (in 1993), probably because of water beneath the runway.

*The coal mines*

A company named Bergen-Spitsbergen-Kulgrubekompani occupied an area north of Adventfjorden and Adventdalen in 1901. In 1904, this company was amalgamated with British interests to form the Spitsbergen Coal and Trading Company which started mines, initially at Advent City on the north side of Adventfjorden and later at Moskushamn further up the fjord. From 1916 onwards, the coal field was worked by Norwegian companies, with mixed success. It was poor quality coal, however, and after 1946 mining has only taken place on the south side of Adventfjorden and Adventdalen. The first surveys here were carried out by the Trondhjem-Spitsbergen Kulkompani which in 1900 and 1901 occupied areas and took samples of coal seams just south and southwest of Adventfjorden. An American iron works owner, John Munroe Longyear, who visited the district as a tourist in 1901, became interested in the coal deposits and the areas were sold in 1906 to Longyear's company, the Arctic Coal Company. The purchase also included, among other things, a tourist hotel on Hotellneset.

Production started when the Arctic Coal Company had built the mining plant, wharf and surface installations. However, the company experienced serious strikes in the early years, so serious that for a time there was talk of sending all the workers home and importing Chinese instead. But despite the difficulties, output increased gradually. Norwegian interests took over the company in 1916 and formed Store Norske Spitsbergen Kulkompani A/S (Store Norske), which has been responsible for the mining ever since. This company, too, had difficulties with strikes initially, and in 1917 the army took command of the plant and sent the workers home. Acts of war in 1942 and 1943, including an attack on Longyearbyen by the battleship "Scharnhorst", caused extensive damage to the plant and work had to be stopped. Following re-building in 1945, coal production has been between 250,000 and 500,000 tons a year since the 1950's. More than half the total output in 1987-1989 was exported to Germany, France and Great Britain.

The coal seams that are worked south of Adventfjorden and Adventdalen are situated near the base of the Tertiary. The seams dip gently southwards. The two lowermost ones, the Svea and Todal seams, are only 35 cm thick here, and are not worked. In Sveagruva, the Svea seam is often more than 2 m thick. The overlying seam, the Longyear seam, varies in thickness from 60-70 cm up to nearly 2 m. All mining in the Longyearbyen area is based on this seam; the two uppermost seams have poor quality coal and are not worked. Confirmed and probable coal reserves in the Longyearbyen coalfield are around 8 million tons, but the quantity that can be extracted is somewhat less.

Mining takes place partly within the permafrost, partly in thawed rock beneath it. The permafrost prevents water from seeping down, and the rock just beneath it may therefore be dry. Because the frozen beds act as an impermeable lid, explosive methane gas may collect in cavities in the rock under this

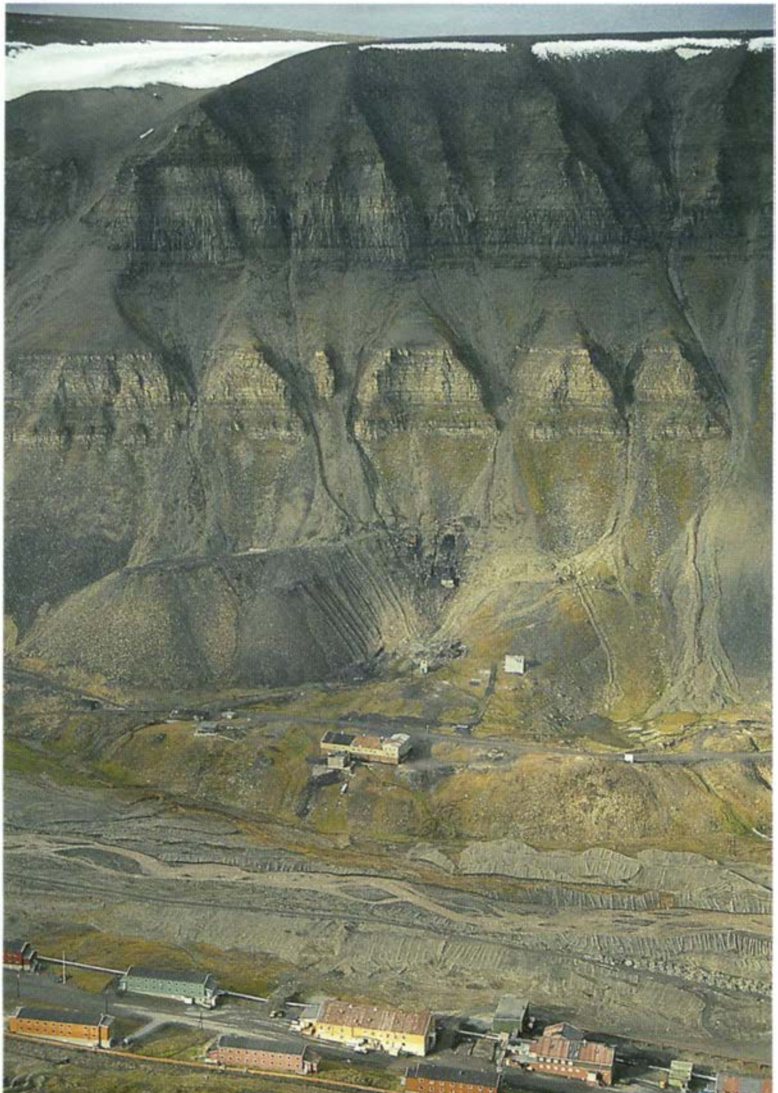


*Fig. 25 The abandoned colliery, Nye Gruve 1 (New Mine 1), looking west across Longyeardalen. Tertiary beds occur above the entrance to the adit, Cretaceous below.*

***Fig. 26 Electrical cutter eating its way into the coal seam. Gruve 7 (Mine 7), Longyearbyen.***

horizon. The gas content is therefore measured regularly and good ventilation is ensured. Coal dust is also explosive, and water or lime dust are therefore applied to dry rock to bind the coal dust to prevent explosions.

Store Norske is now operating Gruve 3 (Mine 3), just southwest of the airport and Gruve 7 at Foxdalen on the south side of Adventdalen. The main galleries in the mines run almost horizontally into the mountainside, and cross galleries branch off on either side. All the coal is gradually taken out between these cross galleries. In Gruve 3, where the seam is mostly around 0.8 m thick, cutting machines initially remove a thin strip lowermost in the seam. Shot holes are then drilled and filled with small charges, and the seam is blasted loose. The coal is then scraped and winched out to the cross galleries where it is loaded on tubs to be taken to the surface.

Explosives are usually not used in Gruve 7 and part of Gruve 3; electrically-driven machinery instead excavates the coal seams which are about 1.6 m thick here, and the coal is taken to the surface on conveyor belts.

The rock above where the coal has been blasted out and scraped away is supported by steel props as long as is necessary for the work. The props are then removed and the roof collapses or slowly subsides where the coal has been removed. Previously, coal was taken from the mine entrance to the washery by overhead cableway, but lorries undertake all the transport now. In the washery, fine and coarse coal are sorted, and stones are removed before the coal is taken to the storage facilities at Hotellneset. Huge payloaders load the coal onto conveyor belts that take it into the ships. The coal is usually shipped from May to November and is used about equally in the metallurgical industry and for power production. Gruve 3 was opened for tourists in 1990.

Production in Gruve 3 is planned to end in 1997, and Gruve 7 is expected to be worked out around 2005-2010. If total output is to be maintained at the present-day level, production will have to begin in Sveagruva or the Central Field (Sentralfeltet) between Sveagruva and Reindalen in 1997.

## BELLSUND (Local map, page 70-71)

The Bellsund district has been much visited since the early days. Ships were able to seek shelter from the westerlies and there were good sites for land bases for whalers. Bellsund was also the first port of call on Spitsbergen for the well-known French research vessel "Recherche" in 1838. For geologists, it is an easily accessible locality for the boundary between the basement in the west and the younger sedimentary rocks of Carboniferous to Tertiary age in the east.

The boundary passes just west of Millarodden on the north side of Bellsund and continues over Midterhuken to cross the 1205 m high Berzeliustinden on the south side of the fjord. During the Tertiary folding episode, the beds in the west were folded up enabling erosion to reach the basement rocks underlying the sedimentary succession. Because the fjords inland from Bellsund lie athwart the dominant trend of the Tertiary folds, there is a good section through the intensely folded strata in the west and the major syncline that spans Spitsbergen from Isfjorden to the east coast.

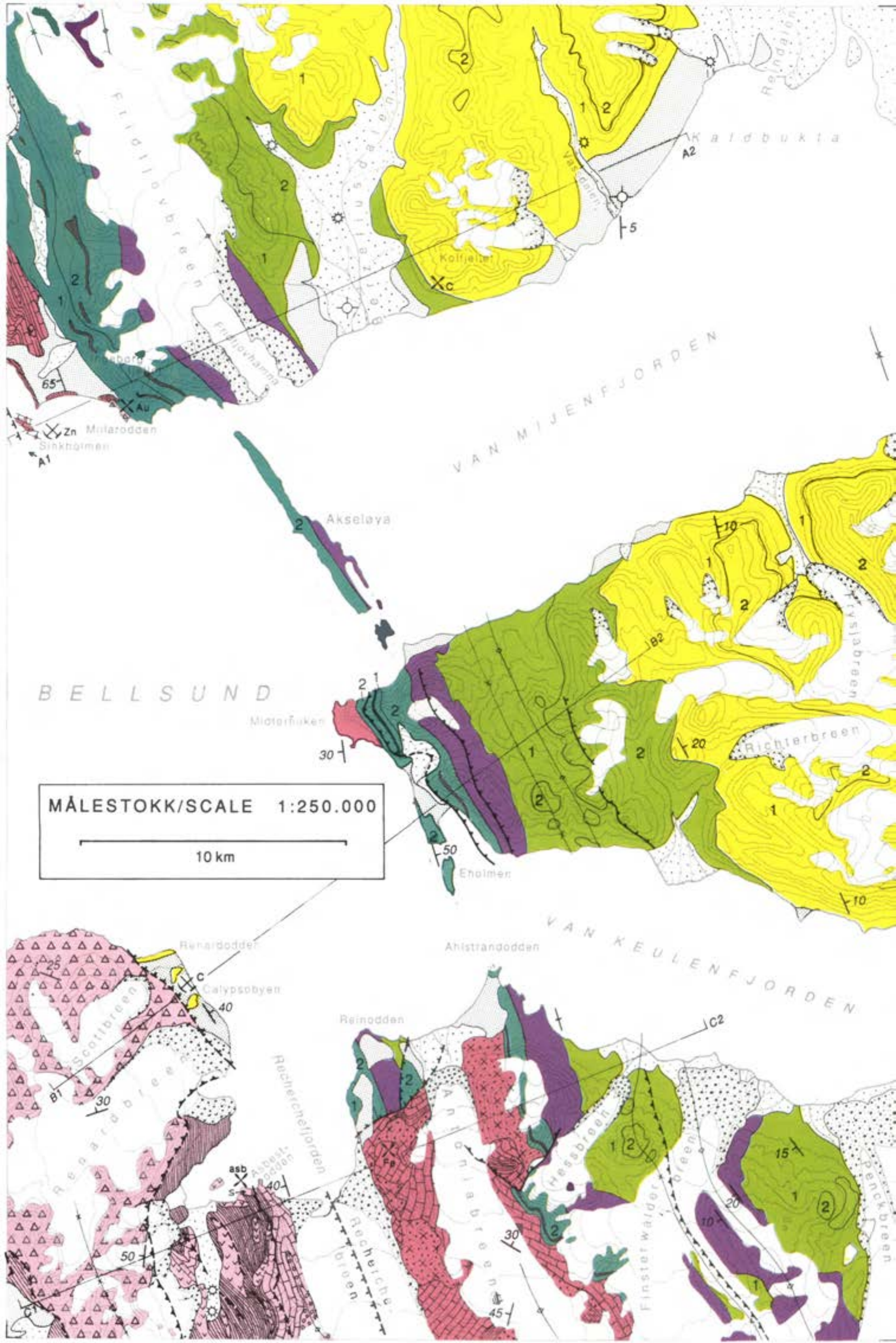
### The north side of Bellsund – van Mijenfjorden

*Basement*

The boundary between the basement and the Carboniferous is easily found just west of the huts on Millarodden. Furthest west on the headland, shaley tillite dips west-northwest. Further west along the shore there is little exposed rock before grey and green phyllites are found close to Skjerpodden. These are probably altered ash beds, i.e. volcanic rocks. From Skjerpodden northwards to the mouth of Ytterdalselva the bedrock consists almost exclusively of black, carbonaceous phyllites with some beds of calcareous and dolomitic limestone. The phyllites contain some iron pyrites and were probably formed from mud deposited in oxygen-poor water.

*Carboniferous to Tertiary*

Whereas these younger beds are almost horizontal along the inner part of Van Mijenfjorden, on Ingeborgfjellet and the shore at Millarodden they are


MÅLESTOKK/SCALE 1:250.000
10 km
BELLSUND
VAN MIJENFJORDEN
VAN KEULENFJORDEN
Kaldbukta
Kolfjellet
Fridtjovbreen
Fridtjovhamna
Millarodden
Sinkholmen
Akseløya
Midterhuken
Eholmen
Richterbreen
Renardodden
Calypsobyen
Ahlstrandodden
Reinodden
Scottbreen
Renardbreen
Recherchefjorden
Recherchebreen
Antoniabreen
Hessbreen
Finsterwalderbreen
Penckbreen
Asbestodden
A1
A2
B1
B2
C1
C2

## LEGEND - LOCAL MAP BELLSUND

**Sediments, sedimentary and metamorphic rocks**

- QUATERNARY, MORAINES
- " BEACH DEPOSITS
- " RIVER DEPOSITS AND UNDIFFERENTIATED DEP.
- " PINGO
- TERTIARY (2, 1)
- JURASSIC (1) AND CRETACEOUS (2)
- TRIASSIC AND LOWERMOST JURASSIC
- CARBONIFEROUS AND PERMIAN (2, 1)
- UPPER PROTEROZOIC — Basement
- MIDDLE PROTEROZOIC — Basement

**Igneous rocks**

- Jurassic-Cretaceous dolerite.

**Rock symbols in the basement**

- Tillite.
- Limestone and dolostone.
- Phyllite.
- Conglomerate.
- Quartzite/gneissose with feldspar.
- Gabbro, greenstone and greenschist.
- S Serpentinite (at Asbestodden).

**Division of the beds from Carboniferous to Tertiary:**

TERTIARY: Van Mijenfjorden group. 1. Firkanten, Basilika, Gilsonryggen and Battfjellet Formations. 2. Aspelintoppen Formation (+ Tertiary beds at Calypsostranda).
JURASSIC and CRETACEOUS: Adventdalen Group. 1. Janusfjellet Formation. 2. Helvetiafjellet and Carolinefjellet Formation.
TRIASSIC and LOWERMOST JURASSIC: Sassendalen and Kapp Toscana Groups.
CARBONIFEROUS and PERMIAN: 1. Billefjorden Gr. 2. Gipsdalen and Tempelfjorden Grs.

- Normal fault, barbs towards downthrow block.
- Thrust fault, teeth towards overthrust unit.
- Syncline/anticline.
- 15 Planar structure (bedding, schistosity, foliation), dip in degrees/vertical/horizontal.
- Abandoned mine/test oit. Fe: iron Zn: zinc C: coal Au: gold asb: asbestos
- Test well for oil

## GEOLOGICAL SECTIONS

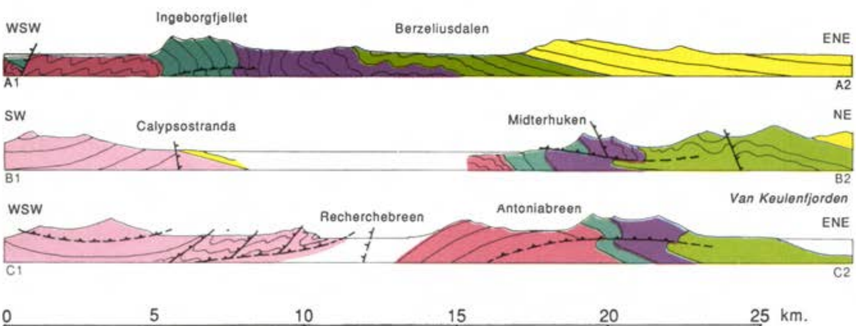



*Fig. 27 Bellsund.*

folded and generally dip steeply northeastwards, resulting in increasingly younger beds becoming exposed eastwards. A walk along the shore from Millarodden to Fridtjovhamna therefore takes one from basement tillite formed about 600 million years ago through an approximately 2500 m thick succession deposited over a period of more than 100 million years in Carboniferous, Permian and mid-Triassic times.

The westernmost part of Ingeborgfjellet has Lower Carboniferous sandstone deposited in fresh water and occasionally carrying some plant fossils. There are also some sills of dark dolerite that were intruded as magma around the transition from the Jurassic to the Cretaceous. These are often weathered brown and are partly covered by orange crustaceous lichen, and form vertical steps in the mountainside.

In Middle and Upper Carboniferous time and most of the Permian, the sea covered large areas and shallow-water deposits dominate. The summit of Ingeborgfjellet has beds from this period, striking north-south.

Just to the east are some highly characteristic, steeply dipping, Upper Permian beds. They are well-bedded, flint-bearing rocks formed from marine deposits. These hard, resistant beds continue southwards across Akseløya, giving rise to the place-names Flintrabben and Flinthaugen. The glacier that excavated Van Mijenfjorden had to surrender here and the island stands out as a barrier at the entrance to Van Mijenfjorden, providing a good example of how landscape forms depend on the bedrock geology.

Mesozoic rocks begin west of Fridtjovhamna, where they are mostly Lower Triassic marine shales; to the east are some strongly folded sandy beds of Upper Triassic and Lower Jurassic age which were probably deposited in shallow water close to deltas.

A characteristic, metre-thick conglomerate whose clasts are unsorted and mostly consist of phosphate-rich rock types, appears in the mid-Jurassic. Some geologists believe this conglomerate to be evidence of a marine transgression and a forerunner of the dark marine shales of the Upper Jurassic and lowermost Cretaceous. These shales are exposed west of ytre Berzeliusdalen. They are less hard and resistant than the sandstone beds in the vicinity and are therefore often plastically folded.

The effects of Tertiary folding become gradually less noticeable east of Berzeliusdalen, and the beds dip more gently. But they still dip eastwards, so that progressively younger ones are exposed towards inner Van Mijenfjorden. The lower slopes of Kolfjellet, in Berzeliusdalen, have alternating Lower Cretaceous sandstones, siltstones and shales. Because the Upper Cretaceous beds were eroded before the Tertiary strata were deposited, a Lower Tertiary conglomerate lies directly upon the Lower Cretaceous on Kolfjellet. Higher on Kolfjellet, and also eastwards along the north side of the fjord, are nearly 2000 m of alternating, almost horizontal, sandstones, siltstones and shales of Tertiary age.

*Fig. 28 Hut built by the Northern Exploration Company in 1910 when prospecting for gold near Millarodden on the north coast of Bellsund.*

*Fig. 29 Adit with remains of a trackway, near the gold claim at Millarodden.*

***Fig. 30 Russian oil rig in Vassdalen on the north side of Van Mijenfjorden in 1987.***

*Minerals, coal and oil*

In 1907, a British engineer named Ernest Mansfield thought he had found indications at Bellsund of gold deposits equal to the best in South Africa. From 1908 to 1912, he led several expeditions to find precious metals, but in vain, and the attempts were abandoned in 1912. Rusty mine trucks and a collapsed trial adit at Millarodden are the visible signs left from this gold-mining period.

On islets named Reiniusholmane, just to the west, calcareous limestone and dolostone contain sulphide mineralisation, particularly one of the southern ones, called Sinkholmen. As the name implies, zinc is found here, in the form of sphalerite. It was discovered by Hoel and Orvin in 1913, and from 1924 to 1926 the Northern Exploration Co. Ltd. took out 386 tons of ore here. A little galena and some copper minerals are found along with the sphalerite.

Two coal seams crop out just above the Cretaceous-Tertiary boundary on Kolfjellet. They were sampled in 1906 and the Northern Exploration Co. Ltd. operated trial workings in 1918-19, 50-60 men spending the winter at Camp

Morton (then called Davis City). The company had high hopes, but the seams proved to have an irregular thickness and mining was abandoned.

Elsewhere, Lower and Middle Triassic shales sometimes contain large quantities of hydrocarbons, and three test wells for oil and gas have been drilled on the north side of Van Mijenfjord. In 1965, American Overseas Petroleum Ltd. drilled to a depth of 3500 m at Blåhuken, about 10 km ESE of Kaldbukta (just east of the local map, page 70), but only found traces of hydrocarbons. Norsk Polar Navigasjon drilled in 1967 outermost in Berzeliusdalen, but nothing of commercial value was found there, either. In 1985, Trust Arktikugol began drilling in the outer part of Vassdalen (between Berzeliusdalen and Kaldbukta), but stopped in 1988 without having found commercial quantities of oil or gas.

**Midterhuken, Nathorst Land**

The basement is exposed at Midterhuken where steeply dipping dolostone, often somewhat fractured, is exposed on the westernmost part of the headland. Further east, some phyllites also occur, sometimes containing a little graphite. The rock types greatly resemble those at Skjerpodden and Reiniusholmane on the north side of Bellsund.

Higher on the mountain, in the east, considerably younger strata of Carboniferous to Triassic age overlie the ancient basement erosion surface. Because they mainly dip eastwards, still younger beds, extending into the Tertiary, appear further east on the peninsula. All these strata are a continuation of those on the north side of Van Mijenfjord, and like there they are most strongly folded in the west. A thrust also transects the Carboniferous, Permian and Triassic in the west. The thrust movements were almost horizontal, and the beds overlying the thrust were displaced eastwards so that identical beds are seen at two different places (see the local map and section p. 70 and 71).

From the fjord near Mariasundet is a beautiful view southeastwards to the Tertiary folds in Permian-Triassic strata on Midterhukfjellet. It is clearly seen that the soft, shaley Middle Triassic beds were most easily folded, the underlying, hard, flinty Permian beds fracturing instead. When Midterhukfjellet is viewed from the southwest, dark, folded dolerite dykes probably strike the eye first. These have intruded the Carboniferous beds and been folded together with them.

The bay north of Eholmen displays some fine strandlines that lie considerably higher than the present shore, providing proof that the land has risen relative to the sea. Pieces of pumice, a porous volcanic rock that is so light it can float on water, are scattered on the surface of these beach ridges, especially on one that is about 11 m above present sea level. The pumice may have derived from submarine volcanic eruptions in the North Atlantic around 6500 years ago. The porous lava must have drifted ashore when the ice was still depressing the land, which was then 11 m lower than it is now.

In summer 1916, an area from Midterhuken eastwards was occupied by the Norwegian company, Spitsbergen Excret, because large quantities of guano were thought to be present there. Guano is an accumulation of seabird excrement deposited over a long period and is used as fertiliser. The Northern Exploration Company Ltd., however, protested about the occupation because it had already laid claim to parts of the area. Agreement was, nevertheless, reached between these companies and the Norwegian government in 1925 giving Spitsbergen Excret the right to limited extraction and shipping of guano. However, no work took place, probably because the deposits were smaller than assumed and therefore not profitable.

### East of Recherchefjorden – Recherchebreen

The boundary between the basement and younger sedimentary rocks passes just west of the top of Berzeliustinden, the highest peak in the area. A thrust is seen just south of the summit, like that near Midterhuken. Here, too, the overlying beds were displaced eastwards. The Tertiary folding is very distinct, especially in the Triassic beds at Aldegondaberget and Foldaksla, north and northeast of Berzeliustinden.

*Basement*

Comparison between the basement rocks around Antoniabreen and those on the west side of Recherchebreen reveals several differences. 1. No tillites have been seen in the east. 2. Up to 100 m thick quartzite beds are found in the east; in the west, most are less than 10 m thick. 3. Feldspathic, gneiss-like rocks with biotite are common in the east (e.g. east of the snout of Antoniabreen), but have not been seen in the west. 4. Dolomitic and calcareous limestones are found in both places, but only contain magnetite and haematite in the east. The metamorphosed basement rocks in the east, moreover, strongly resemble the lowermost, oldest strata further west - those underlying the Slyngfjellet conglomerate (just south of the Bellsund map). The higher metamorphic grade in the east also suggests that these are older, deeper strata.

