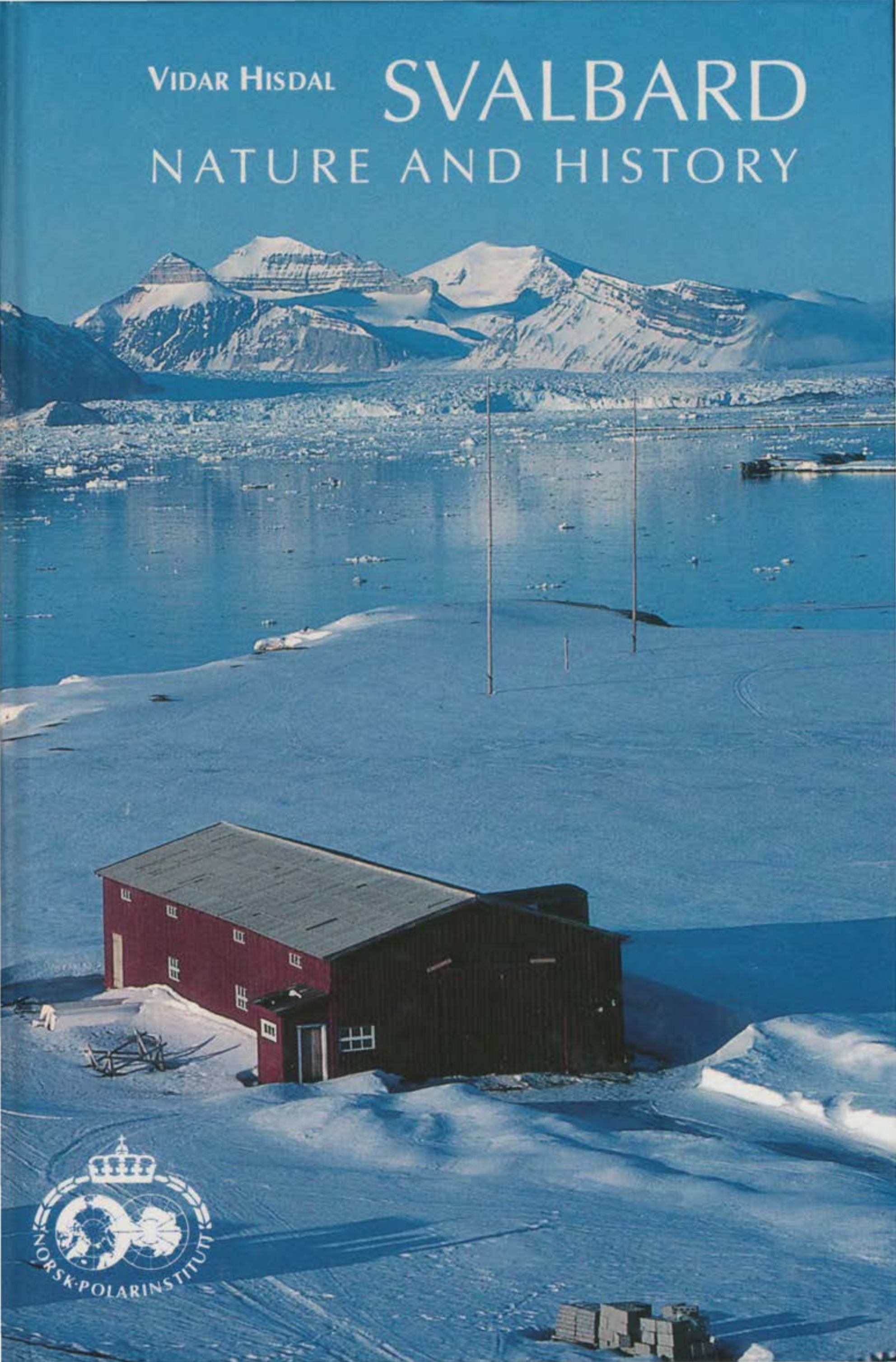
Vidar Hisdal

SVALBARD

NATURE AND HISTORY



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VIDAR HISDAL

SVALBARD
NATURE AND HISTORY

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PREFACE

This is an updated and significantly enlarged edition of an earlier Polarhåndbok entitled *Geography of Svalbard* (1975 and 1985). The book is intended to provide a summary of the natural conditions and history of the islands. More wide-ranging and detailed information from individual areas, will be found in publications listed at the end of this book.

I am grateful to many colleagues at the Norwegian Polar Institute for information and comments on matters within their special fields, particularly Susan Barr, Jon Ove Hagen, Sigurd Helle, Audun Hjelle, Linn Bryhn Jacobsen, Fridtjof Mehlum, Otto Salvigsen and Torgny Vinje. Likewise, I wish to thank all who have helped to prepare diagrams and maps, and provided photographs. A list of photographers is given on page 2.

I am also indebted to Richard Binns, who has translated the Norwegian edition of the book into English, and last but not least Annemor Brekke for her wholehearted effort to solve editorial and financial questions.

A grant kindly provided by the Non-fiction Literature Fund made it possible for me to visit Svalbard again, specially to gather material for this book.

April 1998
Vidar Hisdal

LOCATION AND SIZE

The floor of the Barents Sea is part of a vast continental shelf which rises above sea level furthest northwest to form the Svalbard archipelago.

Svalbard is the name applied to all the islands situated between 74° and 81°N, and 10° and 35°E. By far the largest and most important island is Spitsbergen (called Vest-Spitsbergen until 1969), which has a surface area of 38,000 km^2. A little further east, in order of size, are Nordaustlandet (14,500 km^2), Edgeøya (5000 km^2) and Barentsøya (1300 km^2). This group also includes numerous smaller islands (see the map at the end of the book).

East of this main group are a number of more isolated islands of moderate size. From north to south, they are Kvitøya, to which access is difficult and which is almost entirely glaciated, Kong Karls Land, which forms a separate, small archipelago, and the unusually long, narrow island of Hopen. Far to the south is Bjørnøya, which also belongs to Svalbard, even though it lies midway between the coast of Finnmark and the central part of Spitsbergen.

The total surface area of the islands is approximately 61,200 km^2, or about twice that of Belgium. The extremities are Rossøya in the Sjuøyane group furthest north (80°50'N, 20°21' E), Kræmerpynten on Kvitøya furthest east (80°14' N, 33°31' E), Keilhauøya off Bjørnøya furthest south (74°20' N, 19°03' E), and Fuglehuken on Prins Karls Forland furthest west (78°54' N, 10°27' E).

Even though Svalbard is situated far north, these islands are far from being the northernmost link in the chain of land areas surrounding the Polar Basin. Most of Zemlja Franca Iosifa (Franz Josef Land) to the east, and the northernmost parts of Greenland and Ellesmere Land in the west, extend further north. The world's northernmost land area, Kaffeklubben Ø off the north coast of Greenland, is situated almost 3° closer to the North Pole than Rossøya in Svalbard.