*Carboniferous to Cretaceous*

Younger beds have been down-faulted and preserved on Reinodden, where they are in direct contact with the basement along a fault in the south. A walk along the shore takes us through a succession from Carboniferous in the southwest to Cretaceous in the northeast; the beds dip southwestwards, with the oldest ones uppermost because the sequence has been folded over into an inverted position. Among the fossils that can be found on Reinodden are plant fragments in the Carboniferous, corals in the Lower Permian, bra-

***Fig. 31 At Richardodden on the south coast of Van Keulenfjorden. Steeply dipping Triassic and Permian strata are exposed in the foreground, and behind them is patterned ground on raised strandlines.***

chiopods, sponges and moss-animals in the Upper Permian, and bivalves and ammonites in the Triassic and Jurassic.

*Minerals*

In 1911, Birger Jacobsen found iron ore deposits in the basement on the east side of Recherchefjorden, which he thought were valuable. This ore in Martinfjella consists of magnetite and haematite in beds that were precipitated on an ancient sea floor along with carbonate rocks. All the investigations by Norwegian and Swedish mining engineers in 1912-16 concluded that no commercially viable deposits had been observed.

The Northern Exploration Co. Ltd. investigated the deposits in 1918 and the reports were extremely optimistic, the complete opposite of the earlier assessments by others. For instance, it is stated that "the iron deposits beside Recherchefjorden are without parallel in the world and practically inexhaustible." Two houses were built near the shore west of Jarnfjellet. One is still standing (in 1993) and 600 m to the north are the remains of foundations for a proposed overhead cableway up to the ore horizon. More detailed investigations in 1919 by the company geologist, Charles W. Boise, led to the conclusion that the ore deposit had no commercial significance. Preparations to begin mining were therefore abandoned and have never been taken up since. Small quantities of iron ore have also been found about 1 km southwest of Berzeliustinden, east of Antoniabreen, and a small galena and sphalerite deposit is known on the east side of Martinfjella.

## West of Recherchefjorden – Recherchebreen

*Basement*

The oldest beds are found in the ridges just west of the Recherchebreen glacier. The strata dip towards west-southwest and are strongly folded, and therefore not always easy to follow. Conglomerates with phyllitic beds occur at the base and are overlain by calcareous and dolomitic marbles. These rocks are interfolded and are exposed at several places, including the Ramondbreen glacier, about 5 km south of Observatoriefjellet. The conglomerates form an important key horizon which can be traced almost continuously southwards towards Hornsund. Their total thickness varies, sometimes reaching several hundred metres.

More or less strongly metamorphosed lavas and ashes overlie the marbles, and there are minor intrusions, including plugs, of dark, olivine-bearing plutonic rocks, for instance on the shore northwest of Observatoriefjellet. Basic dykes cut the marbles on Observatoriefjellet (Fig. 32). The basic rocks often contain veins and dykes of serpentine, a magnesium-rich mineral. A fibrous variety, asbestos, is sometimes found, one occurrence on the headland of Asbestodden at the entrance to Chamberlindalen containing so much that a Norwegian company, A/S Kulspids, attempted to work it in 1917-19. The asbestos was, however, mixed with other minerals and the venture was not profitable.

Tillites are among the youngest basement strata in the area. They date from the end of the Proterozoic and are found in a large area between Chamberlindalen-Dunderdalen and Bellsund. They were deposited during a widespread ice age about 600 million years ago and contain numerous clasts of dolostone, and also some quartzite and other rock types. The clasts vary in size from a few centimetres to over one metre. They consist of material eroded from bedrock during this Proterozoic ice age and transported by glaciers to be deposited as moraine.

Along with the tillites are some well-bedded sandstones which must have been deposited in water, probably in glacial meltwater rivers. Some tillite beds contain metre-large boulders in a phyllitic matrix. These are probably what are termed drop tillites, the boulders having been dropped into sea-floor mud when calving glacier ice drifting out to sea melted.

The tillite is well exposed along the shore at Kapp Lyell and west of Calypsobyen where it is in direct contact with coal-bearing Tertiary sandstone and conglomerate. The age difference between these rock types, which sometimes resemble one another, is more than half a billion years!

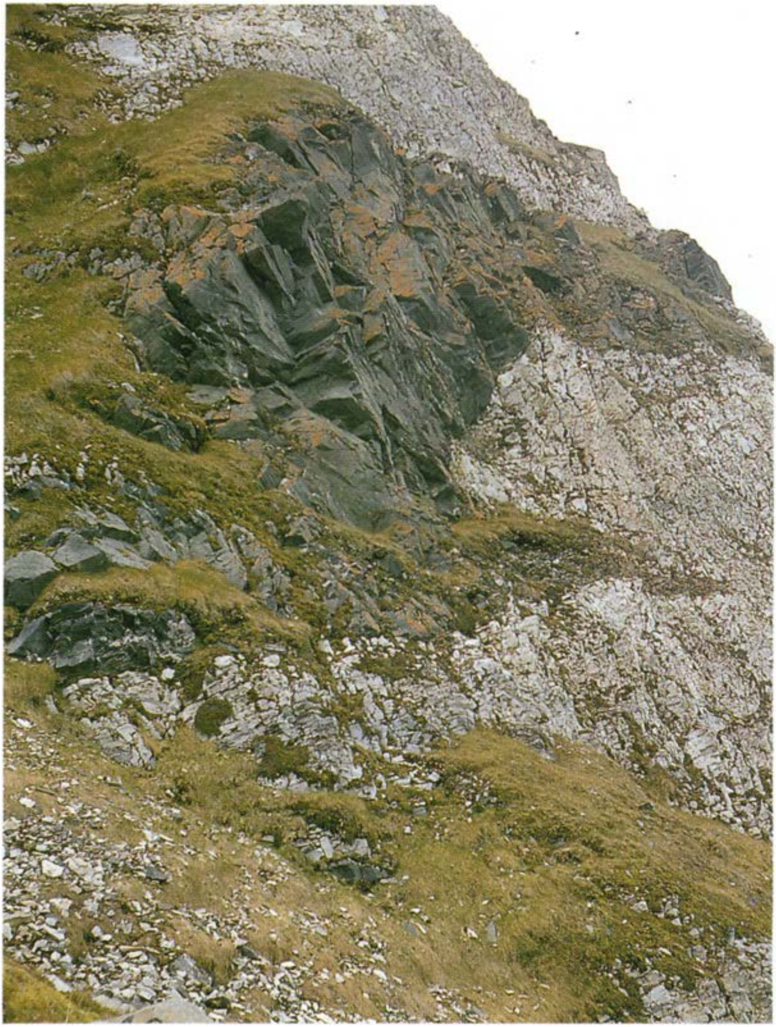


***Fig. 32** Dark gabbroic rock has intruded limestone; both are late-Proterozoic in age. The north side of Observatoriefjellet beside Recherchefjorden.*

The reason for the Tertiary sandstone suddenly appearing here in the basement area is that it has been down-faulted, thereby being protected from removal by erosion. The fault trends southeastwards from Skilvika. The Tertiary beds at Calypsobyen were deposited later than those in the major syncline further east.

*Tertiary coal*

In 1919-20, the Northern Exploration Company Ltd. carried out surveying and trial working of coal deposits in the Tertiary beds at Calypsobyen. A storehouse and radio station were built, but after 133 tons of coal had been mined the field was declared unprofitable. The storehouse and a 30 ton lighter are still standing close to the shore, and the remains of a gallery can be seen southwest of the storehouse.

*Was Svalbard discovered in the 9th century?*

Polish scientists have found traces of human activity, including pottery shards and fragments of charcoal, bone and woolen clothing, in peaty material beneath the moraine in front of Renardbreen. A radiocarbon dating of the peat has given an age of 1130 ± 80 years, signifying that it may have formed around AD 850. It is reasonable to assume that the shards, woolen clothing and so on are equally old. However, there may be substantial sources of error in the date. For instance, contamination from small amounts of Tertiary coal dust would give the peat an excessive age. Hence, for the moment many scientists doubt whether people have visited Bellsund as early as the 9th century.

## SVEAGRUVA - REINDALEN

This area, located near the eastern flank of the major syncline in southern Spitsbergen, only has sedimentary rocks of Cretaceous and Tertiary age.

*Coal and oil*

In 1910, a Swedish expedition occupied an area innermost on the north side of Van Mijenfjorden, where Tertiary coal seams occur. A company called Aktiebolaget Isfjorden-Bellsund was set up in 1911 and preparations for mining began, but coal prices were so low that mining did not start. When the First World War broke out, the price rose sharply and AB Spetsbergens Svenska Kolfält was set up to run the mine. In 1917-18, 50 workers were employed and 4000 tons of coal were produced. Output increased to 52,000 tons in 1920-21 when 201 people wintered there. Coal prices dropped during the 1920's and, like the other mining companies in Svalbard, AB Spetsbergens Svenska Kolfält ran into financial difficulties. A new company was formed and the Swedish government contributed funding, but even

*Fig. 33 Sveagruva, looking north.*

*Fig. 34 Drilling for oil in inner Reindalen in winter 1991.*

though output increased to 116,000 tons in 1924-25, the colliery ran at a loss. Working ceased following a fire in the mine in 1925.

In 1934, the colliery was sold to Store Norske and following surveying and other preparatory work in 1935-38, the intention was to start working it again in autumn 1940. The outbreak of war made this impossible and the colliery was attacked and its surface plant completely destroyed by fire in 1944. Following re-building, Store Norske began working it again in 1946 and output in 1947-48 reached 79,000 tons. Because of difficulties with water in the mine and a poor market for coal, production stopped again in autumn 1949.

New investigations began in Sveagruva in 1970, and plans for re-opening the colliery were drawn up in 1975. These included new housing, a 680 m long landing strip, coal storage facilities and a conveyor belt from there to a new wharf at Kapp Amsterdam. The survey showed predicted reserves of at least 20 million tons, 7.5 million of which were confirmed. There are two important seams, the Svea seam which is often around 2 m thick and the Todal seam. Annual output in the event of full production was estimated to be more than 500,000 tons. This original plan stated that "If Sveagruva is opened, it will give future generations the key to the most significant coal deposits in Svalbard." Some constructional work and plant modernisation were carried out, and mining started on a small scale. Low coal prices have so far prevented normal operation, and only exploratory working employing a few workers has taken place since 1987.

Store Norske has done a great deal of core drilling, using diamond drilling rigs, in what is called Sentralfeltet (the Central Field), between Sveagruva and Reindalen. Because this area is largely glacier-covered, it has often been necessary to drill through thick glaciers to reach the coal-bearing beds. The field covers 17 km² and preliminary results show that the seam is 3 to 5 m thick over large areas. It is estimated that 540,000 tons of coal can be produced annually and that the total workable reserves are around 25 mill. tons. The ultimate results of the investigations will determine whether the Central Field will be put into production. Local and global environmental consequences must also be weighed against the economic and political advantages of mining operations. If it is decided to go ahead with working the field, a road and a power line will probably be built from Longyearbyen to Svea.

Store Norske, Norsk Hydro and the Swedish concern, Petro Arctic, are co-operating on exploration for and possible future exploitation of hydrocarbons (oil and gas). Investigations have revealed an enclosed stratigraphical structure at the head of Reindalen. This can best be described as a fairly large, hat-shaped updoming of the beds, where possible oil and/or gas might have risen and been concentrated uppermost. The geologists thought that two possible reservoirs might have been present in the structure, which is about 20 km long and 4 km broad. Drilling to the basement at 2315 m in 1991, however, gave a negative result.

*Fig. 35 A pingo in inner Reindalen.*

As with other industrial activities in Svalbard, the authorities ensured there would be as little erosion and wear and tear of vegetation and soil cover, pollution, waste dumping and disturbance of wildlife as possible. To avoid vehicle tracks causing extensive damage, transportation of heavy drilling equipment for the drilling in Reindalen was carried out in winter on frozen ground along the river beds in Kjellstrømdalen and Lundstrømdalen.

*Glacial advance and permafrost*

One of the large glaciers, Paulabreen on the south side of Van Mijenfjorden, has had several major advances, the last one less than 600 years ago when it advanced 20 km to cross the entire fjord and bulldoze sea-floor material right up onto the north side. In doing this, the glacier blocked the outlet of Kjellstrømdalen, creating a lake there. The Damesmorena, southwest of Sveagruva, between the fjord and Liljevalchfjellet, is now clear evidence of this glacial advance. 600-year-old driftwood logs have been found inside this moraine, which has a core of old ice. On the inner side of the moraine, nearest to the mountain, shelly marine clay has been pushed up from the floor of Van Mijenfjorden.

In summer, the rivers in Kjellstrømdalen flow rapidly carrying large quantities of meltwater from melting snow and glaciers further east. The rivers transport a great deal of sand and mud, most of which is deposited at the head of Van Mijenfjorden. This creates difficulties for shipping, because new mud is continually being deposited and depths may change significantly in the course of a few years. The port for Svea is situated at Kapp Amsterdam, about 4 km southwest of the settlement. Another problem for shipping is ice in Van Mijenfjorden. This often lies far in to the spring because Akseløya blocks the fjord entrance hindering it from drifting out.

In 1978, an automatic recording station to study permafrost was set up in Sveagruva. Data about permafrost in Svalbard are collected here to show how it is related to meteorological factors and ground conditions. Such data are useful when projecting the construction of buildings and infrastructural facilities. One example is the power station at Sveagruva which has been constructed in a rather unconventional manner. To prevent thawing and movements in the ground beneath, the building has been placed on an artificially cooled sole. The heat released by the refrigeration plant is conserved and used to heat the building.

In inner Reindalen are some of the largest and most typical pingos in Svalbard (Fig. 35). One reaches 42 m above the alluvial plain and is the highest pingo known in Svalbard. Another here has a depression in its top containing a beautiful small lake. There are also several pingos in Kjellstrømdalen. A relatively large one is situated at the entrance to the valley on the south side of the river, about 7 km east-northeast of Sveagruva.

*Fig. 36 Proterozoic phyllite with beds of quartzite south of Signehamna in Lilliehöökfjorden. The easily disintegrating phyllite, along with bird lime, produces luxuriant slopes.*

## NORTHWESTERN SPITSBERGEN

(NORTH OF ISFJORDEN, WEST OF WIJDEFJORDEN)

In contrast to southern Spitsbergen, the youngest rocks are very scarce in this area and four-fifths of the bedrock dates from before the Mesozoic. The only large continuous areas of gneissic, migmatitic and granitic rocks in the western part of Spitsbergen occur north and northeast of Kongsfjorden.

The largest areas of Devonian rocks in Svalbard are located in northwestern Spitsbergen. Here, late in Devonian time, elongated north-south oriented portions of the Earth's crust began sinking relative to neighbouring tracts to form a number of grabens in which Devonian rocks were protected from erosion. The major faults trend along Raudfjorden, Monacobreen and Isachsenfonna in the west, and Wijdefjorden in the east. Some of the Devonian strata are gently folded, whereas overlying Carboniferous beds remain virtually undisturbed, suggesting that there was an episode of gentle folding in late-Devonian time. The folds trend about

*Fig. 37 A vertical aerial photograph of Moffen taken in 1990 using infrared film. The island is 3.5 km long, north-south.*

north-south, approximately parallel to the earlier Silurian folds.

Apart from a few small areas of Tertiary and Quaternary volcanics there are few igneous rocks within the large areas of Devonian bedrock. Some minor intrusions emplaced in the Carboniferous period, about 315 million years ago, have been found at Vestfjorden on the west side of Wijdefjorden. They were clearly affected by later earth movements, perhaps in Cretaceous to Tertiary time.

North of Isfjorden, Cretaceous and Tertiary rocks are found in a few small areas on the northern margin of the great central basin of Spitsbergen. Tertiary beds also occur further north at Forlandsundet and Ny-Ålesund where they have been protected from erosion by down-faulting.

Reinsdyrflya is the largest and most prominent strandflat on the north coast of Svalbard. This plain is more than 300 $km^2$ in area and its highest point is about 50 m.

North of the entrance to Woodfjorden is a small island, Moffen, which consists exclusively of sand and gravel, completely devoid of bedrock. Moffen, which is a nature reserve, is no more than about 2 x 3 km, and stands only a few metres above sea level. The island has a lagoon into which the sea pours through a narrow opening in the west.

*Basement*

Precambrian rocks are only found in a few small areas. 1. The valley floor in innermost Gipsdalen where erosion has removed Carboniferous-Permian strata to reveal a "window" of basement beneath. This consists of folded phyllites and mica schists on which Carboniferous and Permian strata were subsequently deposited. 2. In the fault zone between Billefjorden and Wijdefjorden where the basement has been uplifted in some places, for instance just north of Pyramiden.

*Devonian*

Almost 1000 m of sedimentary rocks deposited in fresh and brackish water are found in the "classical" area that was studied in the early days. Place-names such as Fiskekløfta (Fish Gully) and Planteryggen (Plant Ridge) indicate which fossils can be found. The deposits on the west side of Billefjorden and at the heads of Dicksonfjorden and Ekmanfjorden belong to the Lower Devonian Wood Bay Formation and largely comprise red siltstone, conglomerate and some shales. Beds of Middle and Upper Devonian sandstone and siltstone are exposed in Mimerdalen, west of Pyramiden. Near the faults at Billefjorden, the Devonian beds are strongly folded, whereas further west, near Dicksonfjorden and Ekmanfjorden, they remain almost horizontal.

*Carboniferous-Jurassic*

The, comprising sandy, continental Lower Carboniferous beds grading into marine Upper Carboniferous, Permian, Triassic and Jurassic strata can be looked upon as a continuation of corresponding formations south of Isfjorden.

The early Carboniferous strata contain seams of coal and are found in inner Gipsdalen, around the head of Billefjorden and on some peaks east of Dicksonfjorden. They are lacking in some places because of faulting, e.g. on Lykta, innermost on the east side of Dicksonfjorden; 5 km to the east, the Lower Carboniferous sandstone is preserved on Citadellet. Both these mountains have a characteristic "top hat" of hard, Upper Carboniferous limestone.

Intensive faulting took place in the Billefjorden Fault Zone in mid-Carboniferous time, including rift formation just east of Pyramiden. The east side was down-faulted and eroded material was transported eastwards from the higher areas in the west and deposited in the depressions that formed (page 125).

The late Carboniferous, and Permian strata largely show evidence of having been deposited under desert-like climatic conditions in an environment where sea water evaporated in disconnected basins. Sulphates were formed through chemical reaction between sea water and carbonate-bearing deposits, and are now represented by layers of gypsum and anhydrite.

***Fig. 38 Tarantellen, between Billefjorden and Wijdefjorden, viewed from the south. Light-coloured Carboniferous beds are seen in the foreground. The mountains behind consist of metamorphosed Precambrian rocks, including quartzite, amphibolite and gneiss.***

Conditions were probably quite like those now found in the Persian Gulf. The Billefjorden-Sassenfjorden district has all of about 800 m of Carboniferous-Permian deposits containing numerous layers of gypsum and anhydrite, ranging from a few cm to about 50 m in thickness. Trollfuglfjella, west of Dicksonfjorden, has a good section through 160 m of dolostones and beds containing gypsum and anhydrite dating from Permian time; almost half the total thickness consists of sulphates. Massive beds up to 5.5 m thick occur, the remainder being mostly dolostone with algal structures. Fossil snails are also found. Kongressfjellet and Tschermakfjellet offer unusually good sections through the Triassic beds which dip gently southwards here. Like the classical Festningen section at Grønfjorden, these draw many geologists. A continuous section through a 500 m thick succession of shales and siltstones is easily accessible, revealing fossils of fish, Icthyosaurs, ammonites and bivalves. Saurieberget and Kapp Thordsen, a little further east, are also well worth a visit.

Igneous rocks in the form of dark sills were intruded into the sedimentary rocks around the transition from Jurassic to Cretaceous. These dolerites are clearly visible around the entrance to Billefjorden and from Ekmanfjorden northwestwards, often forming dark, steep caps to ridges and nunataks.

The pressure exerted on western Spitsbergen in the Tertiary was transmit-

*Fig. 39 Permian strata on Templet. Hard siliceous beds belonging to the Kapp Starostin Formation form the upper part of the cliff, the softer Gipshuken Formation being largely concealed beneath the screes below. Viewed towards northeast from Sassenfjorden.*

*Fig. 40 Skansen on the west coast of Billefjorden. Gypsum-bearing beds in the Gipshuken Formation are seen in the lower part and the Kapp Starostin Formation forms the upper slopes. Dalen Portland Cementfabrik operated a gypsum mine in 1918 at Skansbukta, behind the scree on the left.*

ted eastwards resulting in a series of thrust faults north of Isfjorden, where strata were pushed upwards as sheets one above the other from west towards east. The thrust planes in this area seem to be particularly localised to the soft shales of the Middle Triassic and the Late Jurassic- Early Cretaceous.

*Quaternary and landscape features*

Mathiesondalen, east of Billefjorden, has several underground caves and passages. These are karstic features produced by circulating groundwater dissolving the rock which, here, consists of layers of gypsum and anhydrite. To enable this to take place the ground must be warmer than is normal in Svalbard, perhaps because the area is close to a fault zone that can act as a routeway for terrestrial heat from depth.

The roofs of some of these caves have collapsed forming hollows and depressions on the surface, called dolines. On the south side of the sandbank at the entrance to the valley is a lake that in summer has an outlet to the sea by way of a quite strongly flowing river. It is impossible to see where this water originates because no rivers enter the lake. Groundwater probably pours through caverns, reaching the surface on the lake floor.

Some peculiar rocks are found in Mathiesondalen. They are so young it is almost possible to watch them forming as dissolved lime is precipitated from water running and percolating through sand, gravel and moraine. The lime is gradually hardened binding the material to form sandstone, conglomerate and tillite.

Good examples of raised strandlines occur in such locations as the entrances to Billefjorden, Dicksonfjorden and Ekmanfjorden, and outermost in Gipsdalen (Fig. 41). At Billefjorden, the land may have been raised about 90 m since the ice retreated. The age of the higheast strandlines has not been determined with certainty, but a radiocarbon date on driftwood shows that that particular log reached the shores of Billefjorden 10,000 years ago, and many shells found above till in sections have given the same age. Further out along Isfjord, land uplift has been less pronounced and at Ekmanfjorden its maximum has been measured at 62 m. The same variation in height from east to west is shown by accumulations of porous lava, pumice, which drifted ashore 6500 years ago. They are higher in the east than the west. There is at present little or no land uplift in this part of Svalbard.

Glacial advances during the last Ice Age scraped away most of the older Quaternary deposits, but some are preserved. At Kapp Ekholm on the east side of Billefjorden, a section through superficial deposits shows evidence of three advances of major ice sheets prior to the last Ice Age. Outermost on the east side of Dicksonfjorden, north of Lyckholmdalen, marine sediments have been found containing shells that may be 120,000 years old or more. These are of a type that must have lived in warmer water than is now found around Svalbard. There have also been later periods when the climate was

***Fig. 41 Gipsvika in Sassenfjorden. Raised strandlines extend up to about 75 m above sea level, the highest ones being formed about 10,000 years ago. The photograph also shows Gipsdalselva which deposits glacial mud in the fjord, and gravel fans built up by two other glacial meltwater rivers. To the right of Gipsdalselva is a road that was used when coal deposits at the head of the valley were being investigated. This vertical aerial photograph was taken on infrared film in 1990 and the colours have been manipulated with to show vegetation-covered areas in orange. The area shown measures 3.6 x 3.8 km.***

more favourable than today, and the common mussel *(Mytilus edulis)* and other warmth-demanding species have been discovered showing that they lived here between 4000 and 9000 years ago. This part of Svalbard has probably had particularly favourable living conditions for these species.

### *Mines and prospects*

Gypsum and anhydrite are found at several places around Isfjorden, mainly in Lower Permian strata. As early as 1911-12, the Swedish company, AB

Isfjorden-Bellsund, extracted gypsum on both sides of Billefjorden, and Dalen Portland Cementfabrik began mining at Skansbukta on the west side of Billefjorden in 1918. However, more anhydrite than gypsum was found as the workings got deeper, and mining was abandoned.

Mining of phosphoritic Triassic beds has also been attempted. The 1914-18 World War led to a lack of phosphate fertiliser in Norway and the Ministry of Agriculture sent an expedition to Kapp Thordsen to investigate the feasibility of working the phosphorite. Mines were established and operated for a short period, but the deposits were too small to be profitable. Remains from the mining activities can be seen near the shore 6 km northwest of Kapp Thordsen and also 5.5 km east-northeast of the cape on the south side of Saurieberget. That phosphorite is a good fertiliser is seen on the west and south slopes above Isfjorden, where the vegetation is particularly luxuriant.