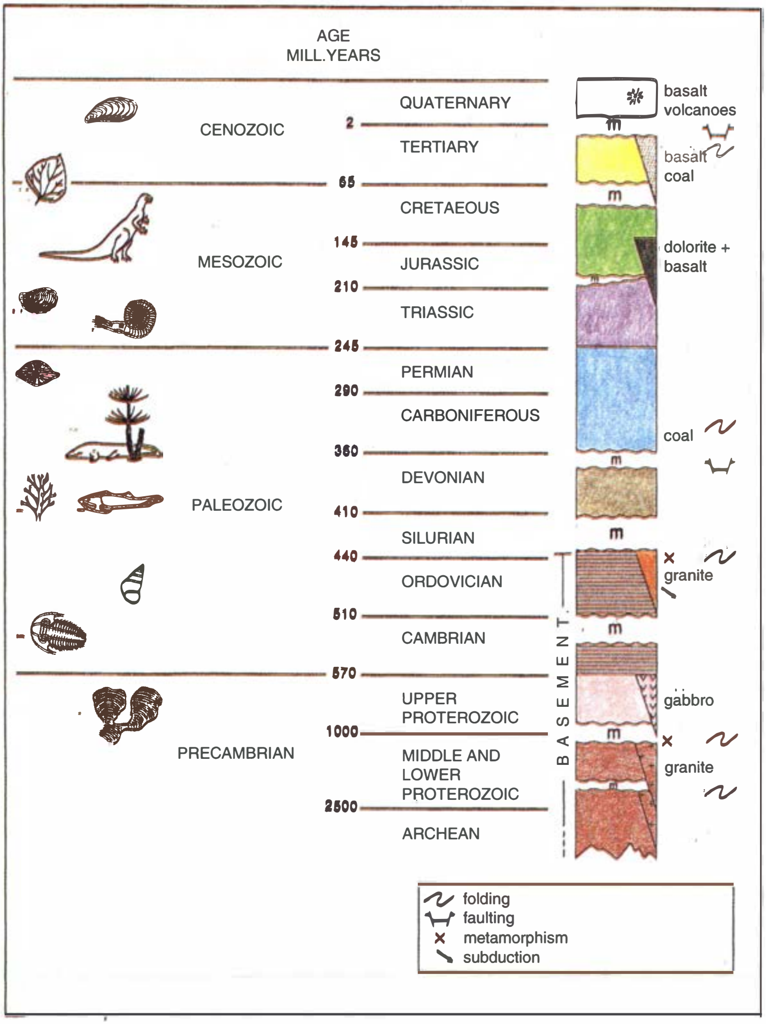

Fig. 1. The geological succession in Svalbard from Precambrian to Quaternary, along with a selection of typical fossils (after A. Hjelle 1993).

The geology of Svalbard is extremely varied. All the main periods of geological time are represented here (see Appendix I). The sparse plant cover, moreover, means that the bedrock is easily available for both the eye and the hammer, wherever the land is ice free. Svalbard has therefore been an attractive place for geologists to study for very many years.

Continental drift

To understand the geological conditions, both in Svalbard and elsewhere, it is vital to know about the vast and, sometimes, dramatic changes that have taken place in the Earth's crust over hundreds of millions of years. The *continental drift* theory is of paramount importance here. It maintains that the Earth's crust is divided into a number of huge sheets (plates), that have been and still are, continuously, yet extremely slowly, moving about relative to one another. Hence, in former geological periods, Svalbard had neither the same shape nor the same geographical location as it has today.

Good evidence exists that Svalbard crossed the Equator some 350 million years ago, on its way northwards. If this movement continues, it may reach the North Pole round about 50 million years hence. During this journey, it has experienced both tranquil phases and periods with folding, faulting and volcanism which resulted in the building-up of mountain chains. Moreover, the types of sediments and fossils present show that this part of the Earth's crust has sometimes been below sea level, sometimes dry land.

Precambrian and Palaeozoic

The oldest rocks, dating from the *Precambrian* and the early part of the *Palaeozoic* era (*Cambrian*, *Ordovician* and early *Silurian*), are exposed in a belt along the west coast of Spitsbergen and also on the peninsula separating Wijdefjorden and Hinlopenstretet, the northern part of Nordaustlandet, on Kvitøya, and furthest south on Bjørnøya. These rocks are well over 400 million years old and used to be called the *Hecla Hoek series* after a mountain on the north coast of Spitsbergen. Nowadays, they are generally referred to in Svalbard as simply the 'basement'. A mineral from northwest Spitsbergen that has been dated to about 3.2 billion years identifies the oldest known rock in Svalbard.

During the *Caledonian orogeny* (mountain building episode), most of these oldest rocks were folded, and pressure and heat transformed them into metamorphic rocks. Towards the end of Silurian time, they were invaded by molten magma from deep in the crust, which cooled to form, for the most part, hard granites whose resistance to erosion helps them to form some of the loftiest mountains on Spitsbergen.

Fig. 2. View southwestwards across Oscar II Land, near the west coast of Spitsbergen. Only the highest ridges and summits rise above the huge ice cover. (V.H.)

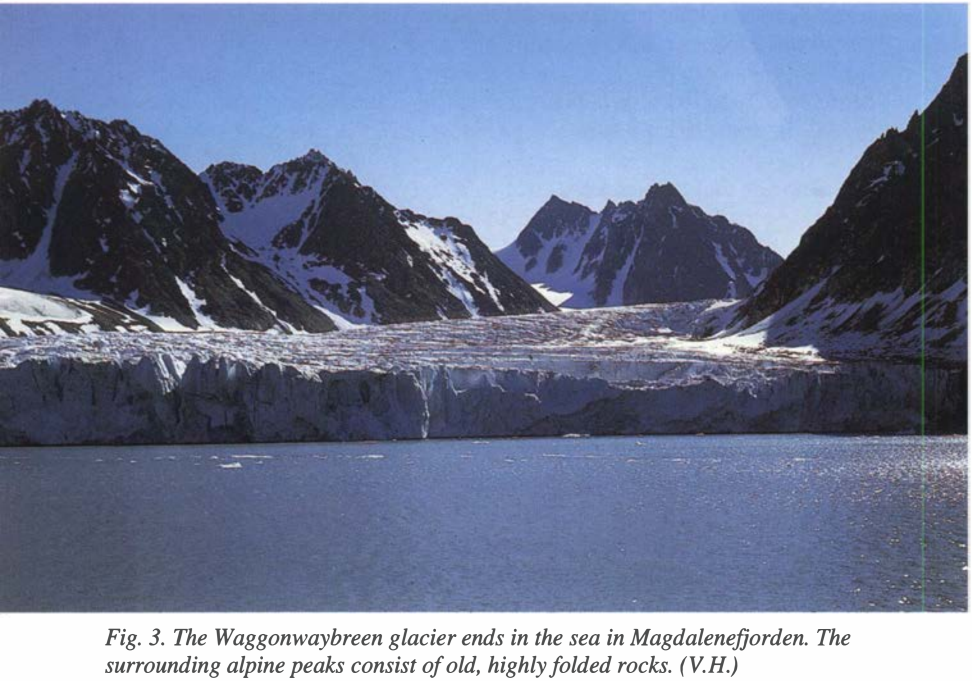

Fig. 3. The Waggonwaybreen glacier ends in the sea in Magdalenefjorden. The surrounding alpine peaks consist of old, highly folded rocks. (V.H.)

Fig. 4. Foldtinden, a mountain north of Bellsund, is in the Tertiary fold belt of western Spitsbergen. These Carboniferous and Permian beds were once horizontal. (Ø.L.)

Fig. 5. Skansen, a mountain on the west side of Billefjorden, one of the inner arms of Isfjorden. The geological layers are seen as differently coloured horizontal strata. (V.H.)

Following the tremendous Caledonian orogeny, these ancient, altered rocks became worn down by weathering and erosion to form what may be called a foundation (basement) for the geological construction of Svalbard. As time passed, this basement underwent faulting and thrusting, and in the course of several hundred million years it has been covered by thousands of metres of sediments.

These overlying, younger beds contrast strongly with the basement below. They are sedimentary rocks, sandstones, shales, limestones and conglomerates, and are more or less horizontal, being little affected by folding.

Devonian rocks, which date from the middle of the Palaeozoic era, approximately 360 to 410 million years ago, are mostly found in a strongly down-faulted area between Isfjorden and the north coast of Spitsbergen. Several thousands of metres of Silurian and Devonian strata are preserved here from Wijdefjorden westwards. These rocks largely consist of conglomerates, shales and red sandstones. Several mountainsides here stand out owing to their bright reddish-brown colour, caused by the high content of iron oxide in the sandstone. Large portions of these sediments seem to have been formed on desert plains which experienced occasional torrential downpours of rain that gave rise to short-lived rivers and lakes. This is suggested by the numerous fish fossils found in these beds, which have helped to clarify important stages in vertebrate evolution. The oldest fossils are jawless fish lacking a rigid, internal skeleton, whereas fish from the Upper Devonian beds are more like their present-day descendants. Primitive fossil plants are also found in these strata.

Early in the succeeding *Carboniferous* period, luxuriant vegetation evolved on land, and this was transformed into the coal seams which the Russian miners at Pyramiden in Billefjorden work. Later in the Carboniferous, and through much of the succeeding *Permian* period, large parts of Svalbard seem to have been covered by a shallow sea, and the rocks and fossils formed then suggest that conditions resembled those we now know in tropical regions. This also agrees well with what we know of the position of this part of the Earth's crust at that time.

Mesozoic

A new phase in the development of the region was initiated at the beginning of the *Mesozoic* era, which spans the *Triassic*, *Jurassic* and *Cretaceous* periods. Svalbard gradually drifted through a zone with a more temperate, moist climate, rather like that now experienced in central and southern Europe. The fossils clearly testify to this shift in the environment. Triassic beds, deposited below sea level, contain fossil bivalves and ammonites (an extinct group of molluscs related to the octopus), as well as remnants of marine reptiles, the dolphin-like *ichthyosaurs* and the long-necked *plesiosaurs*. Cretaceous rocks have yielded fossils of both herbivorous and carni-

Fig. 6. A mountainside at Lomfjorden, in the far northeast of Spitsbergen. Some 150 million years ago dark basaltic lava forced its way between light-coloured limestone strata, 'frying' them in the process. (Ø.L)

Fig. 7. The steep cliffs of this canyon on the north side of Diskobukta, Edgeøya, provide nesting sites for thousands of seabirds. Canyons like this are a typical result of the erosive power of rivers in horizontal sedimentary beds. (F.M.)

Fig. 8. View looking north along Hopen. The nearest, and southernmost peak, Iversenfjellet, is the highest on the island (370 m). As the photograph shows, the island is very narrow (less than 3 km) relative to its length (about 33 km). Passes transecting the island from coast to coast separate a number of plateau-topped hills. A radio station, providing a continuous weather observation service, is located in the middle of the island at the east coast. (B.Ly.)

vorous reptiles that lived on land and were dependent upon a temperate climate.

Among the more sensational fossil discoveries made in Svalbard is an approximately 200 million-year-old *Plesiosaurus* found on Kong Karls Land in 1973. Its stomach contained the remains of its last meal, a mixture of plants and squids. Another notable event took place in 1960 when a cliff face on the shore near the mouth of Isfjorden was found to bear the fossilised tracks of a 130 million-year-old giant, plant-eating reptile (*Iguanodon*). Its stride must have measured about 2 metres, which is not surprising considering that these creatures could grow to a length of 10–12 metres, measured from the tip of their snout to their tail end.

*Fig. 9. Footprints in sandstone, left by a 3–4 m long, carnivorous dinosaur (*Allosaurus*) during the Cretaceous period. They are about 30 cm in diameter and were found in 1976 at Kvalvågen on the east coast of Spitsbergen. Similar prints left by a still larger (10–12 m long) plant-eating reptile (*Iguanodon*) were found some years earlier at Festningen, near the mouth of Isfjorden. These huge creatures roamed the area during the Mesozoic, in a climate that was no doubt much more pleasant for them than what we now experience in Svalbard. Estimates based on the continental drift theory indicate that Svalbard must then have been situated at about the same latitude as present-day central Europe. These animals seem to have become extinct around the transition between the Cretaceous and Tertiary periods. Several hypotheses have been put forward to try to explain their demise. The most favoured one now is that a huge asteroid struck the Earth on the south side of the Gulf of Mexico, whirling so much dust into the atmosphere that many land animals and marine creatures were unable to survive the ensuing period of darkness and cold. (Ø.L.)*

Cenozoic

The onset of the *Cenozoic* era, the early *Tertiary* period, some 60–70 million years ago, heralded the start of a series of dramatic events which were decisive for the magnificent display of Svalbard geology we can witness today. Huge earth movements took place. The Greenland and Svalbard portions of the continental plate were pressed against one another, folding and thrusting portions of the bedrock, particularly on the west coast of Spitsbergen. The resulting, jagged mountains lining this coast were what urged Willem Barentsz and his followers to name this new land Spitsbergen (pointed mountains).

*Fig. 10. Fossilised leaves and shoots which fell to the ground around 50 million years ago, in the Tertiary period. They must have been quite quickly buried by fine-grained sediment, perhaps on coastal plains where there were rivers, lakes and lagoons. Compressed by the increasing weight of overlying beds, the sediment became transformed into rock and the leaves were left as impressions in the stone. In a geological perspective, these fossilised remains are quite young, and they strongly resemble the foliage of species which now grow at lower latitudes. The large leaf on the right is very much like the leaves found now on hazel (*Corylus*) trees and some similar deciduous trees and shrubs. The other prints are almost identical with shoots of a living conifer named* Metasequoia. *It is virtually impossible to explain the considerable climatic changes that these finds indicate, without invoking the continental drift theory. (V.H.)*

Fig. 12. View from the air looking southwards over the northern part of Bjørnøya. The radio station can just be seen near the right-hand edge of the photograph. The island can be divided into three parts. The northern part is a fairly flat lowland plain only 20 to 50 m above sea level, dotted with numerous shallow lakes, as the picture shows. Lakes, in fact, cover more than a tenth of the island. The southeastern part includes the plateau-shaped Miseryfjellet, the mountain just visible in the background to the left. It rises to 536 m, and is the highest point on the island. The southern part of the island also has many steep-sided mountains, with summits rising to 440 m. The south coast is particularly rugged, with precipitous cliffs dropping straight into the sea (see Fig. 11), and it is only possible to land in a few places. The island has no glaciers, but here and there snow patches may survive the thaw. (B.L)

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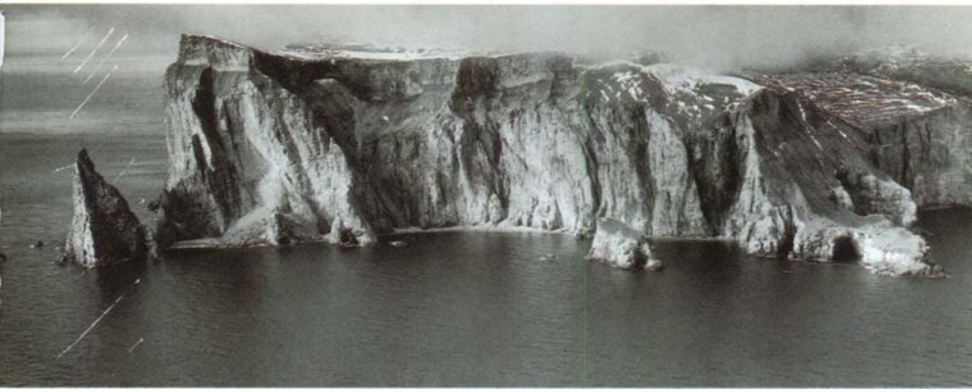

Fig. 11. An aerial photograph looking west towards the impressive bird cliff Fuglefjellet (411 m), at the southern tip of Bjørnøya. On the extreme left, the cliff Stappen rises almost vertically from the sea to a height of 186 m, forming the southern cornerstone of the Svalbard archipelago. In summer, these cliffs are populated by vast numbers of nesting seabirds. The dark cave at sea level in the small peninsula on the right of the picture forms the entrance to a 100 m long tunnel, which wave action has eroded right through the peninsula. This tunnel, called Perleporten (the Pearly Gate), plays an important part in Alistair MacLean's novel Bear Island. *(B.L.)*

Fig. 13. Kapp Linné at the mouth of Isfjorden, with Grønfjorden in the background. A well-developed strandflat with shallow lakes, pools, lagoons and streams is seen in the foreground. Isfjord Radio is situated on the small peninsula near the bottom left-hand corner of the picture. The long lake in the centre, Linnévatnet, is one of the largest and best-known lakes in Svalbard. The cape and lake are named after the famous Swedish botanist. (B.L.)