In 1910, the Pyramiden area was annexed by a Swedish expedition, on behalf of AB Isfjorden-Bellsund. Investigations in the area from 1911 to 1916 showed that the Lower Carboniferous strata contained sufficient good quality coal to justify mining. Following an agreement reached in 1926, the rights were transferred to Russian interests, the Swedes obtaining an area near the present Sveagruva in exchange. Following new surveying and preparations, mining started at Pyramiden in 1940-41. The war brought a stop to the work and production did not resume until after 1945. Pyramiden is now the only mine working north of Isfjorden. The Russian company, Trust Arktikugol, has had an annual output of around 200,000 tons of coal in recent years.

The Lower Carboniferous coal-bearing beds also continue east of Billefjorden, and the Scottish Spitsbergen Syndicate carried out investigations here from 1912 to 1922, both mapping and core drilling. Coal was found at Brucebyen and innermost in Gipsdalen. Preparations were made to work it, but prices in the 1920's were so low that the plans were abandoned.

In the 1980's, the coal deposits in Gipsdalen were again investigated and a British company carried out work in 1990-91 with a view to starting new mining later near Norströmfjellet in the inner part of the valley. An annual output of 1.4 million tons of coal was foreseen, more than the Norwegian and Russian mines together. These plans were over-optimistic and the project is not expected to materialise.

A consequence analysis has been carried out to judge how mining would affect the natural environment in the area. On the basis of these results, plans will be prepared to ensure that any mining development in Gipsdalen will take place in a way that as far as possible avoids damaging the natural environment. This concerns both tracks which can lead to erosion and destruction of vegetation, and disturbance of animal life because of traffic and pollution. Among the geological features that are worth protecting are very fine old beach ridges and patterned ground in the outer part of the valley (Fig. 41), and the inner part has rare types of moraine.

***Fig. 42 Part of the Russian mining town of Pyramiden, looking north.***

## THE ENTRANCE TO ISFJORDEN - PRINS KARLS FORLAND - ENGELSKBUKTA

*Basement*

The rock types strongly resemble those found south of Isfjorden, with shale, limestone, sandstone and tillite as the most common ones. Tillites found on both sides of Forlandsundet are very like those at Bellsund, and a conglomerate at Fuglehuken on the northern tip of Prins Karls Forland was probably formed at the same time as similar conglomerates between Bellsund and Hornsund.

In common with southern Spitsbergen, Tertiary folding and faulting have left their mark on the area along the west coast and pressure from the west has uplifted and exposed the basement. As the westernmost point of Svalbard, Prins Karls Forland was particularly exposed to these plate movements, and faulting is a pronounced feature of the geology. The island is essentially an elongate, uplifted block flanked to both east and west by depressions. In the basement of Forlandet, fossils have only been found near the northern end. They are microfossils, including bacteria, and these minute traces of early life probably date from the very latest Proterozoic, immediately prior to Cambrian time.

An area south of St. Jonsfjorden contains rocks that are alien and rare in Svalbard. They include eclogite and blue schist, which are rocks with combinations of minerals which show that they crystallised under extremely high pressure, deep in the Earth's crust. The pressure was probably around 20 kilobars, which represents a depth of about 60 km, and the temperature must have been close to 600°C. This metamorphism probably took place because rocks from the upper part of the Earth's crust were forced down to a great depth during a collision between the North American-Greenland and Northwest European continental plates. The high-pressure rocks became exposed when erosion removed the overlying rocks. Fossiliferous Upper Ordovician-Silurian beds were then deposited on the erosion surface. The collision must therefore have taken place before these beds were deposited. Age determinations of the high-pressure rocks suggest that the metamorphism took place in early Caledonian time, about 470 million years ago. On the central part of Motalafjella north of the Eidembreen glacier, and on Bulltinden and Holmesletfjella just south of St. Jonsfjorden, fossil snails, brachiopods, sea lilies and corals can be found in Ordovician and Lower Silurian beds. They are not as well preserved as fossils in beds above the basement; usually only fragments are found.

Volcanic rocks occur in the basement at Trollheimen near the innermost part of Eidembreen. They are dark lavas and tuffs, and the relationship between these and the other basement rocks in the neighbourhood is not fully clarified.

*Carboniferous*

Along the coast between Isfjorden and St. Jonsfjorden is a narrow strip of Upper Carboniferous sedimentary rocks. It is broadest in the south where it reaches about 1.5 km; in the north, it is only a few hundred metres wide. This Carboniferous wedge was preserved when the basement was raised on either side during the Tertiary. Just west of the moraine at the snout of Eidembreen a river cutting reveals severely crushed rock marking a fault boundary between the Carboniferous strata and the basement in the east. West of this fault, Upper Carboniferous fossils can be found, mostly corals, sea lilies and sponges. These are often rose-coloured because the original shell material of the animals has been partially replaced by jasper. A small iron ore deposit is found on the northern tip of Hamnetangen, about 15 km north of Daudmannsodden. Haematite occurs here as lenses and small grains in brecciated Carboniferous beds. Since the largest lenses only contain a few tons of ore, the deposit has no economic significance.

Another small wedge of Carboniferous rocks is found at the upper end of Eidembreen, on Trollslottet. Upper Carboniferous beds also appear on Vegardfjellet, innermost on the south side of St. Jonsfjorden, and have the same kinds of rose-coloured fossils as near Eidembreen.

*The Great Trench*

As a consequence of earth movements oblique to the Svalbard block, a large trough or graben formed along Forlandsundet during the early Tertiary. Several thousand metres of sediment were deposited there during the Tertiary, most of it now being beneath sea level in the sound. These beds contain few fossils and their age is uncertain, but they are younger than most of the strata in the major syncline in southern Spitsbergen. The youngest and uppermost beds are probably Middle Tertiary, approximately 35 million years old. The northern end of Forlandsundet mostly has shallow-marine deposits, otherwise the sediments are mainly fluvial and littoral (shore) deposits, sandstones and conglomerates, and they lie directly on the basement.

*A peculiar conglomerate*

About 12 km south of the north end of Prins Karls Forland is Sutorfjellet, a small area on the west coast noted for conglomerates. Some clasts in this Sutorfjella conglomerate are extremely large, up to a couple of metres in diameter, and they are often more or less angular. Some have a reddish weathering colour. No fossils have been found in it and its age is unknown, both Proterozoic, Devonian and Tertiary having been proposed. Structures in and near the conglomerate are almost identical with those in surrounding Proterozoic rocks and the conglomerate is probably about the same age as those.

*Minerals*

On the south side of St. Jonsfjorden, copper minerals, mostly chalcopyrite, have been found at Copper Camp. They occur along a fault in limestone, about 300 m from the shore.

Stratified iron ore comprised of magnetite and haematite is found on Bouréefjellet on the northeast part of Prins Karls Forland, and greatly resembles the deposits on Malmberget, north of Bellsund, and Jarnfjellet, south of Bellsund (page 77). This deposit is situated in an area with glaciers and its size is difficult to assess. It was investigated by the Scottish Spitsbergen Syndicate Ltd. in 1920, but access is difficult and the company did not consider it economically justifiable to start mining.

Norsk Polar Navigasjon drilled at Sarstangen, near the middle of the graben, in 1974. Tests showed gas flowing from the borehole at a rate of about 3800 $m^3$ per day and this was not thought adequate for profitable exploitation.

*Quaternary and landscape features*

The landscape forms in this coastal and fjord district are influenced by the trends of Caledonian and Tertiary folds and faults, which are generally north-south. Both the coastline and rows of mountains often follow this di-

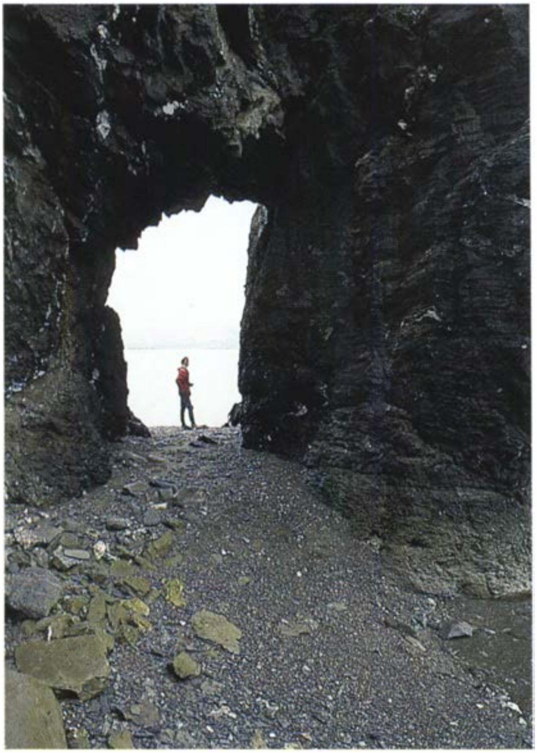


***Fig. 43 A shore cave on the south side of Engelskbukta, south of Ny-Ålesund.***

rection. The coastal mountains, comprised of folded rocks, are often sharp and jagged, whereas the younger, horizontal sedimentary rocks along the fjords give rise to pyramidal or plateau-topped mountains. On the south side of Sarsøyra is a small area with unusually young folds where folding has taken place locally as recently as in the Quaternary, perhaps only a few hundred years ago. When Aavatsmarkbreen was undergoing a westward advance then, it compressed poorly consolidated Tertiary sandstone, giving rise to folds with a north-south axial trend.

The largest strandflats in the area are Daudmannsøyra on the north side of the entrance to Isfjorden, Forlandsletta in the southern part of Prins Karls Forland and Sarsøyra south of Engelskbukta. Sarstangen continues as a submarine sand and gravel bank across Forlandsundet in the direction of Prins Karls Forland and the sound is only a few metres deep there.

On the west side of Prins Karls Forland are some of the largest rock glaciers in Svalbard. A possible explanation is that this area on the margin of

Svalbard may have been ice free for a long time, perhaps 40,000 years, so that the formation of the rock glaciers was able to persist undisturbed by glacial erosion. During the last Ice Age, the ice cover was probably not continuous here, but just consisted of valley and fjord glaciers which began retreating more than 13,000 years ago. Radiometric age determinations of shells from old shore deposits on the northeast side of Prins Karls Forland have given ages of more than 30,000 years. That these shore deposits have not been removed by glacial erosion may signify that the area has been ice free throughout this period.

## THE KONGSFJORDEN AREA (local map Ny-Ålesund, page 98-99)

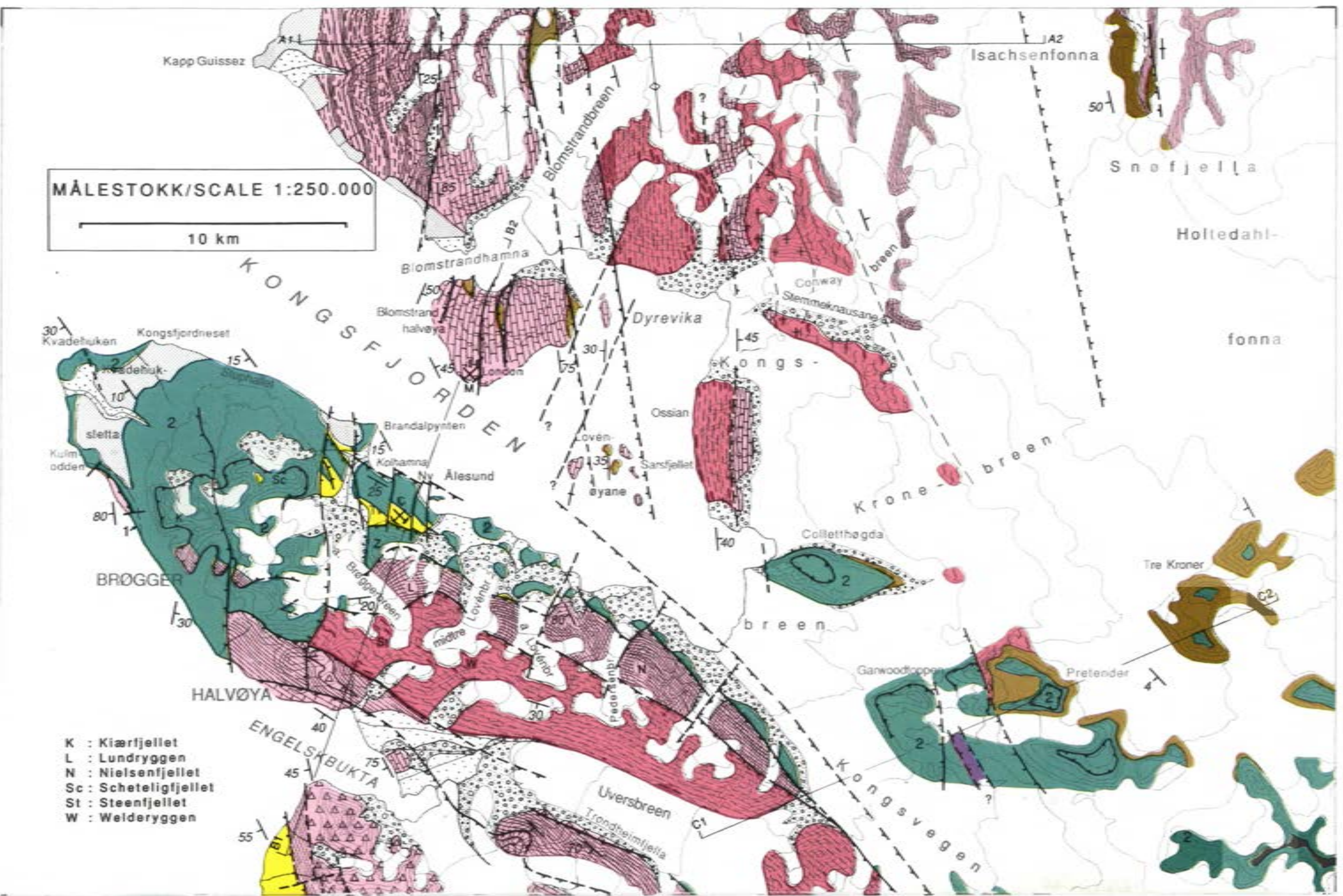
### Brøggerhalvøya

The peninsula of Brøggerhalvøya is situated in the region of Svalbard most strongly affected when Greenland was pressed obliquely against Svalbard at the transition between the Cretaceous and Tertiary. The entire peninsula shows abundant evidence of a great deal of thrusting having taken place, largely from SSW towards NNE. Older strata have sometimes been pushed over younger ones, reversing the original order. A thrust that is easily accessible from Ny-Ålesund is situated at the northern foot of Zeppelinfjellet where Carboniferous rocks are thrust over coal-bearing Tertiary beds, the rocks being clearly brecciated and crushed in the thrust zone.

*Basement*

The southeastern part of Brøggerhalvøya is dominated by basement rocks that were folded in Silurian times and had probably undergone folding and metamorphism earlier, too. In the mountains facing the Kongsvegen glacier and the innermost part of Kongsfjorden, the basement mostly consists of phyllites with beds of quartzite. These are, for instance, found on the summits on the west side of Kongsvegen where Brøggerhalvøya begins and on Lundryggen 3-4 km south of Ny-Ålesund. More strongly metamorphosed rocks, such as mica schists with garnet and amphibole and some beds of marble, occur south of the phyllites. The mica schist contains scattered lenses and veins of granitic rocks, for example in the Steenfjellet - Welderyggen area, and seems to overlie the phyllites. The higher metamorphic grade, however, suggests that it originally belonged to more deeply buried strata and was formed before the phyllite. A possible explanation is that the mica schist has been thrust onto the phyllite.

Such thrusting is very obvious a little further southwest where basement which normally forms the substrate for the Carboniferous and Permian beds has been thrust over these to occupy the summits of Kjærfjellet and Brøggerfjellet. South of the mica schist, near Engelskbukta, tillite and other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Blomstrandhalvøya
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Kvadehuken
Kongsfjordneset
sletta
Kulmodden
Brandalpynten
Kolhamna
Ny Ålesund
Dyrevika
Conway
breen
Stemmeknausane
Kongs-
Ossian
Sarsfjellet
Lovén-
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Krone-
breen
Collettthøgda
Tre Kroner
Pretender
Garwoodtoppen
Kongsvegen
BRØGGER
HALVØYA
ENGELSKBUKTA
Uversbreen
Trondheimfjella
Pedersenbr.
K : Kiærfjellet
L : Lundryggen
N : Nielsenfjellet
Sc : Scheteligfjellet
St : Steenfjellet
W : Welderyggen

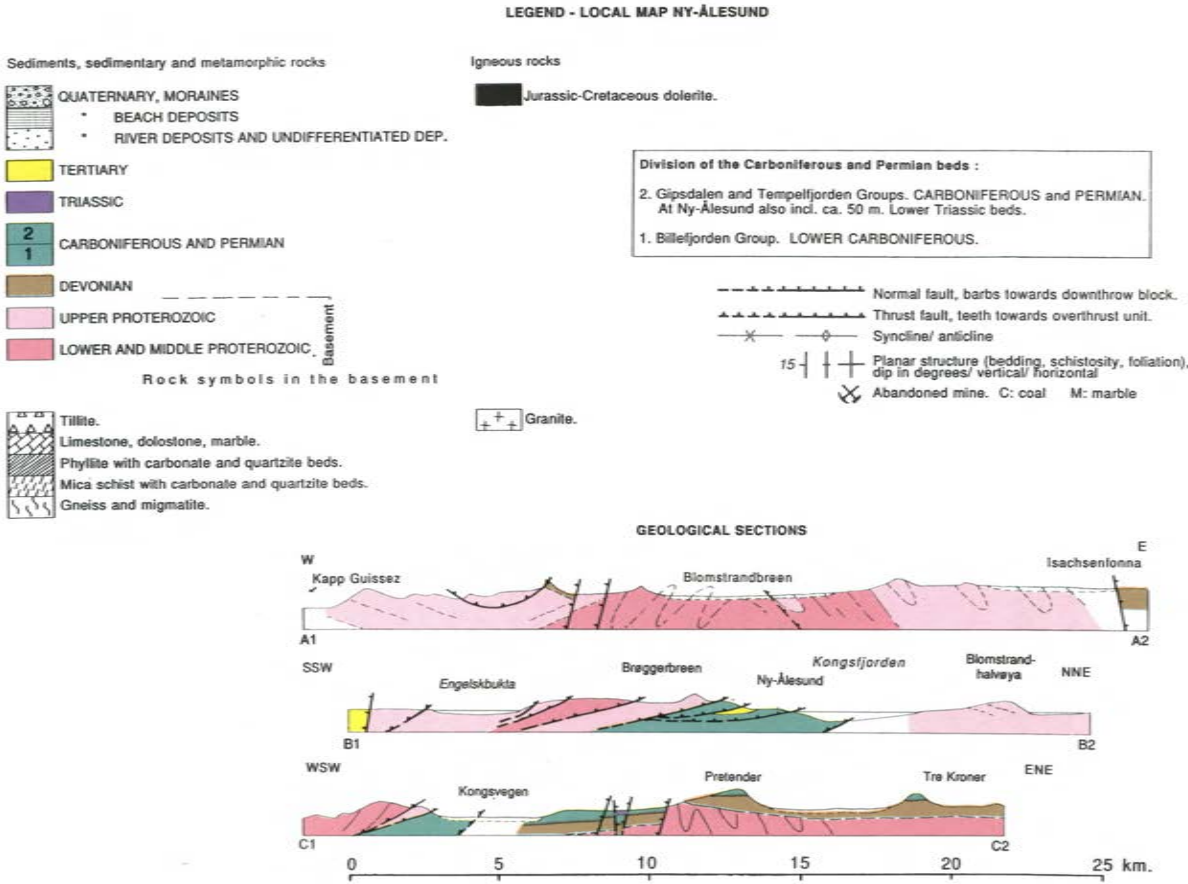



Fig. 44 Ny-Ålesund.

beds that probably belong uppermost in the basement have been down-faulted to abut against the mica schist.

*Carboniferous and Permian*

The north side of Brøggerhalvøya has practically nothing other than sedimentary rocks of Middle and Upper Carboniferous and Permian age. Lower Carboniferous deposits are only seen in the far northwest around Kulmodden, where 200-250 m of sandstones overlie the eroded surface of the basement. In the lower part of this sequence is a 3 m thick layer of shale mixed with impure coal seams. Core drilling through these seams 2.5 km southeast of Kulmodden showed the coal to be too thin and impure here (Fig. 45).

The mid-Carboniferous climate was dry, and reddish sands and gravels were deposited on alluvial plains near the sea, subordinate calcareous and dolomitic beds deriving from deposition in shallow marine environments. Reddish sandstones seen along part of the coast between the headlands of Brandalpynten and Kongsfjordneset, and also just east of Kvadehuken, date from this period. Such rocks are found near Brøggerbreen, the glacier just south of Ny-Ålesund, and the strong red colour of the glacial meltwater river here and in many other rivers and streams near Ny-Ålesund is actually derived from desert sand formed when Svalbard was situated at the same latitude as the North African deserts today.

Deposits from the latter part of the Carboniferous period and from the Permian show clear evidence of having been deposited in shallow marine areas in a wetter climate. The animal and plant life varied, but was mainly rich, and fossil brachiopods, corals, moss-animals, siliceous sponges and sea lilies are frequent. Among elsewhere, they can be examined on the lower eastern slopes of Scheteligfjellet and along the rocky shore east of Kolhamna. Limestone and dolostone are the commonest rock types from this period, and often contain hard, flinty beds.

*Tertiary*

Lower Tertiary beds are found in a small area (4.5 $km^2$) just south and west of Ny-Ålesund. They are surrounded by Upper Carboniferous and Permian rocks and, together with them, are preserved through down-faulting. The faulting mostly trends north-south, like that in the Tertiary at Forlandsundet. The Tertiary beds have a total thickness of about 200 m and strike about NW-SE with a dip of 12-35 degrees towards southwest. They mostly consist of sandstones with some scattered conglomerates, but shales and coal seams are also found, particularly in the lower part. The age of this isolated occurrence of Tertiary rocks probably corresponds with the lowermost Tertiary south of Isfjorden. At the very base, beneath the coal seams, up to 75 m of shales are found which greatly resemble those in the Lower Triassic. Good fossils are lacking, however, so their age is still uncertain.