The central depression extending southwards from Isfjorden was also rejuvenated during this period, emphasising the trough-like attitude of the strata in this area. The youngest Tertiary strata lie innermost in the trough, the older, underlying beds being exposed along its flanks. The Tertiary deposits were originally some 4000 metres thick, but about half of them have now been eroded away.

Numerous fracture zones trending north-south, and the huge down-faulted area between Isfjorden and the north coast of Spitsbergen mentioned earlier, are other important features of the geology that have resulted from the repeated faulting and thrusting that took place during this period.

The faults tended to develop zones of weakness in the Earth's crust which formed paths for lava to intrude. Even as recently as the current geological period, the *Quaternary*, volcanic activity has taken place along a fracture zone trending south from near Bockfjorden. Hot springs and small,

Fig. 14. This aerial photograph shows the small archipelago called Sjuøyane, the northernmost islands in Svalbard. The photograph is taken towards the south, and the islet in the foreground, Rossøya, is the northernmost point in Norway, situated at 80°50' N, 20°21' E. An automatic weather station has been placed on Phippsøya, an island a little further south, near the left edge of the picture. It transmits weather observations via satellite many times a day, and is one of about four automatic stations operating regularly in Svalbard. Part of Nordaustlandet is just discernible in the background. (B.L.)

extinct volcanoes still provide evidence of this volcanism. The largest group of volcanic pools is the Trollkjeldane (Troll springs) in the valley at the head of Bockfjorden. Here, at almost 80°N, a water temperature of more than 28°C has been measured, showing that the groundwater must derive from a very hot layer in the Earth's crust. Springs holding unusually high temperatures, though nothing like as high as those at Bockfjorden, are also found further south on the west coast of Spitsbergen.

The vegetation must have been luxuriant at times during the Tertiary period. Huge accumulations of plants that grew in swampy areas have gradually been transformed into coal. It is these seams which the miners at Longyearbyen, Sveagruva and Barentsburg work. The Tertiary deposits also contain huge quantities of well-preserved fossils, not least from deciduous and coniferous trees that are closely related to species now found at considerably lower latitudes in Europe. Consequently, it is thought that in the early part of the Tertiary period, Svalbard was situated at about the same latitude as southern Norway is today.

Erosion has completely removed all beds younger than 40 million years. The Norwegian Sea acquired its shape during the Cenozoic, and Svalbard found its present position on the Earth.

Ice ages

The details in the landscape which we see before us today have been shaped during the last 2 million years. Traces are found of several ice ages, separated by milder, more or less ice-free, periods. The whole archipelago was covered by a huge ice sheet at least once during the Quaternary period. Studies of sediments on the floor of the shallow Barents Sea indicate that when it was at its maximum extent, the ice cover was continuous from Svalbard to the Scandinavian ice sheet. Most of the floor of the Barents Sea was above sea level at that time.

During the last Ice Age, which ended about 10,000 years ago, Svalbard was depressed by an enormous mass of ice. Gradually, as the ice melted, relieving the load, the land began to rise again resulting in the formation of marine terraces, or strandlines (raised shorelines), at several levels. The land, of course, rose most where the weight had been greatest, apparently in the southeastern part of the archipelago. The highest marine terraces are found on Kong Karls Land in the east, more than 100 m above present sea level, whereas there is no trace of any uplift in the northwest, or on Bjørnøya.

LANDSCAPE

The magnificent features of the landscape are a consequence of, on the one hand, the constructional power of geological processes and, on the other, the destructive effects of water, frost and ice.

Mountains and fjords

Steep, jagged mountains with sharply pointed, alpine peaks are a prominent feature of the landscape over large areas, particularly in western and north-western parts of Spitsbergen. However, in central Spitsbergen, and eastwards to the smaller islands of Barentsøya and Edgeøya, the geology is dominated by horizontal Mesozoic strata which produce mountains topped by plateaus, often separated from one another by broad valleys. Nevertheless, the mountainsides may be precipitous, with huge screes along their base. The various rock layers often stand out clearly, more or less flat-lying and with different colours and shades of light and dark.

Fig. 15. The precipitous mountain on the right is Templet, on the north coast of Sassenfjorden, an eastward arm near the head of Isfjorden. Virtually horizontal sedimentary strata like these favour the formation of characteristic plateau-topped mountains. Rows of gravel ridges on the strandflat in the foreground give clear evidence of the gradual uplift of the land after the last Ice Age.

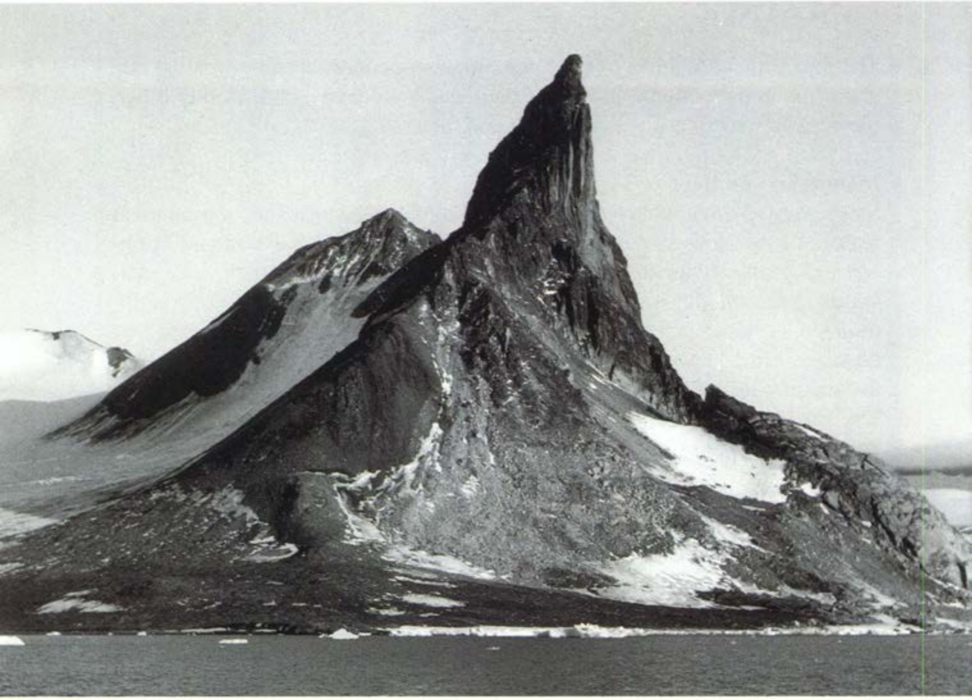

Fig. 16. This picture of Bautaen, (the 'monolith') beside Brepollen, an arm of Hornsund, provides eminent justification of why the Dutch named the land they had discovered, Spitsbergen ('pointed mountains'). Despite its modest height of 473 m, the peak looks very impressive. (H.G.)

The highest peaks in Svalbard, Newtontoppen and Perriertoppen, are in northeast Spitsbergen. According to the most recent measurements (in 1996), the former reaches highest at 1713 m, whereas Perriertoppen is about 1 m lower. However, since both peaks are capped by several metres of snow and ice, their altitudes will vary somewhat according to the amount of precipitation and the date of the measurement. The exact height of the underlying bedrock is still not known.

Other characteristic features of the landscape are the large, branching fjords, which incise deeply into the land from the western and northern margins of Spitsbergen and Nordaustlandet. They have been carved out by glaciers over millions of years, preferably where the bedrock had fractures or zones of weakness. Isfjorden from the west and Wijdefjorden from the north almost cut Spitsbergen in two. Wahlenbergfjorden and Rijpfjorden

Fig. 17. Water and frost acting together form a particularly important erosive process in the Arctic. When the water freezes in pores and cracks in the rock, it expands and bursts the stone apart. As time goes by, large and small fragments break off, to fall down the steep hillsides and form fan-shaped screes at their foot, or to be carried away by the valley glaciers. The same agents later break up the rocks into still smaller fragments, as the photograph shows. (V.H.)

have nearly done the same to Nordaustlandet, too. Only some 20 km of land separate the heads of the fjords in both cases.

Coastal landscape

Long stretches of coast, especially in the west and north of Spitsbergen, consist of a broad, flat expanse of land called the strandflat, which is fringed by shallow sea. The strandflat is more than 10 km wide in places, and is partly covered by shore deposits from the period after the Ice Age. Just how these vast coastal plains have been formed is not entirely clear, but they seem likely to be a result of the erosive power of sea and ice working together during periods when the sea level was higher than it is today.

Fig. 18. Akseløya, viewed towards the north, blocks most of the mouth of Van Mijenfjorden. The ice therefore does not leave the fjord before well into the summer and may make it difficult for ships to reach Sveagruva at the head of the fjord. The originally horizontal sedimentary beds have been folded into a vertical position, producing a striped pattern along the surface of the island. (B.Ly.)

Fig. 19. The Trollkjeldane hot springs close to the head of Bockfjorden, where the groundwater rises from hot layers in the Earth's crust, providing evidence of former volcanic activity in the area. (V.H.)

Fig. 20. One of the Trollkjeldane hot springs, where warm water and gas bubbles are rising. When this picture was taken, the water temperature at the surface was 25°C, and the air temperature only a couple of degrees above freezing. (V.H.)

Fig. 21. Meltwater from the glaciers flows along the valley floor towards Bockfjorden in a broad, branching network of rivers, forming an unpleasant obstacle for walkers. (V.H.)

Fig. 22. A rapidly flowing meltwater stream originating from the Brøggerbreane glaciers on the south coast of Kongsfjorden. The bedrock underlying the glaciers largely consists of red sandstone, which explains the colour of the water. (N.N.)

Flights of ancient beach ridges rising up from the present shoreline form another common feature of the coastal landscape. Each ridge marks the border between the land and the sea at the time it was formed. These strandlines often stand out as prominent terraces in the terrain, more or less parallel with the present coastline.

Large and small lagoons are also very common along flat stretches of coast. These shallow basins are partially or wholly separated from the open sea by beach ridges formed of sand and gravel, and they contain brackish water. Their size often varies according to the state of the tide.

Ice and frost

From what has been mentioned earlier, it will be apparent that many features in the landscape are inextricably linked with the action of ice and frost. Naturally, in such a high-Arctic environment, these forces are still active. The most obvious proof of this is the glaciers, which will be described separately.

Water seeps into pores and fissures in the bedrock, freezes and expands, splitting the rock apart. Rocks and stones break off, crash down the mountainside, and build up huge, fan-shaped screes, masking the lower part of the slope. On plateaus and gently sloping terrain, the frost-shattered rock remains as a mass of debris (block field).

Glaciers flowing between the mountains carry away rocks, stones and gravel, some of which form regular, dark stripes along the ice. Most of the debris, however, is transported on the sole of the glacier. The ice tears off rock, and grinds and wears away at the bedrock beneath it. Finally, all the debris is piled up in ridges (moraines) around the glacier tongue. Fine material, sand and mud, are carried further by the meltwater rivers.

When a glacier retreats, the moraines are left behind as memorials to its former era of grandeur. However, these memorials are generally not quite what they appear. A core of old ice tends to be concealed beneath an insulating layer of rock and gravel. Moraines, indeed, are generally a chaotic assortment of rubbish, ranging from huge blocks of stone to the finest of clay, and pockets of ice.

Frost also has a remarkable ability to sort and arrange. Polygons or rings of small stones may decorate large areas of tundra, and can be an astonishing sight. They are usually a couple of metres across, but can vary greatly in size. The phenomenon is called patterned ground, and arises through the sorting that takes place in the surface layer during repeated freezing and thawing. Polygonal patterns of fractures may also develop where relatively rapid freezing and thawing work on surfaces saturated by moisture.

Similar peculiarities are found on sloping ground, too. A water-saturated surface layer will become extremely waterlogged during the summer thaw and, with the help of gravity, it will creep down the slope on the

Fig. 23. It usually takes a very long time before scars on the terrain made by vehicle tracks are healed. Rejuvenation of the vegetation in such surface scars also takes place extremely slowly. The tracks on this photograph are about 40 years old. (V.H.)

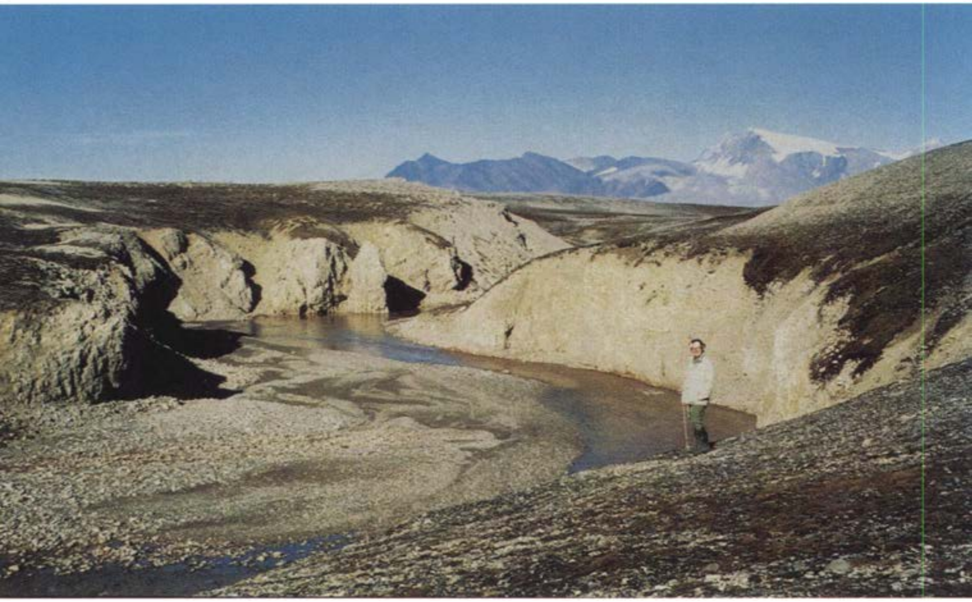

Fig. 24. Meltwater often excavates a deep, twisting, steep-sided channel on its path from the glacier to the sea. (V.H.)

Fig. 25. Alternating freezing and thawing may cause a strange sorting of the material on the tundra surface. A conspicuous result is stone circles like these, photographed on Prins Karls Forland. (O.S.)

Fig. 26. When groundwater forces its way to a cold surface in the lowlands, it freezes and may gradually create a large frozen mound (a pingo), like the formation in the center of this photograph from Smelledalen, near Diskobukta on Edgeøya. (B.Ly.)

Fig. 27. Fine-grained sand and silt which the glaciers have scraped off the surface they are sliding over, are carried to the sea by meltwater rivers. The sand is deposited first, while the lighter silt is carried in suspension in the water and dispersed further afield under the influence of currents and wind. (V.H.)