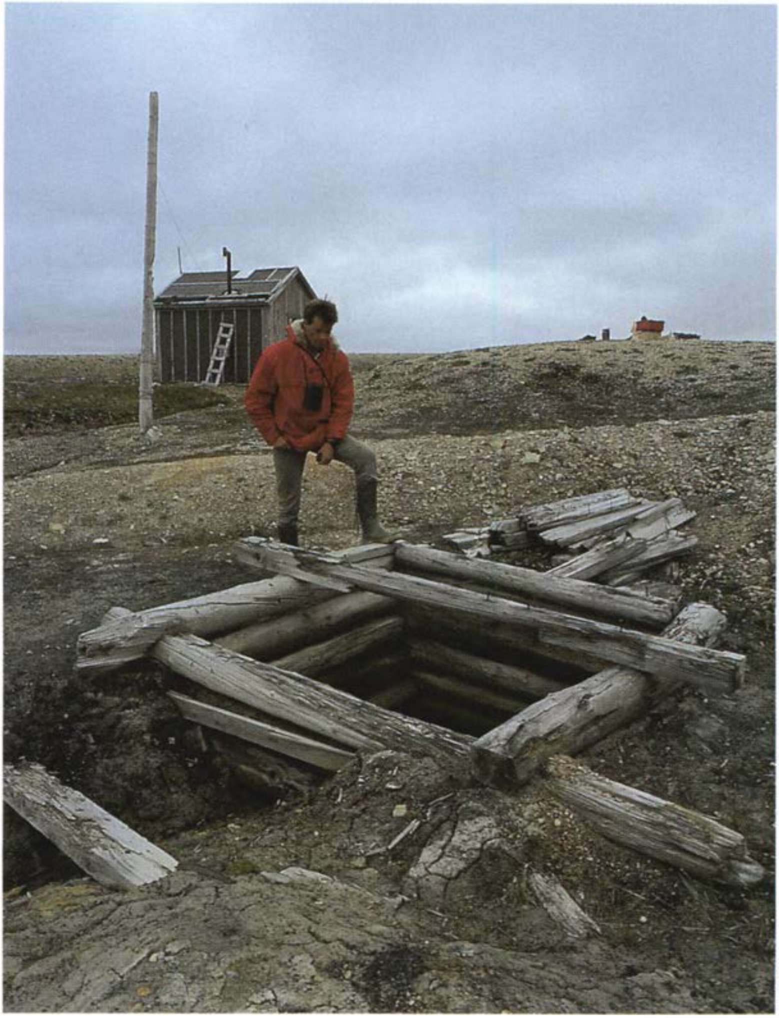


***Fig. 45 A shaft sunk about 1920 to investigate Lower Carboniferous coal seams 2.5 km southeast of Kulmodden on Brøggerhalvøya.***

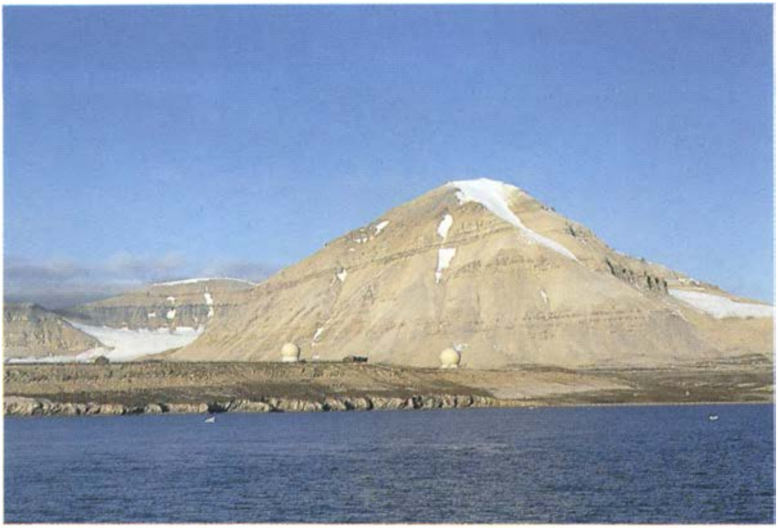
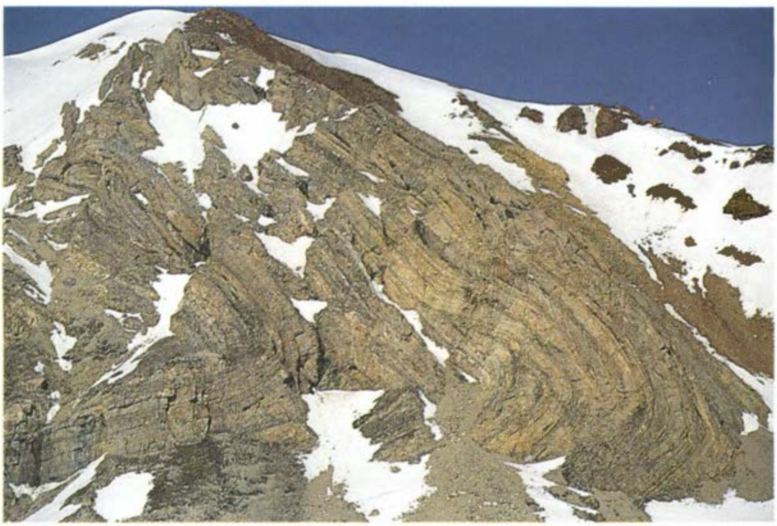


***Fig. 46** Carboniferous and Permian strata in Scheteligfjellet near Ny-Ålesund, looking west. Several parts of the succession have been thrust northeastwards and one of the thrust planes can be seen about a third of the way from the top.*

***Fig. 47** Folded Carboniferous beds in Zeppelinfjellet near Ny-Ålesund. The beds have been folded right over so that the originally lowermost ones are now on top. Viewed eastwards from austre Brøggerbreen.*



*Quaternary and landscape features*

Kvadehuksletta, west of Brøggerhalvøya, is a typical strandflat. In 1973-74, Norsk Polar Navigasjon undertook two small trial drillings for oil and gas here, and proposed building an airport on the flat ground near the sea. For political and other reasons, the airport was not built, but vehicle tracks originating from these activities are still visible in the terrain. This strandflat is an interesting area for Quaternary geologists, partly because of the many raised shore deposits. Radiometric and amino-acid datings show that some of these were formed 130,000-290,000 years ago. Several sets of old beach ridges have been recognised between 55 and 80 m above present sea level. Beneath these, beds have been found that may be as old as 1 million years. The best preserved beach ridges are found at an altitude of 0-40 m, and were formed during the last 12,000 years.

The Kvadehuksletta area has been mapped in detail by the Department of Geography at the University of Oslo (Norsk Polarinstitutt Temakart nr. 8). The plain has many fine examples of patterned ground with polygons and more or less regular circles. Where the ground slopes, the circles are drawn out into solifluction stripes. Distinct polygons occur, for instance, alongside the lower stretch of Kvadehukelva and on the flat area above Stuphallet. They are particularly frequent 2-3 km south of Kongsfjordneset. Below Stuphallet, towards the sea, there are several rock glaciers. Measurements on another near the snout of the easterly branch of the Brøggerbreen glacier near Ny-Ålesund show that the rocks are moving up to 5 cm a year, mostly at the snout of the rock glacier. These investigations and other detailed studies of glaciers and glacial deposits on Brøggerhalvøya have gone a long way towards explaining how the landscape in mainland Norway was shaped during the Ice Age.

Near the beach just west of Kongsfjordneset is a spring with running water all year round. Measurement of the flow rate in May gave 10 litres per second. Streams often flow from Tvillingvatna, just south of Ny-Ålesund, far into the autumn, even though the lakes have no visible inflow. They probably receive meltwater from the western branch of the Lovénbreen glacier that runs through fissures and subterranean limestone caves.

*The coal mines*

That coal was to be found on the south side of Kongsfjord was known as early as 1610 when the English whaler Jonas Poole described the district for the first time. In 1909, a Norwegian expedition occupied some areas around Kongsfjorden on behalf of the Green Harbour Coal Co. In 1916, the rights were sold to Peter M. Brandal of Ålesund, and the same year the Kings Bay Kul Comp. A/S (KBKC) was set up and the rights were transferred to that company. Investigations had shown that there was sufficient coal to justify mining, and surface facilities including a railway, wharf, houses, power station, hospital,

***Fig. 48** Ny-Ålesund, with the waste tips from the coal mines in the background.*

etc. were built from 1917 to 1920. Following a trial period, the annual output gradually increased to a maximum of 109,000 tons in 1927, the number of employees increasing in the same period from 30 to about 275.

From the base upwards, the seven most important seams are Esther, Sofie, Advokat, Agnes, Otilie, Josefine, and Ragnhild. The two lowermost contain most coal, estimated at more than 10 million tons. The seams are cut by faults which cause them to lie at several levels. This, together with the dip of the beds, makes mining more difficult than at Longyearbyen, Sveagruva and Barentsburg where the seams are continuous and horizontal. The mines were hit by several mishaps and accidents from 1926 to 1929 and mining stopped in autumn 1929. The government had given KBKC substantial financial support since 1920 and in 1933 the company was handed over to the state.

From 1919 to 1926, several small-scale trials were carried out using Ny-Ålesund coal to make tar and oil. Several types of coal gave a yield of up to 20 % oil which could be used to run boat engines. However, because of the economic depression in the 1920's, the trials were not followed up.

During the Second World War, the colliery and its associated facilities at Ny-Ålesund were destroyed and the stockpile of coal was set on fire. Mining did not commence again before 1946. Output increased rapidly, but the community was hit by mishaps and accidents in the years 1948-53, with the loss of 43 lives. Despite these serious accidents, mining continued after 1955 until a major explosion occurred in 1962 when 21 people died. This put a final stop to coal mining at Ny-Ålesund. A combination of difficult operating conditions and lack of implementation of safety requirements was probably the reason for this last accident. In the years from 1946 to 1962, the average annual output was just in excess of 40,000 tons, but only two of these years saw a profit.

*The Norwegian Polar Institute Research Station*

Following the tragic explosion in 1962, Ny-Ålesund has gradually become more and more noted for research activities. Kings Bay Kul Comp. A/S is responsible for the practical running of this little community where the research station belonging to the Norwegian Polar Institute has become the centre for research in recent years. Research has been particularly focused on geophysics, geology and biology. There are facilities for about 20 guest scientists, who can use the laboratories and instruments belonging to the station.

Extensive co-operation between Norwegian and foreign scientists takes place at the research station and several nations have now established themselves at Ny-Ålesund. The place will therefore by degrees develop naturally into a significant international centre for arctic research.

## East of Kongsfjorden

The basement is exposed on Ossian Sarsfjellet where phyllites are found close to the fjord, grading further east into limestone and marble. Still further east, on the Stemmeknausane hills, is more strongly metamorphosed basement, mostly gneisses with some grey granite. Gneiss is also found in two knolls sticking out of the glacier a little to the south.

All the other mountains just north and east of Kongsvegen consist mainly of unaltered beds of Middle and Upper Carboniferous and Permian age. Here, just beyond the westerly zone of intense Tertiary folding and faulting, the beds are almost horizontal. The mountains are pyramidal-shaped, typified by Tre Kroner, probably the most beautiful peaks visible from Ny-Ålesund, where horizontal Carboniferous and Permian strata overlie gently folded Devonian exposed below about 1000 m (Fig. 49). Dark doleritic sills are intruded here and there. These are hard and form steep steps in the mountain sides. Streams and rivers, such as the river just south of Ossian Sarsfjellet, are often coloured red by mud originating from the Carboniferous rocks.

Glacial erosion in the area around Kongsvegen is intense and great quantities of rock are broken off, crushed and carried out into the fjords. It has been calculated that glacial meltwater rivers yearly empty about 2 million tons of sand, mud and gravel into the inner basin, close to the glacier snout. This corresponds to 2000 tons for every $km^2$ of the glacier.

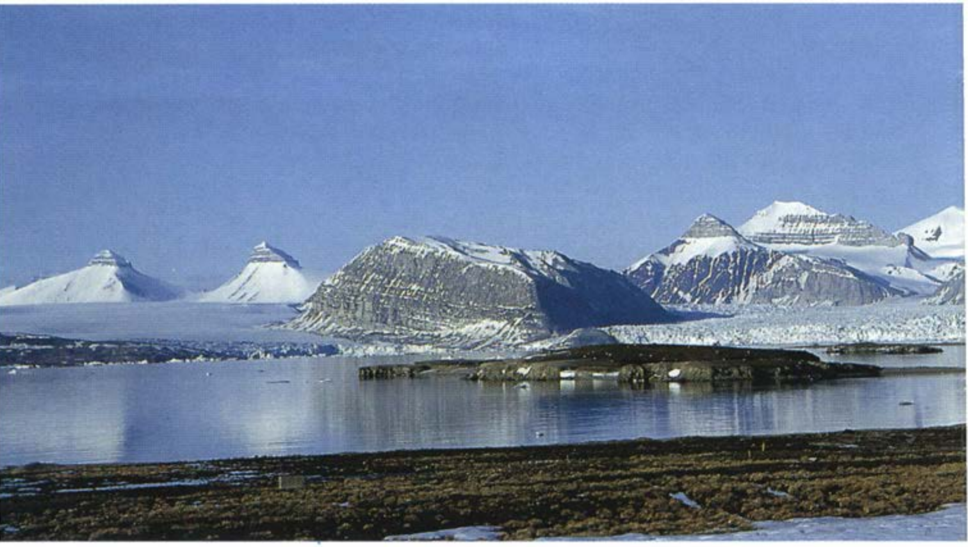


***Fig. 49** The view towards ESE from Ny-Ålesund. From left to right: Exilfjellet, Svea, Colletthøgda, Pretender and Dronningfjella. Note the difference between the "top hat" of Carboniferous beds and the underlying Devonian on Exilfjellet, Svea and Pretender. Colletthøgda and Dronningfjella largely consist of Carboniferous strata.*

## North of Kongsfjorden

*Basement*

Strongly metamorphosed basement rocks dominate north of Kongsfjorden. The most common are gneisses and granites with remnants of schist and limestone beds. The limestone is often altered to marble. Because fold axes north of Kongsfjorden plunge gently southwards, the oldest, deepest rocks reach the surface in the north. The metamorphic grade of the schists and gneisses can be seen to mainly increase northwards, too. In the south, the schists contain a great deal of chlorite and white mica (muscovite), in the north they have black mica (biotite), amphibole and garnet, suggesting that the rocks have been metamorphosed under conditions of higher pressure and temperature.

*Devonian*

A number of faults trend north-south across Blomstrandhalvøya and just east of there resulting in small patches of Devonian sandstone and conglomerate being preserved on the peninsula, some of the Lovénøyane islands and the mountains north of the Blomstrandbreen glacier. The marble on Blomstrandhalvøya has some small caves and swallow holes, typical features of karst landscape, and some of the swallow holes were probably formed before or during the Devonian since they are partially filled with horizontal Devonian sediments.

*Marble quarry on Blomstrandhalvøya*

This peninsula is really an island, because Blomstrandbreen has retreated so far in recent years that only a few metres of glacier ice now connect the "peninsula" to the northern shore of the fjord. On the south side of Blomstrandhalvøya, attempts were made to extract marble between 1910 and 1920, interrupted by the war years. An English company, Northern Exploration Co. Ltd., invested a great deal in a wharf, engineering shops, stores, cutting and sawing equipment, etc.; even a narrow-gauge railway was built. Altogether, a little mining town called London (Figs. 50 and 51). Various types of marble were given imaginative trade names such as Arctic Grand Antique and Queens Bay, but ordinary production never commenced. Some marble was also extracted from Juttaholmen, a small island southeast of Blomstrandhalvøya. The trial quarries are very shallow, the deepest being only 1.5 m. It was said that some marble fractured when it reached warmer regions. These fractures may have resulted from some of the marble being traversed by faults leading to the formation of joint and crush zones. The variable quality of the marble and the generally increased costs after the First World War led to the activity being abandoned after 1920. The remains of machinery and equipment still to be seen show that N.E.C. sank a great deal of money into the marble at London. The marble has since been investigated by others, but the results have not justified a resumption of the quarrying. Some of the old huts from London have been removed to Ny-Ålesund. Thick marble beds also occur north of Blomstrandhalvøya and on Mitrahalvøya, north of the outermost part of Kongsfjorden, but access is more difficult and no attempts have been made to work them.

*Gold deposits?*

Store Norske and Norsk Hydro in co-operation have found relatively rich concentrations of gold in bedrock at Svansen, north of Blomstrandbreen. For the moment, only the find points have been reported to the Commissioner of Mines for Svalbard. They are beyond the boundary of the Northwest Spitsbergen National Park, which means their exploitation cannot be excluded if a future claim is assigned.

***Figs. 50 and 51** London on Blomstrandhalvøya, showing machines and other equipment as well as houses used by the Northern Exploration Company when quarrying the marble on a trial basis.*

*Fig. 52 Gneiss with layers of marble containing skarn minerals. Danskøya.*

## SMEERENBURGFJORDEN - MAGDALENEFJORDEN - LIEFDEFJORDEN

(local map on page 112-113)

Large areas here consist of gneiss, migmatite and granite, often with included relicts of rock types - schist, marble and quartzite - that are common in the Proterozoic strata southwards towards Krossfjorden and Kongsfjorden. A relatively gradual transition is seen from these rocks in the south to migmatites and gneisses in the north. The inclusions have had different ability to resist alteration; feldspathic quartzites are often completely transformed into gneiss, whereas marbles and dark schists are frequently found as partially-digested lenses and beds in granitic rocks. Such mixed rocks, migmatites, are very common in northwestern Spitsbergen.

*Basement*

West of Raudfjorden and Liefdefjorden there is almost only migmatite, gneiss, granite and marble. Metamorphism and folding in Caledonian time have left their obvious mark on these gneisses and migmatites. The mineral assemblages in some of the gneisses show that they crystallised at a depth of at least 15 km. Since they now lie at the surface, erosion must have removed at least 15 km of rock. Some fairly continuous beds of Precambrian sedimentary and volcanic rocks are also found, good examples being seen in

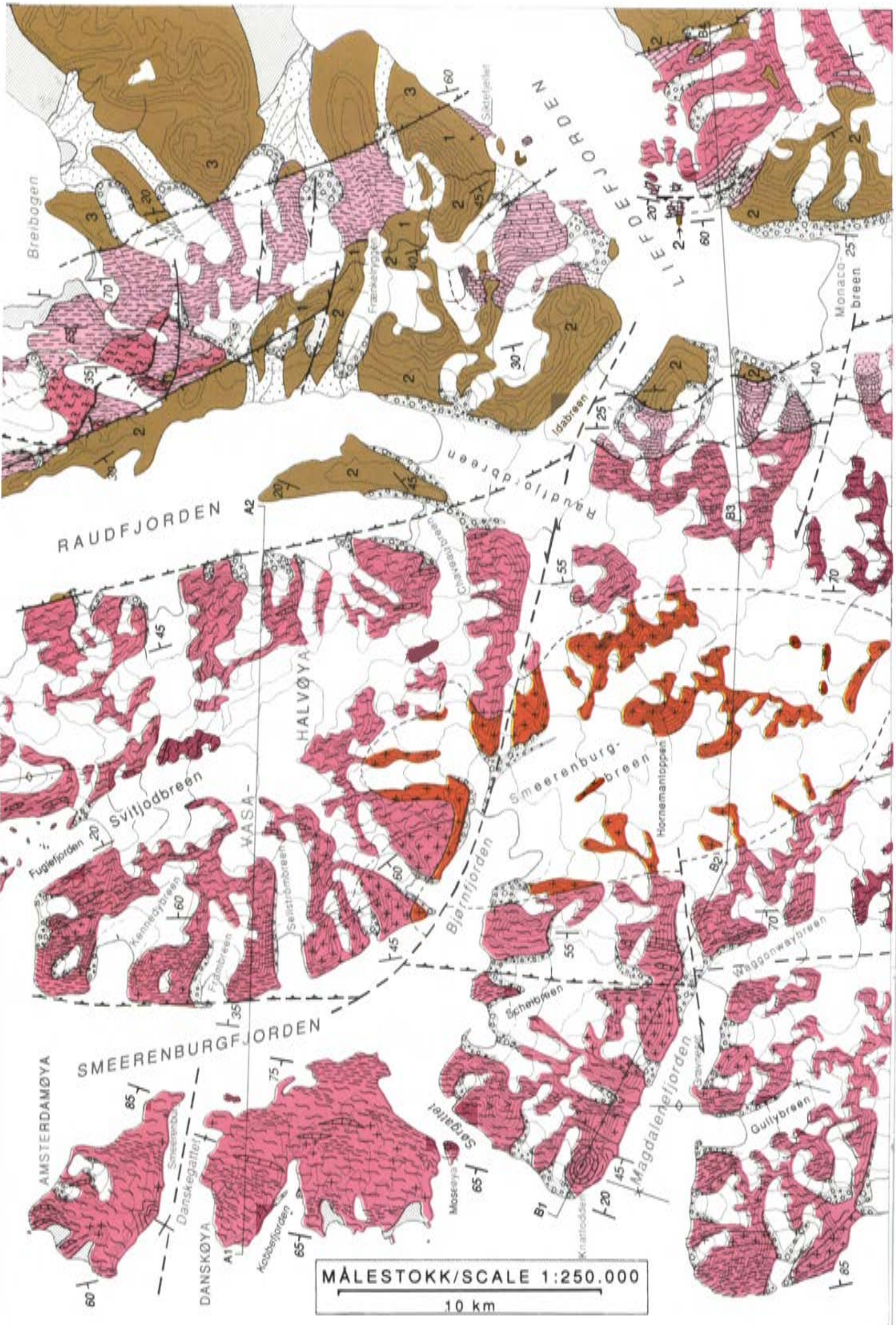
the vicinity of Magdalenefjorden and Sørgattet, as well as east of Smeerenburgfjorden. Folded marble is clearly seen near the summit of the mountain above Knattodden on the north side of the entrance to Magdalenefjorden and the marble appears again at the northern tip of Moseøya in Sørgattet from where it continues as a more or less fragmented unit north-northwestwards across the islands of Danskøya and Amsterdamøya. These rocks have often reacted with gneiss and granite to form skarn (calc-silicate rock), such as just northeast of the head of Magdalenefjorden. Wollastonite, grossular (calcareous garnet), diopside and epidote are among the skarn minerals that occur, and small amounts of vesuvianite, iron pyrites and chalcopyrite are often seen, too. There are also many beds of marble on Vasahalvøya, frequently less than 10 m thick. Near Fuglefjorden on the north side of this peninsula, special combinations of minerals are found, such as diopside, phlogopite, olivine and spinel.

A large granite body, the Hornemantoppen granite, has intruded the migmatite and gneiss east of Magdalenefjorden. The difference in altitudes within the granite is about 700 m, thus the thickness of the granite body is similar or more, perhaps more than 1000 m. Mountainsides composed of the granite form steep, but firm cliffs, and are often visited by climbers. The highest mountaintops carry clear evidence of wind erosion. The rock is medium to coarse grained and has a fresh red colour in contrast to the grey rocks surrounding it. It is massive and shows so few traces of strain and foliation that it has probably crystallised later than the most intense period of Caledonian deformation. Because similar granite is never seen cutting Devonian strata, the granite may have been intruded before the Devonian rocks were deposited. A preliminary radiometric age determination of 411 million years supports this supposition. The structures around the granite suggest that the rocks surrounding it were deformed when it was intruded. On the west side of the granite, planar structures dip westwards, whereas they dip eastwards on the east side; hence, the granite forms the core of a large antiform with an approximately north-south axis.

East of Raudfjorden, remnants of ancient, deep-seated rocks, including eclogite, have been found. These formed in the early Cambrian, under conditions of high pressure and temperature. Similar rocks are also found south of St. Jonsfjorden, where they are overlain by Ordovician and Silurian strata.

***Upper left: Fig. 53  Nunataks comprised of migmatite. Karl Pettersenfjellet, southeast of Magdalenefjorden, looking north.***

***Lower left: Fig. 54  Red Caledonian granite on Aurivilliusfjellet, southeast of Smeerenburgfjorden, looking northeast.***



RAUDFJORDEN
SMEERENBURGFJORDEN
AMSTERDAMØYA
DANSKØYA
VASA-HALVØYA
LIEFDEFJORDEN
Breibogen
Idabreen
Raudfjordbreen
Monacobreen
Svitjodbreen
Fuglefjorden
Kennedybreen
Frambreen
Sellströmbreen
Bjørnfjorden
Smeerenburgbreen
Hornemantoppen
Waggonwaybreen
Scheibreen
Magdalenefjorden
Gullybreen
Danskegattet
Kobbefjorden
Moseøya
Knattodden
MÅLESTOKK/SCALE 1:250.000
10 km

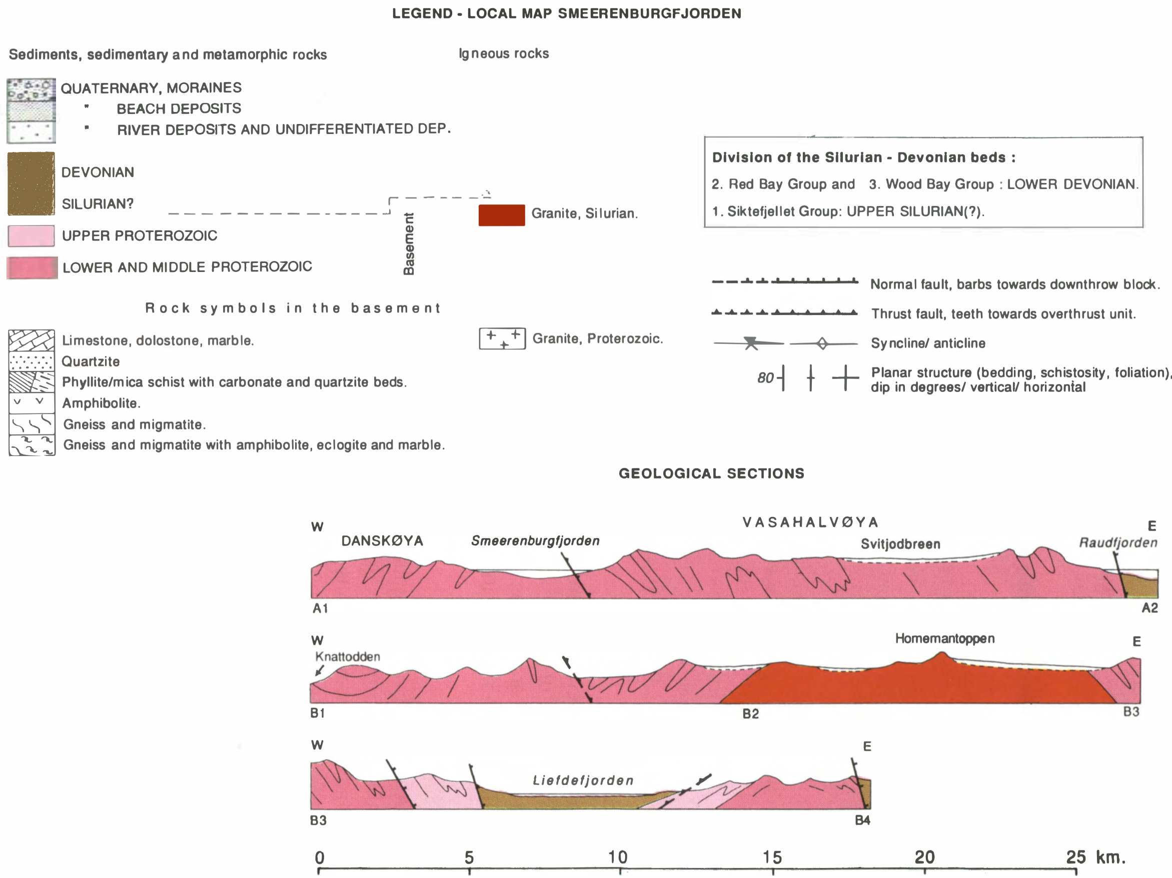



Fig. 55 Smeerenburgfjorden.