Fig. 28. Large quantities of driftwood and flotsam are a common sight on Svalbard beaches, like here at Mossellaguna near the mouth of Wijdefjorden. Most of this driftwood reached the Polar Basin after floating down the huge Siberian rivers and was carried westwards with the ocean currents. These driftwood accumulations in the European sector of the Arctic were an important incentive for Fridtjof Nansen when he hatched out the idea of letting his ship 'Fram' become frozen into the ice north of Siberia to copy the drift of the timber. In an area where trees cannot grow, this free supply of timber for fuel and building material is especially welcome. (B.Ly.)

underlying permafrost, a process called solifluction. If the earth is a mixture of fine-grained material and stones, these components may become sorted by the annual freezing and thawing, causing stone stripes to form down the slope, separated by bands of finer material.

The ground is permanently frozen to a considerable depth. Only the uppermost metre or so thaws during the summer, while further down permafrost reigns supreme. The depth of the permafrost varies from 200 m to 500 m in inland areas, significantly less near the coast where the relative warmth of the sea water has an effect. Permafrost is completely lacking beneath large lakes and glaciers, and the fjords, because the insulating layer of water or ice helps the heat that rises from deep in the Earth to keep the frost at bay.

Even where the permafrost lies like an armour, weak points may be found. In some places, glacial meltwater finds its way through fissures in the bedrock beneath and flows down into a deep layer under the permafrost. Water may thus stand under pressure at depth and eventually succeed in pressing and melting its way up towards the surface, where it freezes and, in the course of many years, builds up mounds of ice tens of metres in height, covered by gravel and stones. The eskimos have named this kind of ice mound a *pingo*, and this has become its scientific name.

Water from a temperate underworld that is confronted with the harsh temperatures at the surface also creates another, related phenomenon. As mentioned earlier, the temperature remains relatively high in the bedrock beneath the large glaciers, close to 0°C all year round. Meltwater may therefore flow out onto plains in front of the glacier, even in midwinter. If the air is sufficiently cold, the water will freeze fairly quickly when it reaches the surface and will form expanses of ice ahead of the glacier, sometimes covering an area of more than 1 km^2.

Water and rivers

Svalbard has few lakes of significant size. Linnévatnet, which is nearly 5 km long, is the best known one, no doubt because it is in a 'populated' area. A few lakes in northern Spitsbergen and on Nordaustlandet are a little larger, but all are well under 10 km long. As might be expected in such an ice-covered land, several lakes are partially dammed by glaciers. An ice-dammed lake may vary greatly in size, in pace with the supply of meltwater and the qualities of the glacier as a water barrier.

However, there are a great many small lakes and pools. Most are formed in depressions on the strandflat, and a few are so shallow that they freeze solid in winter. Bjørnøya has a particularly large number. More than a tenth of its area is covered by lakes, mostly very small ones. The largest, Haussvatnet, is some 2.5 km long.

Rivers are fed by melting glaciers, and are a summer feature. Where the glaciers do not reach the sea, they send shallow, often highly branching

Fig. 29. Aerial view looking northeast over the southern slope of Dunérfjellet on Svenskøya (Kong Karls Land). The long series of narrow, wave-like features crossing the slope are old beach ridges (strandlines) marking the gradual uplift of the land relative to the sea as it recovered from being depressed by the enormous weight of the ice during the Ice Age. (B.L.)

meltwater rivers along the valley floors, or across the strandflats. These rivers transport vast quantities of mud and small stones which the grinding action of the glacier has removed from the underlying rock. Huge areas of the sea in front of the glaciers and river mouths are coloured by this mud.

Even though the rivers are shallow in most places, they should not be underestimated. They may still be very fast flowing and difficult to cross on foot. The water is also ice cold. Many people carry unpleasant memories of negotiating rivers in Svalbard.

The tundra, too, may at times be rather unpleasant for walkers. In periods of constant rainfall, particularly when the snow is thawing late in the early summer, flat tundra quickly becomes waterlogged. Drainage is, of course, poor, because the watertight permafrost stands just a few decimetres below the surface. Groundwater, as such, therefore does not exist. The water remains in the uppermost surface layer, and the tundra can be as heavy as a swamp to walk over.

Its geographical location alone should imply that the weather in the Svalbard area must differ considerably from that elsewhere in the Arctic. Svalbard is situated in the northern part of the ocean separating Greenland from Scandinavia, within the only large gap existing between the land masses surrounding the Polar Basin. A very active exchange of both water and air masses between medium and high latitudes takes place through this 'gateway'.

Import of heat

During the course of a year, both ocean currents and winds provide a net transport of heat towards the north. This explains why the temperature in the Atlantic sector of the Arctic can stay as high as it does. On the whole, the annual heat sum which the Earth receives from the sun in arctic tracts is

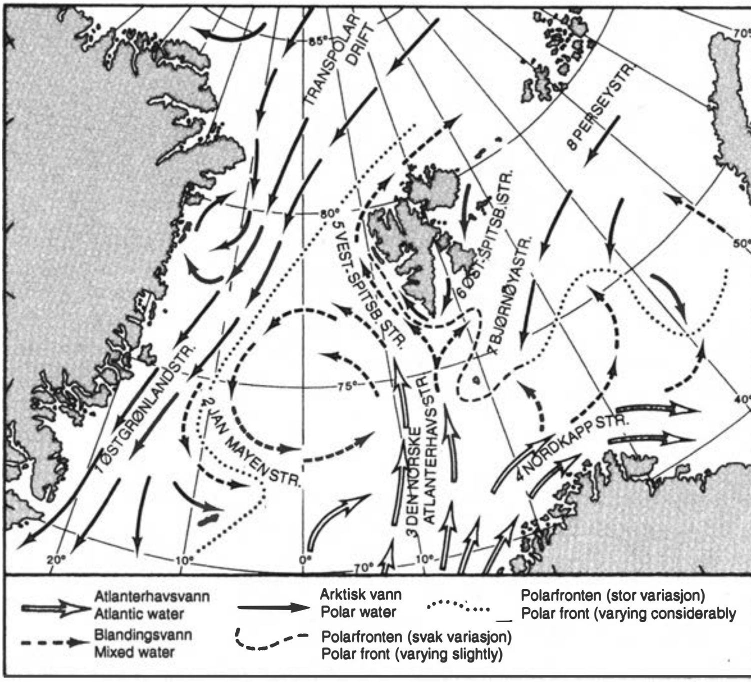

Fig. 30. The arrows denote the directions of the prevailing surface currents in the waters around Svalbard. The 'polar fronts' indicate the approximate positions at the surface of the boundary between relatively warm, saline Atlantic water and cold, less saline water of polar origin.

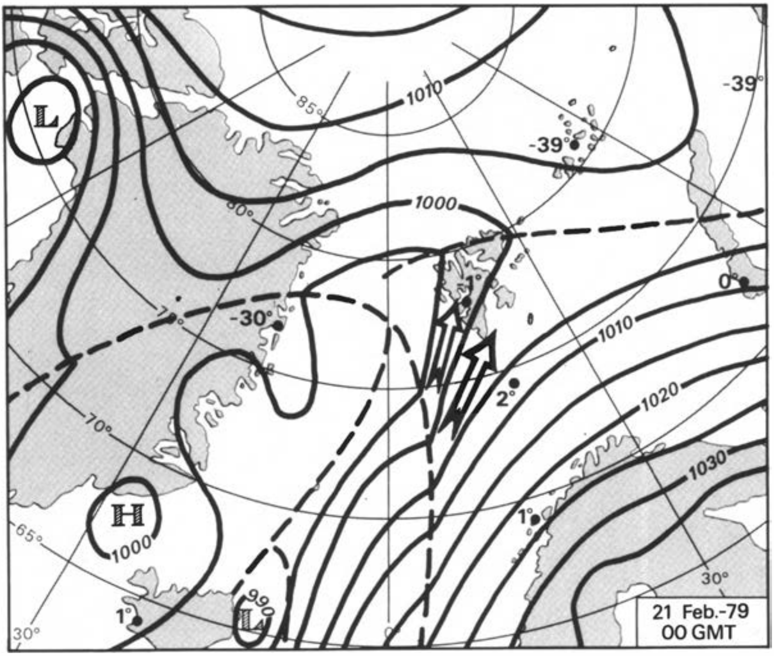

Fig. 31. Simplified weather map for the night of 20 to 21 February 1979. It shows a low-pressure system moving northeast, accompanied by a strong flow of mild, maritime air towards Svalbard. The broken lines denote the boundaries ('fronts') between different air masses. The maximum temperature at Svalbard Airport was 1.5°C on 20 February and 1.4°C the following day. Note the much lower temperatures in both the west (east coast of Greenland) and the east (Zemlja Franca Iosifa).

far less than that lost through radiation to space. Transport of heat from the south makes up this deficit.

In the region we are considering, the weather can be roughly divided into two main types. When depressions dominate the weather scene, passing over or close to the archipelago, mild oceanic air is generally drawn northwards. Such a situation is illustrated on the simplified weather map in Fig. 31. The other type of situation is depicted in Fig. 32, where a high pressure area over the Polar Basin or Greenland reigns supreme, and Svalbard is invaded by polar air from directions between north and east.

The Svalbard region, indeed, is a popular meeting place for cold and mild air masses. It can justifiably be characterised as a battleground, because a confrontation between air masses holding such vastly different tem-

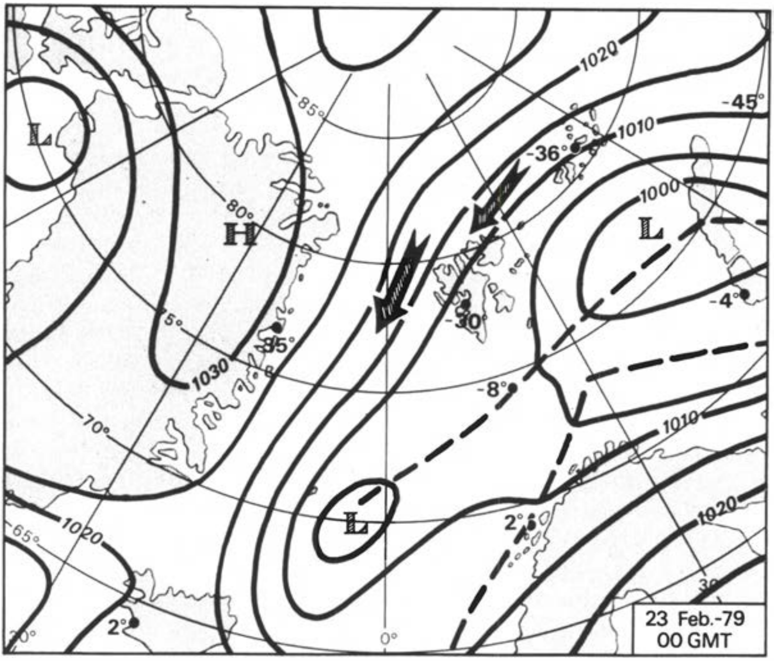

Fig. 32. This weather map illustrates the situation two days after that shown in the previous figure. Cold, polar air is now streaming over Svalbard, between depressions in the south and a high pressure ridge over Greenland. The minimum temperature on 23 February was -36.7°C. In the calm, clear weather which followed, the temperature sank still further, reaching -43.7°C on the 25th. This is the next lowest temperature recorded at Svalbard Airport since measurements began there in 1975.

peratures means an energy-loaded collision which provides nourishment to the most prominent of the 'weather producers', the wandering depressions. This can lead to prolonged periods of unstable, stormy weather, particularly in winter. It is then that the contrasts in temperature and, hence, the concentration of energy, are at their maximum.

In winter, the passage of depressions accompanied by mild maritime air will lead to surprisingly high temperatures, considering the latitude. In this context, the northward drift of warm Atlantic water west of Spitsbergen, a distant branch of the Gulf Stream, is also favourable. It helps maintain a relatively high temperature in the southerly winds. If just one feature that characterises the climate in Svalbard was to be mentioned, it would have to be the high average temperature in winter.

Temperature contrasts

As Fig. 33 shows, the winter temperatures along the west coast of Spitsbergen are specially favourable. The weather station at Isfjord Radio (78°04' N) has an average temperature of around -12°C in the coldest months (January-March). Isachsen, a weather station at about the same latitude in the Canadian polar archipelago in the west, has an average temperature for the same months that is more than 20°C lower. The temperature drops more slowly towards the east, the heating effect of the depressions being noticeable in northeastern parts of the Barents Sea, too. Thus, at Buchta Tichaja (Tikhaya Bay), a weather station at 80°19' N in Zemlja Franca Iosifa, the winter temperature is only 4–5°C lower than at Isfjord Radio. However, still further east, at Mys Tsjeljuskin (77°43' N), on the Siberian coast, it is as much as 15°C lower. The cold continental winter climate makes itself felt (Fig. 33). The contrast in temperature from west to east is much less in summer (Fig. 34), owing to the balancing effect of the sun's heat. The July mean at Isfjord Radio, close to 5°C, is only a couple of degrees higher than that of the other stations mentioned above. The summer temperature is, moreover, rather stable, generally between 0°C and 10°C. Readings in excess of 15°C are uncommon, not even occurring once each summer. On the other hand, summer temperatures below freezing are not unusual, even in the lowlands. The highest temperature recorded on an 'official' thermometer is 21.3°C, at Svalbard Airport on 16 July 1979 (Table 1).

Winter temperatures vary more. When mild depressions and invasions of cold polar air struggle for supremacy, temperatures may vary by 30°C and more in a matter of a few hours. In the coldest months (January-March), the mean temperature on the west coast of Spitsbergen is usually between -8°C and -16°C. The lowest temperature so far recorded in Svalbard, -49.2°C, was read on 28 March 1917 on a station at Grønfjorden that has long since been abandoned. Lower temperatures have certainly occurred, particularly in eastern and northern parts of the archipelago. Otherwise, it is worth noting that even in midwinter the temperature can creep above freezing for brief periods.

When you travel eastwards from the outer west coast into the fjords and valleys on Spitsbergen, a somewhat more continental climate becomes noticeable. The mean temperature in winter is 2–4°C lower, whereas in summer it is a couple of degrees higher. If one makes a larger geographical leap, the temperature contrasts become more marked. Northern and eastern parts of the archipelago are significantly colder, particularly in winter. The west coast of Nordaustlandet can expect average winter temperatures around 5°C lower, and there is a similar temperature reduction at Kong Karls Land, in the east. The same tendency is found in summer, although the differences are less marked. However, too few observations have been made to give more precise details.

An important reason for the colder climate in the north and east is undoubtedly the influence of the drift ice and the cold air from the Polar Basin. In general, the temperature depends very much upon the relationship between the origin of the air masses and radiation conditions, a relationship which varies from season to season. In winter, cold northerly to easterly air currents are generally linked with clear skies and heat loss through radiation from the ground, and the surface air is cooled even more. Flow of air from the south, on the other hand, frequently means overcast skies, which reduce heat loss from the ground by radiation. This often gives a substantial heat benefit and a rise in temperature.

In summer, the relationship between air circulation and radiation conditions is almost reversed. If the sun is not too low, it will heat the surface when the sky is clear, whereas overcast conditions will reduce its warming effect. This explains why the temperature variations in summer are relatively small, as shown in Fig. 35.

Wind

It has been pointed out earlier that the Svalbard region is a favourite battleground for air masses with completely different properties, the mild maritime air from the south and the cold polar air from the north. That the temperature contrasts, and therefore the concentration of energy, are at their maximum in winter, is clearly expressed by the wind statistics. Isfjord Radio, facing the open sea in the west, experiences, on average, over 20 days in January with a maximum wind speed of more than 5 Beaufort (i.e. stronger than Fresh breeze, or 11 m per sec.). Only about six days in July have such strong winds. Similar frequencies of strong wind are noted at the comparatively exposed weather station on Bjørnøya.