**How do we determine the age of rocks?**

An age may be relative or absolute. The lower beds in an undisturbed succession of beds are older than the upper ones; a granite that has intruded a shale is younger than the shale. These are relative ages.

Radiometric methods based on the natural radioactivity of substances give absolute ages. When the substances are formed there is a specific relationship between the amounts of different isotopes. This varies with the time elapsed since their formation because of radioactive breakdown, and the age can be determined by measuring the amounts of the various isotopes. The relationship between different types of amino acids can also be used for age determination.

Some fossils, called index fossils, are so typical for the time they were formed that they provide good indications of when the beds were deposited. Because the best preserved fossils are found in Palaeozoic and younger rocks it is generally in these that dating is done by means of index fossils.

Northwestern Svalbard can boast the greatest geological age found in Norway. East of Raudfjorden, about 5 km southwest of Breibogen, zircon found in a granite has given a radiometric age for the time of its crystallisation of 3.2 billion years.

*Silurian(?)*

About midway along Liefdefjorden there are about 750 m of unmetamorphosed, but folded beds. They belong to what have been called the Siktefjellet Beds, named after a mountain on the north side of the fjord, and are mostly green sandstones, but include some conglomerates with various kinds of clasts. These beds were probably deposited late in the Silurian and are among the earliest deposits on the eroded surface of the Svalbard basement. The Siktefjellet Beds were subsequently gently folded and then eroded before being overlain by the reddish, Devonian, Red Bay conglomerate. They were therefore folded after the main Caledonian deformation in the Silurian, but before the red conglomerate was deposited, probably in the early Devonian. The age of the Hornemantoppen granite, about 411 million years, makes it probable that this was intruded about the same time as the folding episode. The greenish beds on Siktefjellet contrast sharply with the reddish Devonian rocks just above and sedimentary structures suggest they could have been deposited from different source areas - the

Siktefjellet Beds from the west-northwest and the younger Red Bay Beds from the south.

### *Devonian*

The landscape around Raudfjorden is beautiful, with red rock, mostly covered with vegetation near the fjord. The red colour resembles that of sand and gravel in desert regions and these beds were therefore probably deposited in an area experiencing a desert climate. The Red Bay Beds are at the most about 2300 m thick and belong to the earliest Devonian deposits in Svalbard. They mostly consist of conglomerate and sandstone and are thought to have been deposited in deltaic and brackish water areas. The lowermost 800 m contain relatively few fossils, but in some places the overlying beds have abundant remains of both primeval fish and primitive terrestrial plants.

In Frænkelryggen, near Raudfjorden, two beds of quartz-bearing volcanic rocks, each about 4 m thick, have been found in a sequence of siltstones and sandstones containing fossil spore-producing plants of Lower Devonian age. They are probably approximately contemporaneous with similar Devonian volcanic rocks in Scotland, East Greenland, and Novaya Zemlya.

Down-faulted Devonian strata of a different kind from those at Raudfjorden crop out in the outer part of Liefdejorden. They belong to the Wood Bay Beds which have a total thickness of about 2900 m and are younger than the often coarser grained Red Bay Beds. The Wood Bay Beds are mostly fresh-water sandstones and siltstones, the sediment probably being derived from the west. They are often reddish and represent the typical Old Red Sandstone on Spitsbergen.

### *Quaternary and landscape features*

Landscape forms in northwestern Spitsbergen are very strongly influenced by the effects of active erosion by cirque glaciers. Such glaciers form in short valleys in mountainsides and the action of freezing and thawing along their base breaks off pieces of bedrock. When the glaciers move, erosion is able to eat its way backwards and downwards, initially forming a small hollow, later a larger cirque. If mountains are attacked by cirque glaciers from several sides for a sufficiently lengthy period they become transformed into a number of pointed peaks connected by knife-edged ridges. The Magdalenefjorden district has cirque glaciers and mountains in several stages of development. The mountain just south of Gravneset has a typical cirque glacier. Many others can be seen on Vasahalvøya.

Another type of landscape is found on Danskøya and parts of Amsterdamøya, which mostly have relatively low, rounded hills. On the north coast of Amsterdamøya, these hills fall off in steep, north-facing cliffs. Over on the southern part of Danskøya, many boulders of reddish granite can be observed that are not to be found in the bedrock on the island. This granite is typical for the area east of Magdalenefjorden and was brought to Danskøya by glaciers moving northwestwards along Bjørnfjorden from the vicinity of Hornemantoppen. Large, submarine terminal moraines found off the entrances to Magdalenefjorden, Smeerenburgfjorden and west of Danskøya show how far the glaciers travelled. The moraines date from the last Ice Age in Svalbard and are about 20,000 years old. Traces of weathering and erosion left on the bedrock indicate that the glacier surface here has never been higher than about 150 m above present sea level. Large parts of the upland plateau on Amsterdamøya are covered by a block field comprised of angular rocks broken off the bedrock beneath by frost weathering. Far-transported erratics at an altitude of about 400 m on the plateau show that a glacier has nevertheless covered the island during earlier ice ages.

A peculiar "rock" can be seen on the south side of Amsterdamøya, where the early-17th century Dutch whaling settlement of Smeerenburg (Blubber Town) stood. Whale blubber was boiled to produce oil in huge ovens standing close to the sea. Some of this leaked into the sand and in the course of 350 years this mixture of oil and sand has hardened to what may be called oil sandstone. Feathers and other remains of birds are occasionally found in this stone.

## WOODFJORDEN - BOCKFJORDEN (local map on page 118-119)

### *Basement*

Gneiss and migmatite with some mica schist, phyllite and marble form a NNW-SSE trending ridge west of the Bockfjorden-Risefjellet-Vonbreen area. The rocks occupy an antiformal structure with what are assumed to be the oldest in the core and younger ones on the flanks. The total thickness of all the rocks in the antiform is probably less than 1000 m. The marble beds lie outermost in the east and west and are probably youngest. Close to the gneiss and migmatite they often have a reaction zone of skarn minerals such as diopside, hornblende, garnet, and also some iron pyrites. No fossils have been found in the marbles and their age is therefore uncertain. But they, and the mica schists and phyllites accompanying them, strongly resemble the strata on Blomstrandhalvøya and elsewhere on the north side of Kongsfjorden. They are therefore thought to belong to the same succession and are probably mid- to late-Proterozoic in age. Antiformal structures are also seen in the Devonian strata and the formation of the antiform must have taken place after the main folding episode in the Silurian.

### *Devonian, sandstone with primeval fish*

Large tracts of Devonian deposits, totalling more than 4000 m, are found west of Wijdefjorden and around Woodfjorden. They are mostly sand-

***Fig. 56 Fragments of a fossilised armour-plated fish from the Wood Bay Formation in the Devonian of northern Spitsbergen. The bluish-white colour is characteristic.***

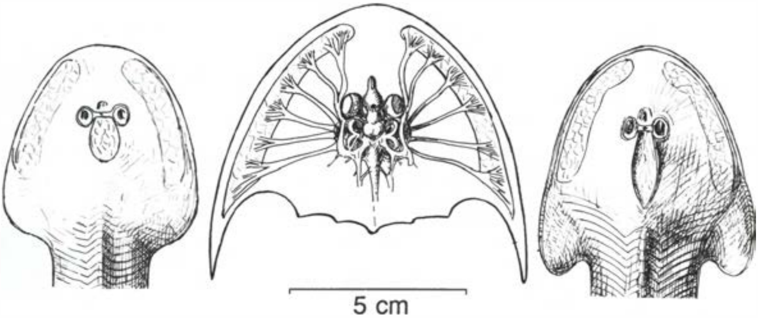
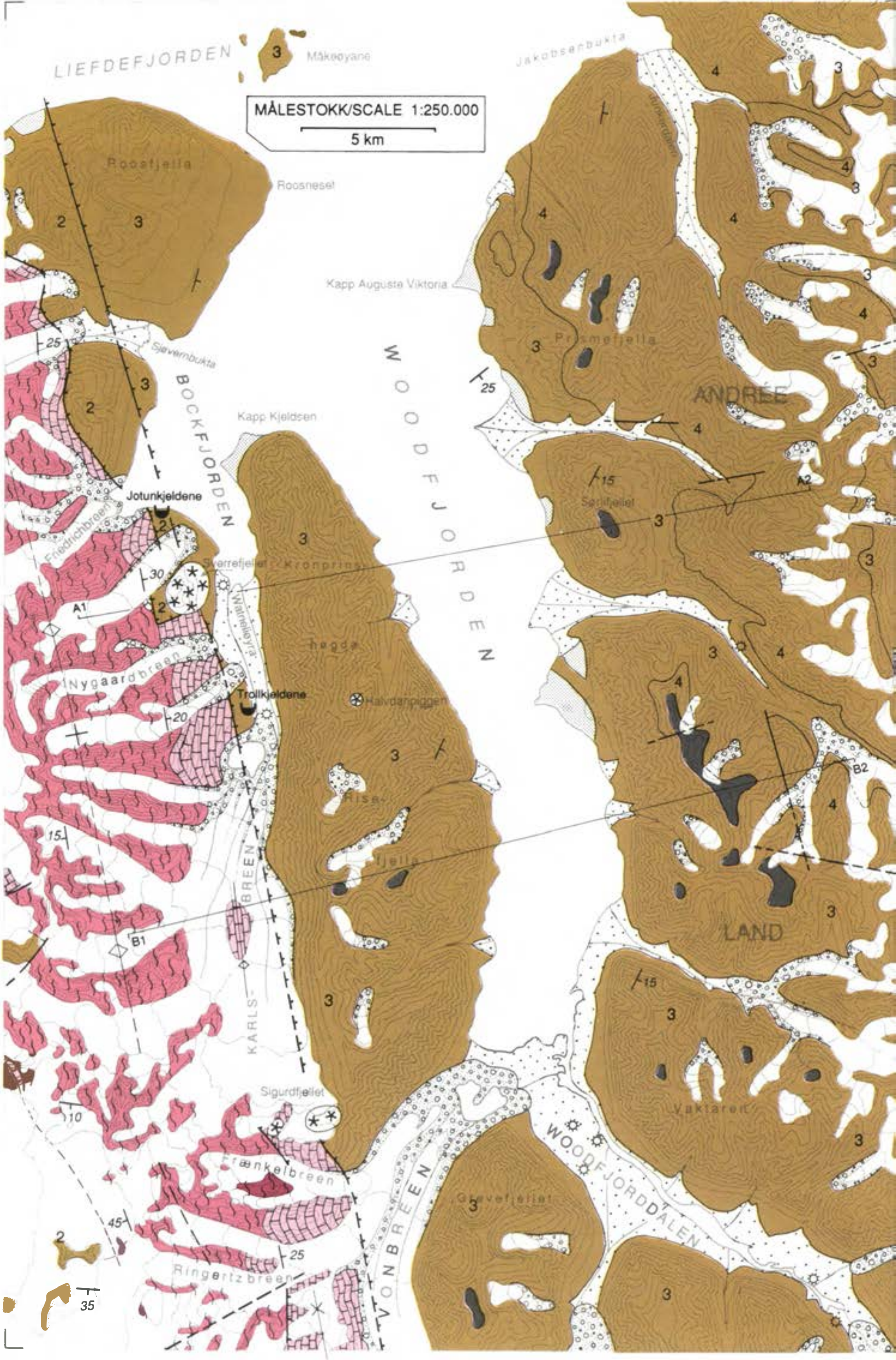



***Fig. 57 On the left and right are plates from the head and body of two forms of the primeval Devonian fish, Cephalaspida. The brain, eyes and some of the nerves going to the sensory areas along the margin of the armour can be seen in the middle. Drawn by Anatol Heintz.***

stones and conglomerates alternating with small quantities of shale and carbonate rocks and were chiefly deposited in fresh or brackish water, lagoons, lakes or broad rivers; current and wave ripples are common in the sandstones and shales. Svalbard was located near the equator during the


LIEFDEFJORDEN
Måkeøyane
MÅLESTOKK/SCALE 1:250.000
5 km
Jakobsenbukta
Roosfjella
Roosneset
Kapp Auguste Viktoria
Sjøvernbukta
BOCKFJORDEN
WOODFJORDEN
Kapp Kjeldsen
Prismefjella
ANDRÉE
LAND
Jotunkjeldene
Friedrichbreen
Sverrefjellet
Kronprins
Høgda
Trollkjeldene
Halvdanpiggen
Nygaardbreen
Rise-
fjella
KARLS-
BREEN
Sigurdfjellet
Frænkelbreen
Ringertzbreen
VONBREEN
WOODFJORDDALEN
Gråvefjellet
Vaktaren
A1
A2
B1
B2

**LEGEND - LOCAL MAP BOCKFJORDEN**

Sediments, sedimentary and metamorphic rocks

- QUATERNARY, MORAINES
- " BEACH DEPOSITS
- " RIVER DEPOSITS AND UNDIFFERENTIATED DEPOSITS
- " THERMAL SPRINGS
- " PINGO

4, 3, 2 DEVONIAN

UPPER PROTEROZOIC

LOWER AND MIDDLE PROTEROZOIC

(Upper Proterozoic and Lower and Middle Proterozoic: Basement)

Igneous rocks

- Quaternary olivine basalt.
- Tertiary basalt.

R o c k  s y m b o l s  i n  t h e  b a s e m e n t .

- Limestone, dolostone, marble.
- Gneiss and migmatite.

**Division of the Devonian beds:**

4. Grey Hoek Group. MIDDLE DEVONIAN.

2.· Red bay Group and 3. Wood Bay Group : LOWER DEVONIAN.

- Normal fault, barbs towards downthrow block.
- Thrust fault, teeth towards overthrust unit.
- Syncline/ anticline.
- 55 Planar structure (bedding, schistosity, foliation), dip in degrees/ vertical/ horizontal .

**GEOLOGICAL SECTIONS**

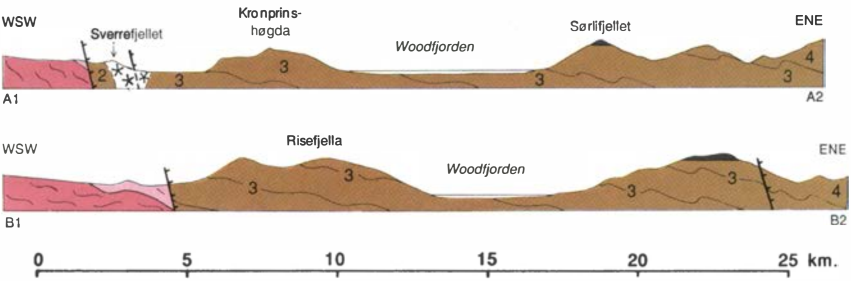



*Fig. 58 Bockfjorden.*

***Fig. 59 Jotunkildene near Bockfjorden.***

Devonian and the reddish "desert hue" derived from trivalent iron oxide is common in the Wood Bay Beds here, too.

The oldest fossil fish found in Svalbard are in early Devonian beds in northern Svalbard, including the area around Woodfjorden and between Liefdefjorden and Raudfjorden. They were jawless, primeval fish lacking a hard internal skeleton, but the forepart of their body was covered by bony, armour-like plates (Fig. 4). By studying these fish, scientists have obtained a great deal of information about the early history of the vertebrates. Some of the fossils are so well preserved it has been possible to study the shape of the brain and the layout of the most important nerves (Fig. 57). Fossil fish are also found in Upper Devonian beds, but these are proper fish with jaws. Among these are lobe-finned fish which had powerful breast and stomach fins and evolved into the first terrestrial vertebrate, the armour-plated toad. These rocks also contain many fossils of spore-producing plants which grew on the alluvial plains and beside shallow lakes.

*Tertiary lava*

Here and there around the southern part of Woodfjorden, dark olivine-basalt lava flows overlie the Devonian rocks. On Eidsvollfjellet, about 15 km southwest of the head of the fjord, they directly overlie the basement. The basalt crops out in 10-30 m thick horizontal sheets, forming steep cliffs and displaying distinct columnar or prismatic jointing, as on Prismefjella and Sørlifjellet, east of Woodfjorden. The lava flows were probably less than 300 m thick and are between 2 and 12 million years old. The fluid basaltic lava poured across a large area, filling existing valleys and low-lying areas. Following erosion, only small remnants remain, often forming hard, protective caps on some of the highest peaks. Similar lava flows have been found on Tavlefjellet, west of Wijdefjorden - indeed even as far east as Lomfjorden in northeastern Spitsbergen.

*Quaternary volcanoes and thermal springs*

West of the inner part of Woodfjorden, three volcanoes, or more correctly remnants of volcanoes, are found - Sverrefjellet, Sigurdfjellet and Halvdanpiggen. The first two are close to a fault running almost north-south across Bockfjorden, and the molten rock may have followed the easiest path along this zone of weakness on its way up through the Earth's crust.

Sverrefjellet is most easily accessible and has also been most thoroughly studied. It is a stratovolcano, lava and volcanic breccia occurring in alternate layers. The lava is dark, porous alkali basalt, often containing abundant nodules and fragments of older rocks carried up from depth. Some derive from the crust (e.g. Precambrian gneisses), but the majority are olivine-rich rocks with a mineral content testifying to their origin in the mantle, probably deeper than 50 km. Many lines of evidence suggest that the eruptions took place rapidly, perhaps explosively. The cone shape of Sverrefjellet resembles that of a present-day volcano, but what is seen now is merely the remnant of the original volcano; the hard rocks in the core have withstood erosion best and therefore stand highest. Glacially transported boulders are strewn over the mountain, all the way to its summit; the last eruption therefore took place prior to the last time the area was covered by a glacier, probably about 100,000 - 150,000 years ago.

Halvdanpiggen and Sigurdfjellet are smaller in extent, but greatly resemble Sverrefjellet, their dark lavas containing fragments of massive rocks transported up from deeper parts of the Earth's crust.

That the volcanic forces have still not completely died out is shown by the occurrence of thermal springs. The water in the springs is groundwater that has circulated in the bedrock at a sufficient depth to maintain the temperature when it surfaces at 20°C or higher all year round. Near the fault running along Bockfjorden and past Watnelieøyra, thermal springs occur alongside both Bockfjorden and the inner part of the spit. Jotunkjeldane beside Bockfjorden are small springs, the smallest not much larger than a bucket, whereas Trollkjeldane in the valley about 5 km south-southeast of Sverrefjellet are larger. These six springs measure up to 10 x 3 m. The highest temperature recorded in Trollkjeldane is 28.3°C.

The spring water dissolves minerals on its way up through the bedrock; as much as 2-3 grams of dissolved substances per litre of water have been measured at one place. When the water issues at the surface and partially evaporates, salts are deposited. Benches and terraces have therefore been built up around the springs, mostly consisting of carbonate deposits. Mosses, algae and diatoms, not found elsewhere in Svalbard, thrive in the springs.

The Bockfjorden area is probably the northernmost land area with thermal springs today.

Measurements of the temperature in Tempelfjorden suggest that heat may also be rising from the depths of the Earth here, too. Like Woodfjorden, this is situated in an area with faults. Precise measurements have not been made and it may well be that the temperature differences merely result from current paths in the fjord water.

*Minerals*

Galena has been found in Devonian sandstone at Kapp Auguste Victoria on the east side of Woodfjorden. The deposit is small and has not been worked. Copper minerals have been found in many boulders on the mountainside just south of Sigurdfjellet. Just north of Halvdanpiggen is a 2-3 m broad, about 2 km long, dyke containing barytes, quartz, haematite and copper minerals including chalcocite, bornite and azurite. Barytes dykes are also found in several places on the west side of Woodfjorden. These mineral deposits differ from those in southwestern Spitsbergen, where sphalerite, galena and chalcopyrite dominate, and the dykes were probably formed in connection with the volcanic activity in the area.

# NORTHEASTERN SPITSBERGEN AND NORDAUSTLANDET

## NY-FRIESLAND AND OLAV V LAND

### (East of Wijdefjorden, north of Tempelfjorden - Wichebukta)

*Basement, granite*

The best preserved sedimentary rocks in the Svalbard basement are in northeastern Spitsbergen and the northwestern part of Nordaustlandet. Whereas the west side of Spitsbergen was in a very exposed position with respect to the Tertiary earth movements, the strata were more protected further east in Ny-Friesland and adjacent to Hinlopenstretet. Folded and tilted beds of metamorphosed shale, limestone, quartzite and other rocks with a total thickness of several kilometres strike north-south.

These basement strata, deposited in the Proterozoic, Cambrian and Ordovician, have been more or less strongly folded and metamorphosed. Because they mostly dip eastwards, increasingly younger beds crop out in that direction. They are mainly sedimentary rocks and are often divided into three sequences, lower, middle and upper. They are almost exclusively Proterozoic in age, Cambrian and Ordovician rocks occurring only in the uppermost portion of the upper sequence.

Recent investigations have shown that earth movements took place between the lower and middle sequences. Crushed rock (breccia) occurs along the boundary, for example, 10 km west of Newtontoppen, and there is an abrupt change from strongly metamorphosed rocks in the west to less altered ones in the east. The western part is severely folded and beds are repeated; the total thickness of strata between Wijdefjorden and Hinlopenstret is probably 13-14 km.

The oldest and lowermost beds in the west are most strongly metamorphosed, and are often gneisses. They are seen, for instance, on Atomfjellet east of the inner part of Wijdefjorden. Amphibolites a little higher in the sequence are probably metamorphosed doleritic sills or basaltic lavas. In northwestern Ny-Friesland, a Proterozoic granite, radiometrically dated to 1750 million years, is surrounded by metamorphosed sedimentary rocks of early Proterozoic age or perhaps still older.

The middle sequence, east of the crush zone, has regular layering and is easy to follow in the terrain. The folding was less intense than in the west, and the nature of the strata shifts from gneisses and schists west of the boundary to dominantly quartzite, limestone and dolostone deposited in shallow seas and lakes in the east. Well-preserved ripple marks are found in the quartzite at several localities, such as Hellerusthamaren, a nunatak about 25 km northeast of Pyramiden. The upper Proterozoic sequence includes dolostone with distinct algal structures, among the oldest traces of life found in Svalbard.

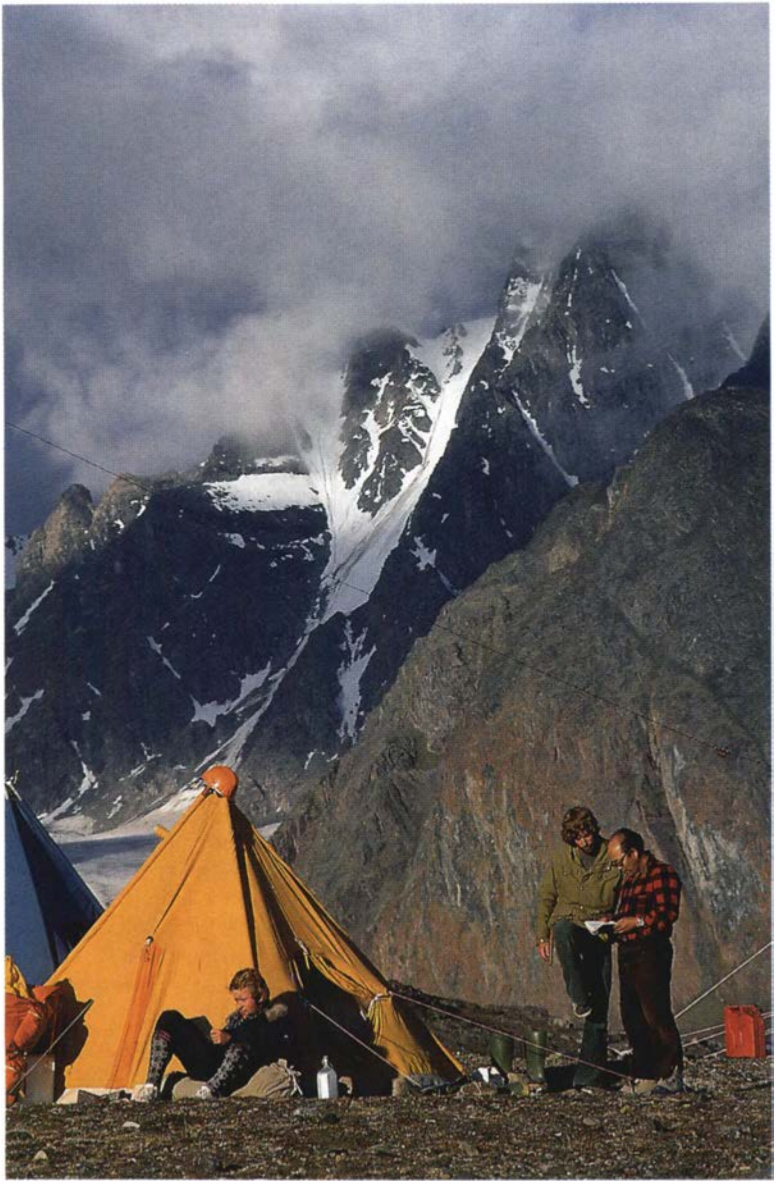


*Fig. 60 A camp for geologists on the east coast of Wijdefjorden. Atomfjella, comprised of metamorphosed and strongly folded Precambrian rocks, are in the background.*

The upper basement sequence is very similar on both sides of Hinlopenstretet. In Ny-Friesland the beds dip eastwards, in Nordaustlandet westwards, thus describing a large syncline whose axis follows the sound. Details of the bottom topography here show that both folding and faulting have helped to determine the form of Hinlopenstretet.

The succession near the sound includes characteristic tillites of uppermost Proterozoic age. On Nordaustlandet, they are exposed, for example, around the outer part of Murchisonfjorden, and in Ny-Friesland near Polarisbreen, northeast of Newtontoppen. Above the tillites, limestones and shales contain fossil trilobites, graptolites, snails and squids showing that they were deposited in Lower Cambrian and Ordovician times. Particularly numerous and good fossils have been found on the west side of Hinlopenstretet, just north of Lomfjorden. Trilobites here are so well preserved that the manner by which they shed their skin, and other details in their mode of living, have been clarified. At one place in Ny-Friesland, Ordovician limestone has been found to contain so much volatile hydrocarbon that it smells of oil.

The highest mountains in Svalbard, Newtontoppen and Perriertoppen (22 km northwest of Newtontoppen), both 1717 m high, are located in Ny-Friesland. Newtontoppen is in a large area of red granite which is often extremely coarse grained with feldspar crystals measuring up to 5 cm. Radiometric age determinations suggest that it intruded the ancient basement in the Devonian. Granite is also seen on a few small nunataks on the uppermost part of Nordenskiöldbreen. On Raudberget, 35 km north-northeast of Newtontoppen, a granite forms the lower slopes, and the top consists of red-weathering, horizontal Carboniferous beds that have been deposited on the ancient, eroded granite surface.

*A disturbed zone. Carboniferous and Permian*

There has been a long history of earth movements in the Billefjorden-Wijdefjorden district - the Billefjorden Fault Zone. The effects of disturbances in this zone are seen as far south as just east of Sveagruva, downward and upward movements of the crust having taken place since Devonian times, perhaps even earlier. Whereas basement is exposed east of Wijdefjorden, to the west several thousand metres of Devonian deposits have been down-faulted and preserved. North-south lateral displacements have probably also taken place along Wijdefjorden. Crushed (brecciated and mylonitised) rocks along the east side of the fjord are clear evidence of faulting. Devonian is lacking east of the fjord, and where Carboniferous beds are present they therefore directly overlie the basement. Tertiary strata are also deformed near the fault zone in Billefjorden, showing that some movement also occurred in the late-Tertiary. Some beds were displaced 3-4 km eastwards at that time, possibly as much as 10 km. There is evidence that the direction of faults in the zone is influenced by the trends of ancient structures in the underlying basement.

Movements have also taken place further east, where the Lomfjorden Fault Zone extends from Lomfjorden all the way south to Storfjorden. To the east of that zone is an area of down-faulted Carboniferous-Permian rocks. Movement took place here as recently as during the Tertiary when Svalbard touched Greenland, and the zone is closely related to the more intensive fault zones further west on Spitsbergen. East of Wijdefjorden, several small areas of Carboniferous-Permian rocks have been preserved in the same manner; here, they have been down-faulted to the west. The thickness of the Carboniferous-Permian succession in Ny-Friesland exceeds 600 m.

*Young lavas*

The youngest rocks found in northeastern Spitsbergen are basaltic lavas which cap some small nunataks west of Lomfjorden. The lavas have not been folded or metamorphosed and their chemical composition resembles that of the Tertiary basaltic lavas found on many summits between Woodfjorden and Wijdefjorden. These and the basalts west of Lomfjorden are probably remnants of large Tertiary lava sheets.

*Quaternary and landscape features*

Northeastern Spitsbergen is largely covered by glaciers and there are fewer and smaller areas of Quaternary deposits here than in the southwest. River valleys are smaller and most of the unconsolidated material consists of weathered bedrock in the shape of boulders, sand and gravel.

Strandflats are chiefly found furthest north in Ny-Friesland, at Polhemflya, Verlegenhukflya, Eolussletta and Basissletta. There are beautiful raised strandlines here whose surfaces are sometimes so firm and smooth they could be used in an emergency as landing strips for quite large planes.

## NORDAUSTLANDET AND THE NEIGHBOURING ISLANDS

Because less than a quarter of Nordaustlandet is ice free, much of the geology is concealed beneath glaciers. The northern half of the island consists almost entirely of basement; Carboniferous, Permian and Triassic strata are exposed south of Wahlenbergfjorden. Nordaustlandet and the surrounding islands have no permanent population now. A research station was set up at Kinnvika in Murchisonfjorden for the International Geophysical Year in 1957, and was manned until 1959.

*Basement, granite*

Beds more than 5000 m thick, dating from the Late Proterozoic and Cambrian-Ordovician time, form the bedrock in the northwesternmost part of Nordaustlandet, between Lady Franklinfjorden and Hinlopenstretet. This is a lowland area without glaciers and provides perhaps the longest and best sections through these ancient rocks that are available in Svalbard. The beds strike NNW-SSE and are moderately folded, the fold axes generally plunging gently southwards. Fossiliferous Cambrian and Ordovician beds are found on the headland at the outer extremity of Murchisonfjorden and form the uppermost, youngest strata. They are immediately underlain by uppermost Proterozoic tillite. A granite boulder found in 600 million-year-old tillite near Wahlenbergfjorden has given a radiometric age of 1275 million years, showing that the substrate from which the boulder originates is at least that old. In the east, around the central part of Murchisonfjorden, there is a transition downwards in the succession to mostly calcareous and dolomitic limestones, often densely packed with fossil algal colonies - stromatolites. Near the head of Murchisonfjorden, beautiful red and green shales alternate with sandstones. Still further east, towards Lady Franklinfjorden and also on Lågøya, the bedrock consists mostly of shale, siltstone and quartzite.

On the Botniahalvøya peninsula, between Lady Franklinfjorden and Brennevinsfjorden, is an abrupt change to volcanic rocks, comprising lavas, volcanic breccias (agglomerates), and dykes and sills. Age determinations have shown that these were formed 800-900 million years ago. Other Proterozoic lavas are found in Rijpdalen, the valley separating the Austfonna and Vestfonna glaciers. Their chemical composition suggests they may have been intruded approximately contemporaneously with fracturing of the Earth's crust and formation of an ocean during the Proterozoic.

The volcanic rocks on Nordaustlandet are less altered than those in Ny-Friesland and also differ chemically. Even though both belong to the lower portion of the succession they therefore probably have different origins.

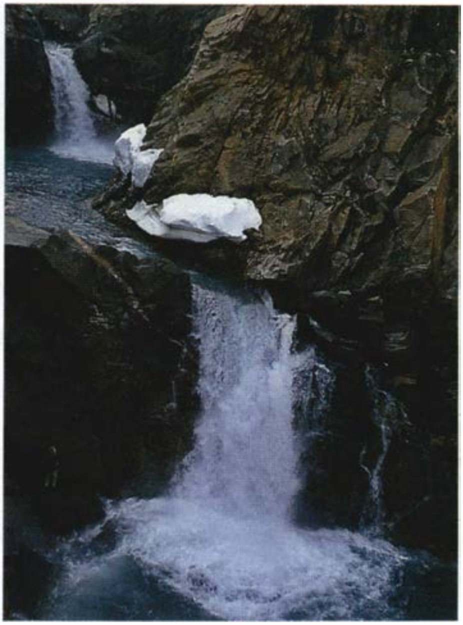
Sedimentary rocks, mostly quartzites and schists, crop out beneath the volcanics in the east and are intruded by medium-grained granite on the east side of Brennevinsfjorden. Preliminary age determinations suggest that this granite was intruded in the Silurian, but a Proterozoic age cannot be ruled out. The contact between the granite and the sedimentary rocks is sharp and can be clearly seen in Kontaktberget at the head of the fjord. The heat from the granite metamorphosed the adjacent rocks creating hornfels, with a burnt appearance. A considerably coarser granite, which is sometimes gneissose and has feldspar crystals up to 10 cm across, is found further north and east. This type of granite, in which potash feldspar is surrounded by a shell of plagioclase feldspar, is termed a rapakivi granite. The boundary towards the medium-grained granite is diffuse and the age of the coarse granite is at present uncertain; it may have originated in the Proterozoic and been partially recrystallised during the Silurian.

In the vicinity of Nordkapp, another medium-grained granite has intruded already metamorphosed sedimentary rocks. Just to the south, in the direction of Beverlysundet and Ekstremfjorden, are numerous dykes of coarse grained granitic material (pegmatite), formed in association

*Fig. 61 Reddish Rijpfjord granite has intruded dark, Precambrian mica schist. On this island in Rijpfjorden, remains of the mica schist overlie the granite in the form of a hat.*

*Fig. 62 Migmatite on nordre Repøya, on the north side of Nordaustlandet.*

*Fig. 63 At Stegjuvet, east of Kræmerbukta in Rijpfjorden, reddish Rijpfjord granite has intruded dark metamorphic rocks.*



with the granite. They border up to mica schist in the west.

Sjuøyane, seven small islands constituting the northernmost land in Svalbard, are practically entirely composed of migmatite, gneiss and granite. Most of the largest island, Phippsøya, consists of massive or slightly foliated, medium-grained granite. Migmatitic gneiss with garnets is the most common rock type on Parryøya and the northernmost small islands. The gneisses often contain discontinuous layers of metamorphosed sedimentary rocks, mostly mica schists, but also quartzite. Some marbles are also found around the north end of Phippsøya.

Weakly metamorphosed Proterozoic sedimentary rocks crop out just west of Rijpfjorden and west of the outer part of Duvefjorden. They are mainly quartzites, sandstones and shales and the youngest of these are likely to have been deposited simultaneously with strata on and south of Lågøya. The easily recognisable Rijpfjorden granite has intruded on the eastern and southern shores of Rijpfjorden. It is medium grained, reddish and contains both light and dark mica. Bedrock in contact with the intruding granite was lifted up, forced aside, heated and metamorphosed. A good example of this is seen on a small island west of Springarodden in Rijpfjorden where the sedimentary rocks were displaced by the granite, and dark layers of metamorphosed shale now form a roof on the top of the island, with granite beneath (Fig. 61).

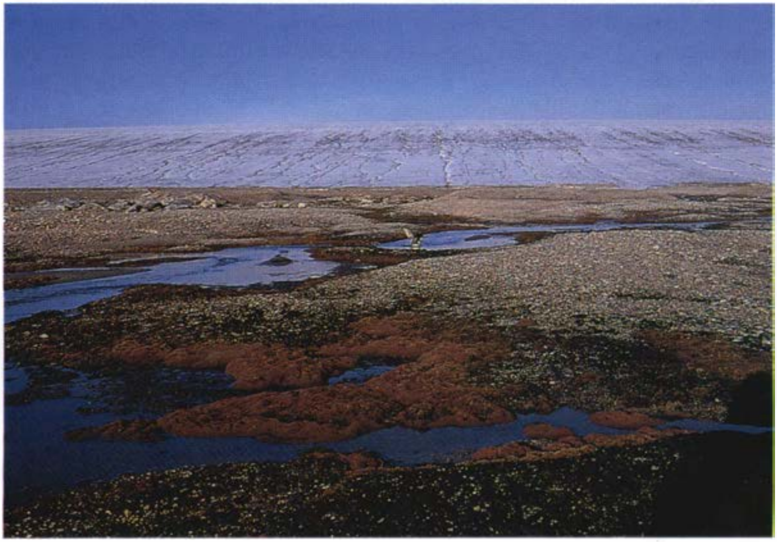
***Fig. 64** Three generations of rock can be seen on the east coast of Storøya. The oldest rock is grey Proterozoic gabbro. This has been intruded by light-coloured granite. Dark sheets of dolerite of Jurassic-Cretaceous age are the youngest, cutting both the gabbro and the granite.*

East of Duvefjorden is mostly migmatite, gneiss and granite. Both here and on Sjuøyane, the migmatite, gneiss and metamorphosed rocks are probably older than the sedimentary rocks further west beside outer Rijpfjorden and Franklinfjorden. In the east are largely Precambrian sedimentary rocks that were metamorphosed and invaded by granite, the last time during the Silurian. On Kapp Laura in the far northeast of Nordaustlandet, characteristic, layered gabbros and diorites are exposed. Their thickness is estimated to exceed 3 km. They intruded the Precambrian rocks towards the end of the Caledonian earth movements. The same kind of gabbros and diorites are found on Storøya, the small ice-free headlands on the east coast of Kvitøya, and the southern half of Karl XII's Island. Gneisses and granites are the most common rock types on the flat headland of Andréeneset, furthest south on Kvitøya. It was here that Salomon August Andrée and his two friends perished in 1897; the ballooning expedition had its last camp between the knolls of gneiss near the beach and the barren glacial meltwater plain in front of the Kvitøyjøkulen glacier (Fig. 66).

A small, but geologically interesting area, is Isispynten, an approximately 1 km long point protruding from beneath Austfonna on the east coast of Nordaustlandet. Several rock types occur here, the oldest being gneiss containing

*Fig. 65 Folded banded gneiss from Andréeneset on Kvitøya. Younger granitic veins transect the fold.*

*Fig. 66 An alluvial plain formed by a glacial meltwater river on Andréeneset, Kvitøya; Kvitøyjøkulen in the background.*



fragmented layers of calc-silicate rock (skarn). The gneiss is transected by amphibolite, itself invaded by grey granite and basic sheets. The final igneous rock to intrude, cutting all the above, was light red granite, in the form of dykes. It resembles the Rijpfjorden granite and is probably contemporaneous with that. Four generations of rocks can therefore be observed at Isispynten.

*Carboniferous, Permian and Triassic*

No Devonian strata have been found on Nordaustlandet, and Middle Carboniferous beds were deposited directly on folded and eroded basement. Good examples are found near Wahlenbergfjorden, on the north side on Idunfjellet and innermost on the south side of the fjord on the promontory of Clarendonnæringen. The thickness of the entire Carboniferous, Permian and Triassic on Nordaustlandet is about 640 m.

On the south side of Wahlenbergfjorden, good sections occur through almost horizontal strata on the mountains around the bay named Palanderbukta. Apart from up to 35 m of sandy beds lowermost, the strata largely consist of marine deposits of Middle Carboniferous to Lower Triassic age. As in the Kapp Starostin Beds of the Festningen section in Isfjorden, the Upper Permian contains richly fossiliferous and siliceous beds. These Upper Permian beds are easily distinguished because they are highly resistant and form steep cliffs such as on Selanderneset, a headland outermost on the south side of Wahlenbergfjorden (Fig. 68). The lower portion of these hard beds contains large numbers of fossil brachiopods, moss-animals and sea lily ossicles. Green glauconitic sandstone characterises the uppermost Permian. The Triassic strata forming the uppermost, approximately 210 m, of the succession south of Wahlenbergfjorden are chiefly shales and siltstones. The large plateau glacier of Austfonna conceals the boundary between the basement and the Carboniferous, but it is likely to run east-southeastwards from the inner part of Wahlenbergfjorden. This agrees with the presence of erratics derived from the Carboniferous beds and found on Isispynten.

*Dark intrusions*

The youngest rocks on Nordaustlandet are sheets of dolerite of Jurassic-Cretaceous age. Large ones are found, among elsewhere, around Wahlenbergfjorden and on the islands in Hinlopenstretet, and they also occur in the basement on Lågøya and around the entrance to Brennevinsfjorden (Fig. 67). Beside Wahlenbergfjorden, the dolerite occurs as sills between the horizontal sedimentary rocks. Because of their ability to withstand weathering, the sheets are often preserved as caps on hill tops, as on Idunfjellet.

*Quaternary and landscape features*

The shapes of hills on Nordaustlandet and surrounding islands show that the large glaciers during the various ice ages mostly scraped, wore down

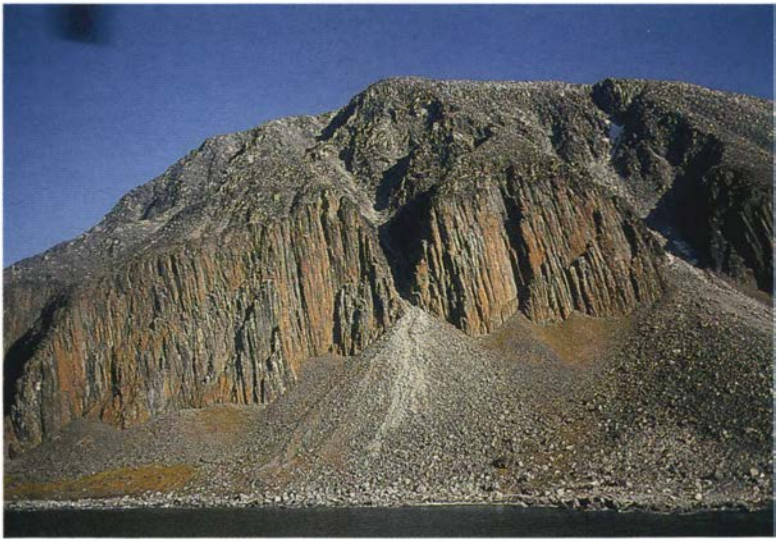


*Fig. 67 Doleritic sill showing columnar jointing. Basisfjellet on the north side of Brennevinsfjorden, Nordaustlandet, viewed from the southwest.*

*Fig. 68 Selanderneset, outermost on the south coast of Wahlenbergfjorden on Nordaustlandet. The lower half of the hillside consists of Permian strata, and these are overlain by Triassic rocks. On the summit is a sill of hard, dark dolerite of Jurassic-Cretaceous age.*

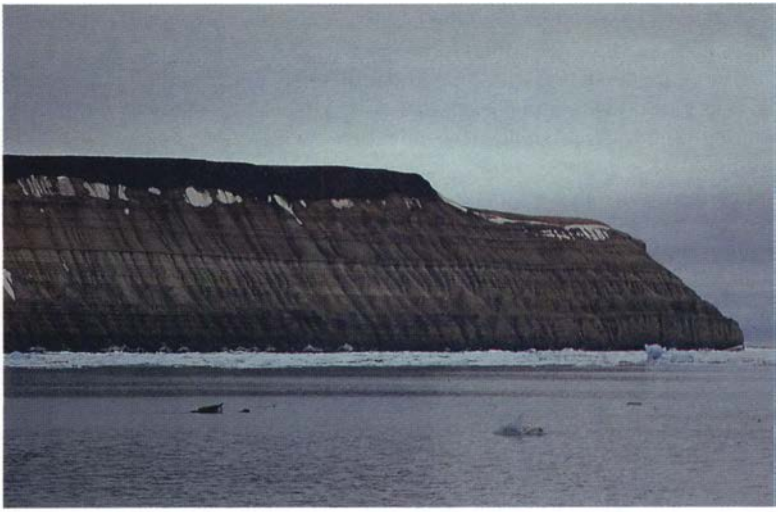


***Fig. 69 Migmatite erratic on Behounekodden, north of Austfonna, Nordaustlandet.***

and smoothed out the landscape. The islands are dominated by rounded hills, not the sharply pointed mountains that typify areas with the same rock types in northwestern Spitsbergen. Large areas of glacier still survive on Nordaustlandet and have many features in common with glaciers in Greenland and the Antarctic. Austfonna is almost a small ice cap; measuring approximately 7000 $km^2$, it is about half the size of Northern Ireland and thirteen times larger than the largest area of glaciers on the Norwegian mainland, Svartisen in North Norway.

The superficial deposits on Nordaustlandet almost entirely consist of screes, block fields and raised strandlines; there are scarcely any fluvial deposits and rivers often flow on either bare rock or block field. The Stega at the head of Rijpfjorden flows along a canyon in granite, cascading down many steep steps (Fig. 63). The largest strandflats are found in northwestern Nordaustlandet, around Murchisonfjorden and on the low, flat, 80 $km^2$ large Lågøya. In Murchisonfjorden, the direction of inlets and headlands is clearly pre-determined by the NNW-SSE trend of major folds. Svartknausflya, just west of Bråsvellbreen, is the largest strandflat in the south. Here, it is obvious that the land has risen since the Ice Age; a series of raised strandlines crosses the plain up to an altitude of 120 m. Whalebones are found at 70 m and tree trunks thought to have drifted ashore more than 46,000 years ago now lie 90 m above sea level. The largest area of moraine on Nordaustlandet also lies just west of Bråsvellbreen, more or less continuous moraines covering an area of about 70 $km^2$.

# THE ISLANDS IN THE EAST

## BARENTSØYA, EDGEØYA, HOPEN

### *Permian*

The oldest rocks on the islands date from the Upper Permian and are only exposed in a few small areas in the far northeast of Barentsøya and central and southern parts of Edgeøya. They correspond to the hard, Upper Permian beds on Spitsbergen which, among elsewhere, are prominent on Akseløya and Templet, and consist of alternating sandstone and siliceous limestone, often containing large quantities of brachiopods. The Permian beds on Barentsøya owe their presence to a gently southwestward-plunging syncline, the oldest strata therefore appearing in the northeast where the exposed Permian is approximately 300 m thick. On Edgeøya, updoming of the strata has led to exposure of the underlying Permian beds.

### *Triassic*

Triassic sedimentary rocks, mostly Upper Triassic, cover the greater part of the islands. Shales, siltstones and sandstones formed from deposits near river estuaries and in shallow marine shelf environments are most common. The total thickness is about 700 m. A thin (0.1-0.4 m), but widespread, coal seam is found in the Upper Triassic on both Barentsøya and Edgeøya. Fossilised tree trunks and leaves can be found in and near the coal seams. Ammonites are otherwise common fossils, and some beds contain many reptile remains. The beds are horizontal or only gently dipping, except at Mistakodden on the extreme west of Barentsøya where they are intensely folded on NE-SW trending axes, perhaps because of pressure exerted on the strata when magma was intruded, crystallising into dolerite.

Some unusual faults are found in a few areas. They cut through some beds, but do not extend into the underlying strata. These are called growth faults, and are caused by sliding in unstable masses during deposition in a river delta. The underlying material was stable and therefore remained in place. Such faults are particularly prominent at Kvalpynten on southwestern Edgeøya.

Hopen and the southernmost part of Edgeøya probably only have Upper Triassic rocks. The beds dip gently eastwards and the very uppermost ones may belong in the Jurassic. The Triassic strata on Hopen are around 500 m thick and contain some thin coal seams and plant fossils, particularly in the east.

### *Jurassic-Cretaceous*

Dark dolerite was intruded into the Triassic strata around the time of the transition from Jurassic to Cretaceous, and is most prominent on Barentsøya and the southern part of Edgeøya. The small Tusenøyane islands consist entirely of dolerite. Many underwater rocks formed of this hard rock make the waters in this area difficult for larger ships.

## Igneous rocks

Igneous rocks form when molten rock (magma) is cooled and solidifies. They are classified by their mode of formation and mineral content. Plutonic rocks solidify at great depth, slow cooling often producing coarse-grained rocks, examples being granite and gabbro. Dykes and sills are minor intrusions formed from magma that penetrates into fissures in the rock and solidifies at relatively shallow depths. These are medium- and fine-grained rocks, exemplified by dolerite. Extrusive rocks crystallise from magma that rises all the way to the surface where it solidifies; rapid cooling and solidification often results in fine-grained rocks, an example being basalt.

GRANITE Medium- to coarse-grained plutonic rock. Main minerals are alkali-feldspar, quartz and mica.

GABBRO Dark, coarse-grained plutonic rock chiefly containing calcium-rich plagioclase and iron- and magnesium-rich minerals such as pyroxene, hornblende and olivine.

DIORITE Grey or greyish black, coarse-grained plutonic rock composed of plagioclase, hornblende and often dark mica. Resembles gabbro, but the plagioclase is less rich in calcium.

BASALT Dark, fine-grained extrusive volcanic rock, containing among other minerals, plagioclase and pyroxene. Chemically resembles gabbro.

DOLERITE Medium-grained, dark dyke rock, containing the same minerals as gabbro and basalt.

SILLS AND DYKES Sheet-like bodies of rock, usually formed from molten matter that has penetrated into a fissure in existing bedrock and solidified. Whereas sills penetrate between rock beds and solidify there as plate-like bodies, dykes transect the strata and are frequently vertical or steeply inclined to bedding.

*Quaternary and landscape features*

Block fields, and finer weathering material too, cover the greater part of the islands, but other Quaternary superficial deposits are also found, especially on Edgeøya. The northeast has large areas of raised shore deposits, and this is probably one of the areas in Svalbard where old strandlines are most prominent. Large tracts of patterned ground are also present here. The largest fluvial deposits are found in Dyrdalen on southern Edgeøya.

*Oil and gas*

Caltex drilled to a depth of 2823 m on northwestern Edgeøya in 1972 and found only slightly metamorphosed Ordovician and Silurian strata, directly overlain by the Carboniferous, in the lower part of the borehole. In the same year, Fina drilled further south on the island, reaching a depth of 2531 m where there was Devonian sandstone. The difference between the boreholes may be explained by inferring a fault between them causing a relative uplift of the land to the north to form dry land during the Devonian with no possibilities for deposition of strata. On Hopen, Fina drilled a 908 m deep borehole in the south in 1971 and a 2840 m deep one in the north in 1972. Neither oil nor gas were found on Edgeøya or Hopen.

## KONG KARLS LAND

*Triassic, Jurassic and Cretaceous*

The strata are almost horizontal and their total thickness of about 400 m spans the time from late Triassic to early Cretaceous. Some of the sequence is poorly indurated, particularly the Jurassic deposits, which often consist of sand and clay. Triassic and Lower Jurassic beds are largely sandy and were deposited in deltas or shallow water; beautiful, large-scale cross beds are common (Fig. 70). The sea covered huge areas in the late Jurassic and early Cretaceous, and dark shales with some limestone beds dominate. As many as ten species of belemnite have been found in these deposits and a well-preserved skeleton of a swan-necked marine reptile, a Plesiosaur, was found in 1973 in a Jurassic bed on the north side of Kongsøya. Even its stomach was preserved, containing the fossilised remains of its last meal, consisting of plants and squids. Sandstones are common in the uppermost Cretaceous, and occasionally contain coal seams.

The hills on the northwest coast of Kongsøya have good sections through the succession, and fossilised tree trunks and roots in which the organic material has been replaced by silica can be found in the Cretaceous. The structure of the silicified wood is so well preserved that it is possible to count the annual rings and study the structure of the cells in this 130 million years old fossilised wood. On Svenskøya the most continuous succession is found in the southwest.

Early in the Cretaceous, magma forced its way to the surface on Kong Karls Land to solidify as dark basaltic lava. Two lava flows have been found, separated by Lower Cretaceous sandstone. The lower and largest one varies in thickness from 15 to 43 m. The basalt often displays distinct hexagonal columnar jointing, this being especially prominent in the cliffs along the coast, for example, on the western part of Kongsøya. The basalt has protected the frequently unconsolidated beds beneath from erosion, helping to preserve Kong Karls Land as a land area instead of it having be-

***Fig. 70 Cross-bedded Jurassic sand on Hårfagrehaugen, on the north side of Kongsøya, Kong Karls Land.***

come sand and mud on the floor of the Barents Sea.

*Quaternary and landscape features*

More than 80 % of Kong Karls Land is lower than 100 m and much of this lowland consists of strandflat with raised strandlines. The extensive ice sheet of the last Ice Age reached its greatest thickness in this part of Svalbard, and land uplift has also been at its maximum here, as much as about 130 m. Calculations show that the ice sheet may have eroded away a thickness of more than 1000 m of bedrock in the Kong Karls Land district during the last Ice Age.

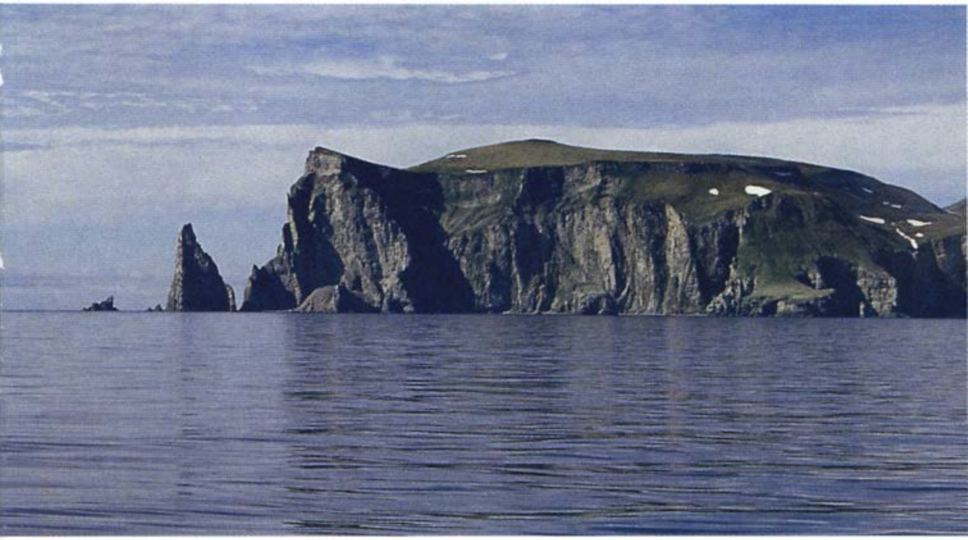


***Fig. 71 The southern tip of Bjørnøya seen from the northwest, showing Fuglefjellet and the craggy stack named Stappen. All the stack and most of the cliff consist of gently dipping Ordovician dolostone, but horizontal Upper Carboniferous beds occur at the top.***

## BJØRNØYA (BEAR ISLAND)

Although this island only measures 175 $km^2$, many geological periods are represented, from the Precambrian basement to the Triassic. Basement rocks are exposed on less than a quarter of the island, being confined to Proterozoic and Ordovician strata on the lower slopes of Antarcticfjellet in the southeast. Carboniferous beds are found on the highest peaks here. Igneous rocks are not present, and the youngest rocks, which are Triassic, only occur on the very summit of Miseryfjellet on the east side of the island.

*Basement*

The basement on Bjørnøya only comprises originally sedimentary rocks, and these are less metamorphosed and deformed than otherwise in Svalbard. The strata, which exceed 1200 m in thickness, are mostly dolomitic and calcareous limestone. Proterozoic beds with fossil algal structures (stromatolites) are found lowermost on Antarcticfjellet. These are probably contemporaneous with similar beds just beneath the tillites on Spitsbergen and Nordaustlandet. There are also dolostones which may be of Cambrian age. Increasingly younger beds are exposed up the mountain and the uppermost

***Fig. 72** Miseryfjellet on the east side of Bjørnøya. Devonian occurs lowermost, Carboniferous in the cliffs, and dark Triassic beds at the top. A large landslide is seen on the left, Carboniferous and Triassic strata having slid down from the upper part of the mountain to lie on the beach.*

basement is Ordovician limestone containing numerous fossils, especially squids, but also snails, brachiopods and corals. These are closely related to species found in North America, but unlike forms that can be found in rocks of the same period in the Oslo region or the Baltic. This is one reason why geologists believe that at least parts of Svalbard were originally closely related with a continent in the west (Laurentia) before the ocean closed and the Caledonian mountain chain was formed in Silurian times.

*Devonian-Triassic*

The deposits on Bjørnøya dating from the Devonian and Lower Carboniferous form what may be looked upon as a single transitional unit having a total thickness of more than 700 m. It is predominantly a continental sequence comprising sandstones, mudstones and conglomerates. Coal seams and well-preserved plant fossils, mostly fern-like plants, are found in many beds. The strata were deposited on extensive alluvial plains and are readily distinguished from the Ordovician calcareous and dolomitic marine limestones forming the basement. The Devonian and Lower Carboniferous sediments were transported from a higher area of land located to the southwest, the difference in height probably being a result of a NW-SE trending fault.

The Upper Carboniferous and Permian strata (totalling about 550 m) and the Triassic (about 200 m) are, as on Spitsbergen, dominated by marine and coastal deposits. They are often rich in fossils; some Upper Carboniferous beds consist practically entirely of brachiopods including *Spirifer keilhavii*, a species first found here by the Norwegian geologist Keilhau in 1827. This was one of the first fossils described from Svalbard. The Triassic strata on the summit of Miseryfjellet, mostly consist of grey shales deposited in a shallow marine environment, and among the fossils found in them are armour-plated toads and many species of bivalve. Block faulting and uplift in the Bjørnøya region in the Permian has resulted in the thickness of Lower Triassic strata being less than in most parts of Spitsbergen. Even though the uppermost Permian beds are lacking on Bjørnøya, conditions seem to have remained relatively stable since the mid-Permian.

*Quaternary and landscape features*

A flat plain in the north and west, and hills in the south and southeast, is how the landscape can be described in simple terms. The plain is almost a strandflat, mainly less than 50 m high, covered by rocks and having numerous tarns and lakes. Most are shallow, but depths of more than 30 m have been measured in places. The plain generally ends in a 10-30 m high cliff facing the sea, which makes landing from a boat impossible in most places. The sea is steadily excavating its way inland, and erosion is particularly rapid in the less consolidated, younger rocks.

The southern part of the island is dominated by two mountains, Miseryfjellet (535 m) and Antarcticfjellet (360 m). The southernmost coast with Hambergfjellet and Fuglefjellet has vertical cliffs more than 400 m high, particularly where the sequence contains hard, resistant dolomitic beds. Near the southern tip, the excavating power of the waves, along with jointing in the rock, have formed troll-like stacks such as Sylen (80 m) and Stappen (186 m). Caves are also found here, including the well known, about 100 m long, Perleporten which can be entered using a small boat.

Bjørnøya no longer has glaciers, but fragments of moraine, ice striations and erratics show that there used to be active glaciers here. Perhaps conditions used to be like they are now on Kvitøya in northeastern Svalbard. Such distinct strandline terraces as can be seen elsewhere in Svalbard are not found on Bjørnøya which was situated marginally to the ice masses and was practically not depressed. There has therefore only been an insignificant amount of land uplift since the last Ice Age. In areas with Devonian and Lower Carboniferous sandstones, such as central and northeastern parts of the island, the surface is often strewn with angular boulders formed by frost weathering of the bedrock. Where limestone is present, the surface is more even and solifluction is extensively developed. Permafrost on Bjørnøya usually penetrates to 50-75 m below the surface, not as deep as in other parts of Svalbard. Northwest of a lake named Djupvatnet on the southwestern side of the island, a stream called Jordbruelva has dissolved Middle Carboniferous limestone creating a 3 km long subterranean course.

*Former mining activity*

In the basement on southeastern Bjørnøya, around Russehamna and Sørhamna, mineral deposits are found in veins and dykes in dolomitic and calcareous limestone. A 10-30 cm broad vein of barytes accompanied by some galena is found at Russehamna. This was first investigated in 1916. The same type of barytes-galena deposit was found and investigated in 1927 a little further southeast, at Blyhatten and Russeelva. All these deposits also contain a little sphalerite and small quantities of iron pyrites and chalcopyrite. A company named Bjørnøen A/S began mapping these mineral deposits in 1925 and carried out trial working of galena until 1930. The irregularity and small size of the deposits and high operating costs led to mining being abandoned then, after about 500 tons of lead ore had been extracted.

Coal seams can be seen along the east coast from Miseryfjellet to the northeastern tip of the island. They are found in both Devonian and Lower Carboniferous strata, the best ones in the Devonian. I/S Bjørnøen and later Bjørnøen A/S operated a coal mine near Tunheim from 1916 to 1925, in barren landscape on the northeastern side of the island. What was called the A seam, about 1.45 m thick, was worked. A railway line, power station, radio station and engineering shop were among the facilities constructed, and in the most active period up to 182 men spent the winter there.

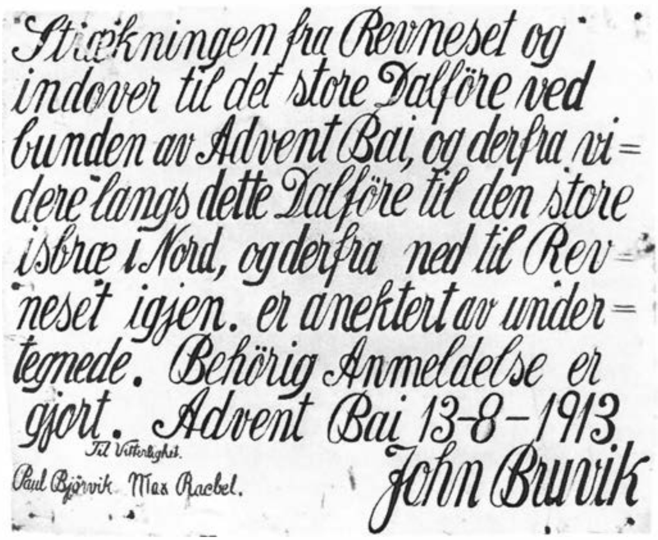
The coal deposits on Bjørnøya are more difficult to work than those in the Isfjorden district on Spitsbergen because most seams are thin and impure, and faults split the deposits into several blocks. Loading of coal at Tunheim was also difficult because of the absence of a natural harbour. With low coal prices in the 1920's, Bjørnøen A/S gradually got into financial difficulties and had to receive support from the Norwegian government. In 1925, it was decided to temporarily cease mining operations, and there has never been any activity there since. The only permanent residents on Bjørnøya man the radio station on the north coast of the island.

# ECONOMIC GEOLOGY

Because the natural environment of Svalbard is extremely sensitive to disturbance caused by vehicles, machinery, constructional work and the like, large parts of the archipelago are protected by legislation. Five large Nature Reserves and Parks have been set up, as well as a number of smaller ones. Together, these cover about 54 % of the area. Mining and prospecting for coal, minerals, oil and gas is therefore largely limited to the non-protected areas. Interim exceptions are granted only where claims had already been approved when the protected area was established. The protected areas are dealt with on page 153-154.

The Mining Regulations for Svalbard have been laid down in a special document that Norway was required to prepare to comply with the terms of the Svalbard Treaty signed in 1920. Prior to that, Svalbard was in reality a no-man's land lacking legislation controlling industrial activity. The Commissioner of Mines (Bergmesteren), as the representative of the Norwegian government, according to specially stipulated requirements complying with the Mining Regulations, is empowered to give citizens of treaty signatories the right to prospect for minerals and rocks, and allots claims (specifically defined areas) where mining and quarrying may be carried out. The Mining Regulations, in other words, determine the procedure that must be followed to obtain permission to carry out mining or quarrying in Svalbard. The legislation also embodies provisions concerning taxes, fees and other charges, the relationship between the claim holder and the landowner, and protection of the workers. The Commissioner of Mines undertakes the required inspection of find points, claims and mining and quarrying plant to ensure that the regulations are adhered to. As of 1 January 1993, a total of 7329 $km^2$ or about 12 % of the area of Svalbard was covered by claims. Of this, Store Norske Spitsbergen Kulkompani A/S has about 45.4 %, Kirkland A/S about 14.7 %, Trust Arktikugol 7.6 %, Petro Arctic AB about 6.4 %, Statoil about 6.6 %, and seven other companies a total of about 19.3 %.

Because Svalbard is situated far from the most important markets for raw minerals, and transportation and operating costs are high, it is more difficult to achieve profitable operations here than in areas further south. Many attempts at coal and mineral extraction have therefore ended in failure. There has, nevertheless, been lively optimism and hope of profitable discoveries, and many attempts have been made to start extraction, particularly in central and western parts of Spitsbergen. Remains of operating plant, huts and houses are therefore still to be seen in many places. Nowadays, only coal is extracted in Svalbard.



Strækningen fra Revneset og
indover til det store Dalföre ved
bunden av Advent Bai, og derfra vi=
dere langs dette Dalföre til den store
isbræ i Nord, og derfra ned til Rev-
neset igjen. er anektert av under=
tegnede. Behörig Anmeldelse er
gjort. Advent Bai 13-8-1913
Til Vitterlighet.
Paul Björvik Max Rachel. John Bruvik

***Fig. 73** An early notice recording the annexation of an area of coal deposits between Adventdalen and Sassenfjorden.*

## HEAT FROM FROZEN ROCK

Even though coal was discovered as early as the whaling period, and several small loads were shipped to North Norway during the 19th century, it was not before about 1900 that people became aware that large coal deposits were to be found in Svalbard. When the skipper of a sealing vessel, Søren Zachariassen, returned to the mainland in the summer of 1899 with about 6 tons of good quality coal from the Isfjorden district, serious interest for the coal and mineral deposits in Svalbard began to be aroused.

In 1900, a business venture named Kulkompaniet Isefjord was started, followed in 1901 by Trondhjem-Spitsbergen Kulkompani. In 1906, the latter company sold the areas it had annexed near Adventfjorden to two Americans named Ayer and Longyear who started the Arctic Coal Company in the same year. In 1916, they sold their rights and plant to Store Norske Spitsbergen Kulkompani A/S (commonly called Store Norske) which is currently the only Norwegian company carrying on mining in Svalbard. Its mines are close to Longyearbyen and use modern equipment to extract Tertiary coal. To have more legs to stand on, Store Norske in 1988 set up several subsidiaries, Svalbard Samfunnsdrift A/S with responsibility for the infrastructure and running the community in Longyearbyen, Svalbard Næringsutvikling A/S which is intended to promote the establishment of new, profitable business interests in Svalbard, and Spitsbergen Travel A/S concerned with tourism,

## Coal, useful minerals and rocks

COAL Combustible, carbon-rich rock formed from peat and other plant remains through compression and slight heating in the absence of oxygen. Lignite (brown coal) forms first, and contains some water and other substances. The process continues to form bituminous coal and, finally, anthracite, the cleanest form of coal. Bituminous coal is worked in Svalbard.

COAL SEAM A common term for a bed of coal.

GALLERY A mine tunnel.

FACE Position in mines where coal or ore are actually mined - often called STOPE in other mines than coal mines.

SCREENING Manual sorting at the pit head to separate large stones from coal (or ore).

DRESSING Mechanical cleaning process to separate coal or ore from stones.

MAGNETITE Iron oxide containing both bivalent and trivalent iron; black, shiny and magnetic. Important iron ore.

HAEMATITE Iron oxide containing trivalent iron. Often occurs in black, shiny flakes.

GALENA Lead sulphide, an important lead ore, often occurring in cubic crystals.

SPHALERITE Zinc sulphide, an important zinc mineral; often found with galena.

IRON PYRITES Iron sulphide, light-coloured, shiny, bronze-coloured mineral.

CHALCOPYRITE Copper-iron sulphide, darker, shiny and bronze-coloured; important copper mineral.

ARSENOPYRITE Iron-arsenic sulphide, shiny and silvery.

GYPSUM Hydrous calcium sulphate. One mode of formation is through evaporation of sulphate-bearing sea water in a carbonate-rich environment.

ANHYDRITE Anhydrous calcium sulphate, often found with gypsum.

PHOSPHORITE Phosphate-rich sedimentary rock, often formed from animal excrements.

➡

MARBLE Altered (metamorphosed) limestone. Increase in heat and/or pressure causes limestone to recrystallise to coarser and often purer marble. Dolomitic marble is recrystallised dolostone.

ASBESTOS A variant of the mineral serpentine, a magnesium silicate. Occurs as fibres and flakes, and is an alteration product of olivine and pyroxene.

BARYTE Barium sulphate. Because of its high specific gravity, one use is in drilling mud for petroleum-drilling purposes.

and providing accommodation and meals. In 1934, Store Norske purchased Sveagruva at the head of Van Mijenfjord and has been working this on a limited basis in recent years. The plant has been ready for permanent working since 1987, but because of low coal prices only exploratory mining is so far (1993) taking place. The Store Norske mines together have extracted more than 21 million tons of coal between 1916 and 1993.

Kings Bay Kull Comp. A/S worked Tertiary coal deposits in Ny-Ålesund from 1920, but much faulting in the seams made these mines difficult to work and mining was abandoned in 1962 following a serious explosion.

There is also coal on Bjørnøya, of Devonian and Carboniferous age. Two Stavanger-based companies, I/S Bjørnøen and later A/S Bjørnøen, extracted a total of 116,000 tons from 1916 to 1925.

Russia has two mines working in the Isfjorden district, Barentsburg about 45 km west of Longyearbyen and Pyramiden in Billefjorden. Both are run by Trust Arktikugol. At Barentsburg, the company works Lower Tertiary seams that are almost identical to those worked by Store Norske near Longyearbyen. These seams provide bituminous coal that is cleaner and has a higher calorific value than the central European lignites of the same age. Considerably older coal, of Carboniferous age, is worked at Pyramiden. There used to be a third Russian colliery at Grumantbyen, 12 km southwest of Longyearbyen. In recent years, the total output of the Russian collieries has been around 400,000-500,000 tons a year, most of it being used in the power supply industry at Murmansk and Archangel. As in Longyearbyen, an effort is now being made to obtain additional income from increasing tourism in the region.

## GOLD, IRON AND MARBLE

Since the turn of the century, many attempts have been made to find and exploit deposits of minerals and stone. Many deposits have been found along the west coast of Spitsbergen and on Bjørnøya, but they have been small and when extraction has commenced it has always been of brief duration. Names such as Copper Camp near St. Jonsfjorden, Gipsdalen (Gypsum Valley) near Sassenfjorden, Sinkholmen (Zinc Holm) at Bellsund, Asbestodden and Jarnfjellet (Asbest Point and Iron Mountain) near Recherchefjorden, and Blyvika (Lead Cove) on Bjørnøya are all linked to small deposits of this kind. There was often a great deal of optimism and large sums of money were sunk into projects. At Millarodden on the north side of Bellsund, a hectic gold rush took place in 1908-12, but nothing came of it. Ore prospectors from the Northern Exploration Co. Ltd. claimed to have found "the world's largest iron ore deposit" at Recherchefjorden in Bellsund in 1918. More thorough investigations in 1919 showed that the deposit was economically insignificant. Similar iron ore deposits occur at Malmberget, about 15 km north of Bellsund, and Bouréefjellet on the northern part of Prins Karls Forland.

From around 1910, N.E.C. investigated marble deposits on Blomstrandhalvøya (also called Marble Island), just north of Ny-Ålesund. A great deal of money was spent on buildings and quarrying equipment, but despite reports telling of "marble of excellent quality and in unlimited quantity" this deposit was not economically viable, either.

In the younger sedimentary rocks of Devonian to Tertiary age, ore and mineral deposits are few and small. Gypsum is found in Carboniferous-Permian and phosphorite in Triassic strata at Sassenfjorden-Tempelfjorden and Billefjorden. However, as its quality is often inconsistent only small quantities have been taken out.

In 1985, Store Norske and Norsk Hydro signed an agreement to cooperate on prospecting for and exploitation of natural resources. An ore prospecting programme began in 1986, partly involving geochemical surveys. The prospecting has been directed at metals of high unit value, such as gold. Analyses for gold have revealed interesting areas in northwestern Spitsbergen.

## IS THERE OIL IN SVALBARD?

A small volume of gas was discovered at Grønfjorden as early as 1918, and in 1926 both that area and Sassenfjorden were examined more closely, but with negative results. Certain Mesozoic and Tertiary beds are rich in organic material, and the most promising source rocks for oil and gas seem to be dark shales of Lower and Middle Triassic age. They may contain large quantities of hydrocarbons and as early as 1919 it was reported that Triassic shales at Mohnbukta on the west side of Storfjorden smelled of oil. Modern petroleum prospecting did not, however, commence before 1960. In recent years, many companies have been carrying out investiga-

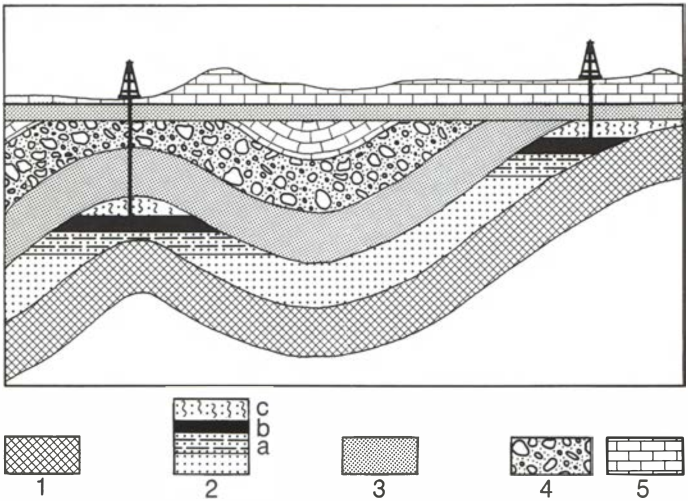



*Fig. 74 Oil drilling: 1. Source rock, 2. Porous reservoir rock with water (a), oil (b), and gas (c), 3. Impermeable cap rock, 4 & 5. Overlying rocks.*

**Oil and gas deposits**

Several conditions need fulfilling before oil or gas can be found. First and foremost, a source rock has to be present. This is a bed in which remains of dead animals and/or plants have accumulated to become chemically transformed into oil or gas. Microfossils can provide a great deal of information about the potential for finding source rocks.

If deposits of any significance are to be developed there must be a reservoir rock above the source rocks, i.e. porous, permeable bedrock in which oil and gas, which are light substances, are able to collect. Above these beds, there has to be an impermeable cap rock to form a "lid" preventing oil and gas from escaping to the surface. If source rocks, reservoir rocks and cap rocks have been ascertained, the last step prior to exploratory drilling is to locate structures which form good traps, for instance, an updoming of the beds where large quantities of oil and gas are able to collect (Fig. 74).

Reflected and refracted sound waves can be employed to map structures and the mechanical properties of rocks downwards through the Earth's crust (seismic methods). The sound can be produced by using compressed air, electricity or explosives. The method is widely used, along with measurements of gravity and magnetism (gravimetry and magnetometry), to find the most suitable places to drill for oil and gas.

tions on land and in the fjords on Spitsbergen to search out the most promising areas. Seismic studies are now widely used to determine which structures and beds occur beneath the surface. Strict measures have been introduced to protect the vulnerable natural environment in Svalbard when seismic work and drilling are going on.

Much exploratory drilling for oil and gas has been carried out in Svalbard since 1963, the deepest hole being about 3300 m. Even though several small gas finds have been made, no economically profitable gas or oil accumulations have been located. However, because the geology of the continental shelf surrounding Svalbard in part strongly resembles that in Svalbard itself, exploratory drilling and investigations of the bedrock on land will prove useful for those searching for oil and gas beneath the Barents Sea.

## TASKS AND CHALLENGES AHEAD

The main elements of the geology of Svalbard are now known, and the pioneering era is largely over. With the general mapping accomplished, work is now going ahead on preparing more detailed maps of the solid geology on a scale of 1:100,000. A great deal of effort is going into making these maps as precise as possible, and also obtaining a survey of the environmental consequences of human activity in Svalbard. Both pure and applied research on geological aspects are required to solve these tasks. Some fields of Svalbard geology on which much effort is now being expended are outlined below.

*1. Pollution and wear and tear on the natural environment of Svalbard.* Human activity will always have some impact on the natural environment. Such impact is particularly obvious in Svalbard in areas surrounding settlements, where the original environment has had to give way to buildings, roads, etc. It is important to protect the landscape as well as possible from various forms of disturbance. Geologists must contribute by mapping surface deposits to locate areas that will withstand disturbance best, and where such impact as vehicle tracks will be as slight as possible. Particularly vulnerable areas should be registered and protected from disturbance and traffic. In 1990, the Norwegian Polar Institute carried out infrared aerial photography of Svalbard. The 6000 photographs obtained are proving an important tool for mapping wear and tear on the terrain.

Even though Svalbard has an isolated location, the natural environment here, too, is exposed to far-transported pollution. To be in a position to monitor events, one requirement is to register the contamination of super-

***Fig. 75 Tracks left by a caterpillar-tracked vehicle 20 years ago on the coast between Isfjorden and Bellsund.***

ficial deposits such as sand, earth and clay on a long-term basis. A study of the content of far-transported environmental pollutants in the bottom sediments of fjords in Svalbard has already started and similar investigations are planned for land areas.

*2. How old is the Svalbard basement?* The youngest segment of the basement contains age-defining fossils, but the age of the older rocks is more difficult to determine and it is necessary to resort to radiometric age determinations of minerals. The oldest rocks have taken part in many of the upheavals experienced by the Earth's crust and minerals may have been recrystallised and "born anew" several times, the oldest ages being completely or partially obliterated.

New and improved methods of radiometric age determination are then able to help. Analyses carried out by advanced laboratories, combined with detailed field observations, enable increasingly older geological events to be distinguished. As the results of the new analyses become available, a new image of the oldest bedrock will appear. Work on these problems is strongly internationalised and scientists from many countries are participating.

*3. What happened in the Tertiary?* Great upheavals were caused when the European and North American continental plates drifted towards each other early in the Tertiary. The west coast of Spitsbergen was uplifted and the coastal belt became folded and faulted. Later in the Tertiary, when the two plates moved apart and the Northern Atlantic Ocean opened, faulting took place again and sedimentary basins were created. Geologists from several Norwegian and foreign universities and the Norwegian Polar Institute have in recent years been studying the effects of these Tertiary earth movements in Spitsbergen. The investigations have, among other things, shown that the impact was greater and can be traced further east than previously assumed. The work is continuing and it is planned to publish a special map of parts of Spitsbergen on a scale of 1:200,000. These investigations are of great value for the series of 1:100,000 geological maps being prepared for western Spitsbergen. This work, which has been going on over a large area, will facilitate the interpretation of problematical structures and deposits.

*4. Why is the climate changing?* Study of the deposits and of fossils found in them, from Precambrian times to the Quaternary, clearly demonstrates that the climate has changed considerably through the ages. These changes are reflected in the deposits and many scientists are now trying to find out more about the causes of the changes.

The European Science Foundation is co-ordinating a wide-ranging research project intended to investigate the relationship between climatic variations and deposits during the latter part of the Quaternary period around the northernmost Atlantic Ocean. The investigations are lasting four years, taking place in Greenland in 1990 and 1992 and in Svalbard in 1991 and 1993. Scientists from seven European countries are taking part in the project, including some from the Norwegian Polar Institute and several Norwegian universities. Much of the work in Svalbard is taking place on the easterly islands and in the Barents Sea. In 1993 the programme will include studying the transport of eroded material from land to sea in the Kongsfjorden area. The scientists are hoping that the results of the PONAM project will enable them to improve predictions of future changes in climate and perhaps put them in a position to propose measures to avoid undesirable changes.

# TAKE CARE OF SVALBARD!

Everyone who travels in polar regions or takes part in activities of one sort or another should be aware that the natural environment here is particularly sensitive to disturbance. Most plants and animals are more easily affected here than in more southerly latitudes, because they are in the border region of where life can exist at all. Helicopter traffic, for instance, tends to disturb birds in the breeding season. Excavation work and driving across the terrain often leave tracks and other scars on the landscape which may remain visible for a generation or more (Fig. 75). In many cases, the damage will become worse over the years, because frost action, thawing and soil erosion will become more effective. Vehicle tracks can become deep ditches. The permafrost, which is often several hundred metres deep, creates special problems. Only a thin surface layer thaws in summer. Because of the poor drainage, driving on such partially thawed ground may result in boggy areas where the original vegetation perishes. Since vital processes are slow moving and the breakdown of alien substances is slowed down by the low temperatures, pollution can often have a far more serious effect in the Arctic than at other latitudes.

Burying rubbish helps little. The frost soon brings it back to the surface. Burn as much as possible and take the rest back with you. Broken glass, tin cans, steel wire, cables and so on must not be left behind. They will damage birds and animals. Do not throw rubbish into the sea. It will appear on the beach later.

The cultural history of Svalbard is relatively young and objects regarded as cultural monuments are therefore often significantly younger than on the mainland. Human activity in Svalbard during the last 400 years is, nonetheless, well known, and may even go still further back. It is possible to come across relics of former activities. These cultural monuments are concrete proof of historical events in Svalbard, and it is important that they are not destroyed or disturbed. All such visible relics of earlier commercial operations, expeditions and other activities are valuable and should be preserved where they are found.

These general rules should naturally be followed whether you are inside or outside the areas protected by law.

## NATURE CONSERVANCY REGULATIONS

Increasing numbers of collisions between commercial interests and nature conservancy provided the impetus for a major effort on the part of the Norwegian government early in the 1970's to draw up conservancy regulations. A brief summary of the nature conservancy regulations that are currently in force is given below.

All wildlife not specifically listed among species permitted to be hunted


***Fig. 76 Protected areas in Svalbard.***

at that particular time of year, is protected according to the terms of the "Regulations concerning management of game and freshwater fish in Svalbard and on Jan Mayen".

Protected areas have been designated to counteract damage to the natural environment. These are shown in figure 76. The most important regulations in force are:

NATIONAL PARKS These areas are protected against all disturbance of a mechanised nature. It is forbidden to deposit rubbish or leave behind substances or objects which may damage animals or plants, or are unsightly. Mammals and birds and their habitations or nests are not to be damaged or disturbed. Plants and fossils must not be removed or damaged. Use of terrain-going vehicles and landing by aircraft is forbidden, except when exemption is given for special objectives.

NATURE RESERVES The same regulations as for national parks, except that the Governor (Sysselmannen) also has the power to forbid all traffic.

BIRD RESERVES The same regulations as for national parks, except that all traffic is forbidden from 15th May to 15th August.

PLANT PROTECTION AREAS All plant growths are protected from being collected or destroyed. As regards the Ossian Sars Plant Protection Area, it is also forbidden to put up tents.

A complete survey of the regulations that are in force are given in the "Nature Conservancy Regulations for Svalbard and Jan Mayen", publication T 516, published by the Norwegian Ministry of the Environment.

ADDITIONAL REGULATIONS To avoid damaging the natural environment through mining, quarrying, drilling for oil and gas, and so on, special, detailed regulations have been drawn up to regulate such activity.

## CULTURAL CONSERVANCY REGULATIONS

In view of the increase in traffic in Svalbard, it has also become necessary to introduce regulations protecting cultural monuments. The following are among the categories protected:

All graves, stones and bedrock with carved lettering or figures, meeting places and religious sites, irrespective of age. All fixed or moveable cultural monuments are, moreover, protected if they are thought to date from 1945 or earlier. This applies to buildings, house foundations, signs informing of occupation, hunting sites, blubber ovens, defences, and remains of mining and quarrying activities.

Additional information is given in "Regulations concerning cultural monuments in Svalbard", publication T 870, available from the Norwegian Ministry of the Environment.

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Agardhfjellet, map sheet D9G, *Temakart nr. 21*, 1992
Billefjorden, map sheet C8G, *Temakart nr. 5*, 1988
Braganzavågen, map sheet C10G, *Temakart nr. 4,* 1991
Isfjorden, map sheet B9G, *Temakart nr. 16*, 1991
Markhambreen, map sheet C12G, *Temakart nr. 22*, 1992
Sørkapp, map sheet C13G, *Temakart nr. 17*, 1992
Van Keulenfjorden, map sheet B11G, *Temakart nr. 15,* 1990
Van Mijenfjorden, map sheet B10G, *Temakart nr. 2*, 1985
Kvalvågen, map sheet C11G, *Temakart nr. 23*, 1993

**Preliminary maps on 1:100,000 scale. Black and white, without description**
Torellbreen, map sheet B12G
Negribreen, map sheet D8G
Adventdalen (new edition), map sheet C9G
St. Jonsfjorden, map sheet B8G

**Scale 1:40,000**
Quaternary geology and geomorphology in Gipsdalen

**Scale 1:10,000**
Geomorphology and Quaternary geology of Kvadehuksletta, Temakart nr. 8, 1987 (without description)

The above maps can be ordered from the NORWEGIAN POLAR INSTITUTE, PO Box 5072 Majorstua, N-0301 Oslo, Norway. A catalogue of the maps and publications of the institute will be supplied on request.

**Norwegian Polar Institute maps and the following references have been used when preparing the maps in this handbook.**

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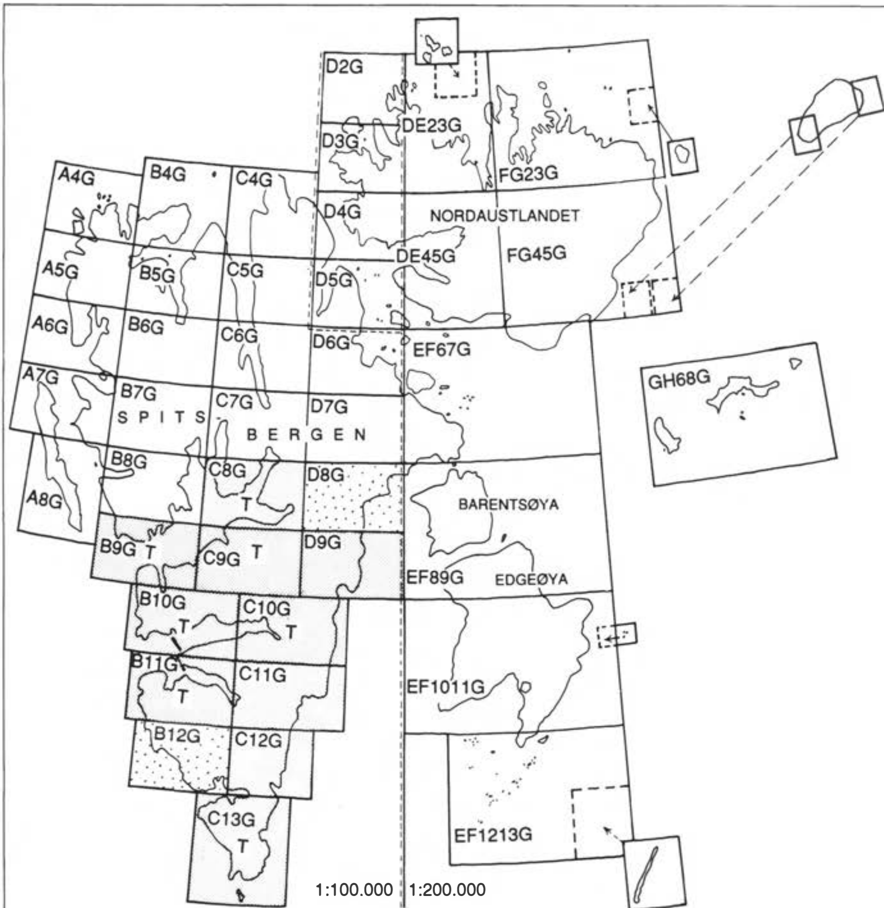
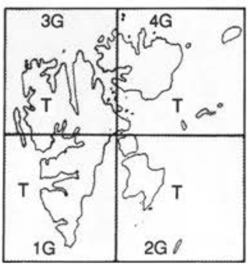
Various unpublished reports and notes from A. Andresen, T. van Autenboer, D. G. Gee, T. Gjelsvik, A. Hjelle, Y. Ohta and E. Tveten.

# INDEX

**Glossary of Norwegian geographical expressions translated into English.**

| | |
|---|---|
| **-berg(et)** | mountain, hill |
| **-bre(en)** | glacier |
| **-bukt(a)** | bay, inlet |
| **-dal(en)** | valley |
| **-elv(a)** | river, stream |
| **-fjell(a)** | mountain |
| **-fly(a)** | broad plain or plateau |
| **-fonn(a)** | glacier, ice sheet |
| **-halvøy(a)** | peninsula |
| **-hamn(a)** | harbour |
| **-holm(ane)** | holm(s), islet(s) |
| **-høgd(a)** | hill, height |
| **-jøkul(en)** | glacier |
| **-kapp** | cape, promontory, headland |
| **-kyst(en)** | coast |
| **-næring** | cliffbound headland or promontory |
| **-nes(et)** | headland, promontory |
| **-odde(n)** | point, tongue of land |
| **-pigg(en)** | peak |
| **-pynt(en)** | point |
| **-rygg(en)** | ridge |
| **-slette(a)** | plain |
| **-sund(et)** | sound, deep bay, |
| **-stretet** | strait, sound |
| **-tange(n)** | spit, tongue of land |
| **-topp(ane)** | peak(s), summit(s) |
| **-vatn(a)** | lake(s) |
| **-vik(a)** | cove, inlet |
| **-øy(ane)** | island(s) |
| **-øyr(a)** | sand spit, sandbank |




1:500.000

1:1.000.000 - SVALBARD & JAN MAYEN (utgitt/published)

1992

Trykt i farger, med beskrivelse (teksthefte: T).
Printed in colour, with description (booklet: T).

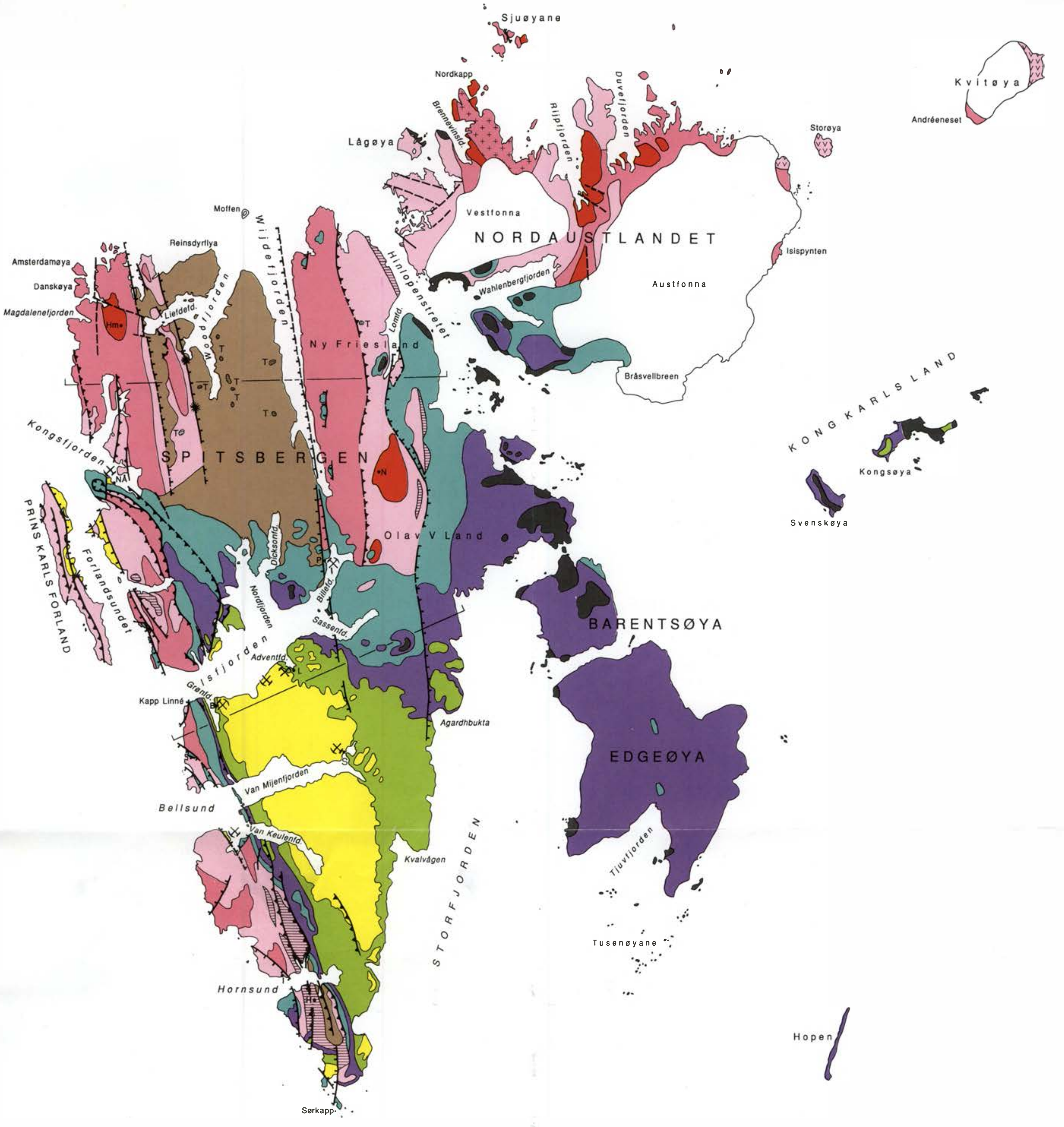
Foreløpig utgave (sort-hvit)
Preliminary edition (black-white)

C9G, 1G : Ny utgave under arbeid
New edition in preparation

A7G, A8G, B8G : Under arbeid
In preparation

BJØRNØYA
1:50.000

*Fig. 77*




MÅLESTOKK / SCALE 1 : 2 000 000

Km.

0 50 100 150 200

L: Longyearbyen NÅ: Ny-Ålesund K: Kinnvika S: Sveagruva
B: Barentsburg P: Pyramiden I: Isbjørnhamna

N: Newtontoppen 1717 m. H: Hornsundtind 1431 m.
Hm: Hornemantoppen 1131 m.

SKJEMATISKE GEOLOGISKE SNITT
*SCHEMATIC GEOLOGICAL SECTIONS*


Fra nord for Kongsfjorden til Hinlopenstretet
*From north of Kongsfjorden to Hinlopenstretet*


Fra sør for Kapp Linné til innerst i Storfjorden
*From south of Kapp Linné to innermost Storfjorden*

AVSETNINGSBERGARTER OG OMDANNEDE BERGARTER
*SEDIMENTARY AND METAMORPHIC ROCKS*

- Tertiær / *Tertiary* — NYTID / *CENOZOIC*
- Jura og kritt / *Jurassic and Cretaceous* — MELLOMTID / *MESOZOIC*
- Trias og underste jura / *Triassic and lowermost Jurassic*
- Karbon og perm / *Carboniferous and Permian*
- Devon og øverste silur / *Devonian and uppermost Silurian* — OLDTID / *PALEOZOIC*
- Kambrium, ordovicium og undre silur / *Cambrian, Ordovician and Lower Silurian*
- Øvre proterozoikum / *Upper Proterozoic* — Grunnfjell / *Basement*
- Undre og midtre proterozoikum / *Lower and Middle Proterozoic* — URTID / *PRECAMBRIAN*

STØRKNINGSBERGARTER
*IGNEOUS ROCKS*

- Kvartære basaltvulkaner / *Quaternary basaltic volcanoes*
- Tertiær basalt / *Tertiary basalt*
- Jura-kritt, doleritt og basalt / *Jurassic-Cretaceous, dolerite and basalt*
- Silur-devon/prekambrium?, granitt / *Silurian-Devonian/Precambrian?, granite*
- Sen proterozoikum?, gabbro / *Late Proterozoic?, gabbro*
- Normalforkastning, tagger mot innsunket blokk / *Normal fault, barbs towards downthrow block*
- Skyveforkastning, tenner mot overskyvningsblokk / *Thrust fault, teeth towards overthrust block*
- Kullgruve, i drift/nedlagt / *Coal mine, active/abandoned*