The wind depends very much on the terrain. The lowest air layers are usually relatively cold and therefore extremely stable in arctic regions. The air currents consequently tend to avoid climbing over elevated ground, which instead diverts them. Hence, the shape and position of mountains, valleys and fjords determine the direction and strength of the wind. This also applies to the weather in general, and significant local differences can easily arise. Consequently, Svalbard forecasts predict the weather best out at sea, or where the landscape is not too rugged.

Some terrain-controlled weather phenomena are particularly striking. For instance, katabatic winds, which may be specially strong at the snout of steep valley glaciers when cold air pours down between precipitous mountainsides. Such winds often gust unpredictably and may put small vessels at risk in many fjords.

Fog and precipitation

While strong winds mainly occur in winter, fog typically develops in sum-

Table 1. *The table shows a selection of climatological elements for four stations in Svalbard. Temperatures are given in °C, while the values for fog are the percentage frequency of fog on the station at the hour of observation. The numbers given for wind force equal to or larger than 6 Beaufort (Strong breeze) are the percentage frequencies of days these wind forces are observed. The data are based on a publication by Førland et al. 1997 (see list of literature), where further climatological information may be found.*

Ny-Ålesund (78°55'N, 11°56'E)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean temp. (1961-90)	-13,9	-14,6	-14,2	-11,1	-4,0	1,5	4,9	3,9	-0,3	-5,7	-10,0	-12,5	-6,3
Abs. max. temp. (1975-96)	5,1	4,7	5,0	5,5	8,0	11,2	17,0	13,6	12,3	7,5	7,4	5,8	17,0
Abs. min. temp. (1975-96)	-36,6	-41,1	-42,2	-34,0	-19,1	-8,5	-0,5	-5,5	-15,0	-20,6	-27,2	-34,3	-42,2
Fog at obs. hour (1975-96)	0,0	0,2	0,2	0,4	0,2	1,8	2,3	2,6	0,8	0,0	0,1	0,0	0,7
Days with wind ≥6B (1975-96)	3,5	2,9	3,1	2,2	1,1	0,6	0,3	0,6	1,0	2,3	2,7	2,8	1,9

Svalbard Lufthavn (78°15'N, 15°30'E)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean temp. (1961-90)	-15,3	-16,2	-15,7	-12,2	-4,1	2,0	5,9	4,7	0,3	-5,5	-10,3	-13,4	-6,7
Abs. max temp. (1976-96)	6,7	5,9	6,3	5,5	10,6	14,3	21,3	16,5	15,2	8,9	6,6	7,2	21,3
Abs. min. temp. (1976-96)	-38,8	-43,7	-46,3	-39,1	-21,7	-8,4	0,2	-3,9	-12,6	-20,8	-33,2	-35,6	-46,3
Fog at obs. hour (1976-96)	0,2	0,3	0,1	0,1	0,8	1,7	0,9	0,8	0,6	0,0	0,0	0,0	0,5
Days with wind ≥6B (1976-96)	45	41	38	30	16	14	16	15	17	28	37	41	28

Hopen (76°30'N, 25°01'E)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean temp. (1961-90)	-14,2	-13,7	-13,7	-11,3	-4,7	-0,4	1,9	2,3	0,7	-3,3	-8,6	-12,2	-6,4
Abs. max. temp. (1946-96)	4,0	4,5	3,6	5,4	8,8	15,7	17,4	14,1	11,0	9,1	7,1	5,5	17,4
Abs. min temp. (1946-96)	-35,5	-34,7	-36,9	-30,2	-22,1	-9,9	-4,3	-4,4	-12,4	-29,0	-31,7	-35,6	-36,9
Fog at obs. hour (1956-96)	1,7	2,1	2,8	3,9	5,5	13,4	26,1	22,8	12,5	5,8	2,4	1,4	8,4
Days with wind ≥6B (1946-96)	44	41	31	25	14	13	15	11	18	28	36	45	27

Bjørnøya (74°30'N, 19°00'E)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean temp. (1961-90)	-8,1	-7,7	-7,6	-5,4	-1,4	1,8	4,4	4,4	2,7	-0,5	-3,7	-7,1	-2,4
Abs. max. temp. (1923-96)	5,3	5,0	6,2	5,7	16,5	23,6	22,4	21,5	15,5	10,5	8,4	6,4	23,6
Abs. min temp. (1923-96)	-29,8	-29,1	-31,6	-25,6	-17,8	-8,4	-4,7	-2,4	-10,4	-22,2	-21,5	-28,1	-31,6
Fog at obs. hour (1956-96)	1,6	1,6	1,8	2,5	6,1	12,8	22,3	19,4	11,5	5,1	1,8	1,3	7,3
Days with wind ≥6B (1937-96)	68	65	65	50	34	27	24	27	39	58	65	66	49

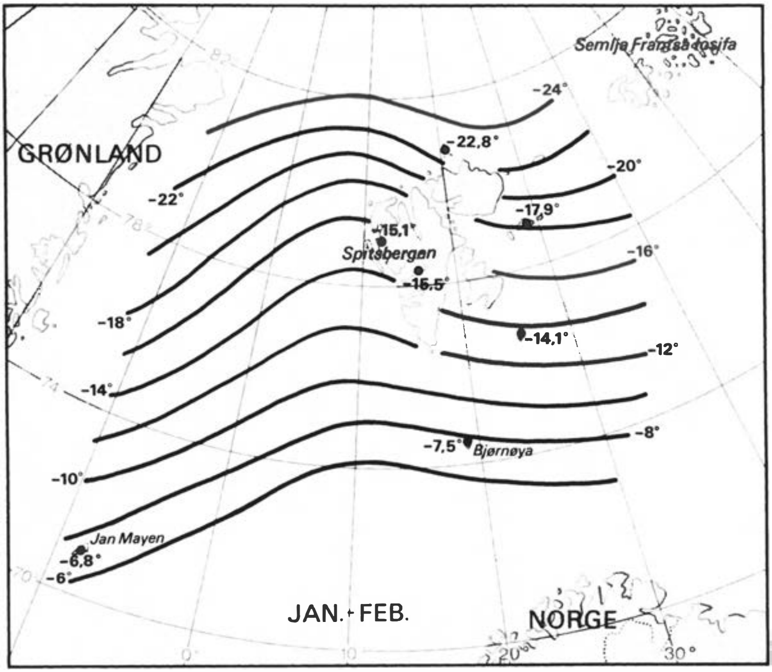

Fig. 33. This and the next figure show the average temperatures in January–February and July–August for the years 1982–1983, which seem to have been fairly close to 'normal'. Supporting data are available during these periods from the automatic weather stations on the isolated islands of Kongsøya in the east and Phippsøya furthest north. The temperatures in January–February are specially high along the west coast of Spitsbergen and over the ocean to the west. It becomes colder both westwards and eastwards, the big drop in temperature towards Greenland being particularly striking. The comparatively high temperatures close to Svalbard are related to the frequent flow of mild air from the south, when the depressions from the south and southeast cross Svalbard and the Barents Sea. In addition, in the sea west of Spitsbergen there is a tongue of open, relatively warm water, whereas in the east the sea is cold and largely ice covered. The low temperatures in the west, towards Greenland, are partly caused by the steady flow of pack ice from the north and the fact that the influence of depressions is much less here. Moreover, persistent anticyclones will be accompanied by radiative heat loss, thus giving rise to severe, cold, continental weather over Greenland and on the ice off the coast. In Svalbard, there is naturally a substantial drop in temperature northwards. The average temperature in winter drops 15°C from Bjørnøya to Phippsøya, or about 2.5° per degree of latitude. This entails a strong concentration of energy, and forms the basis for the very changeable and stormy weather.

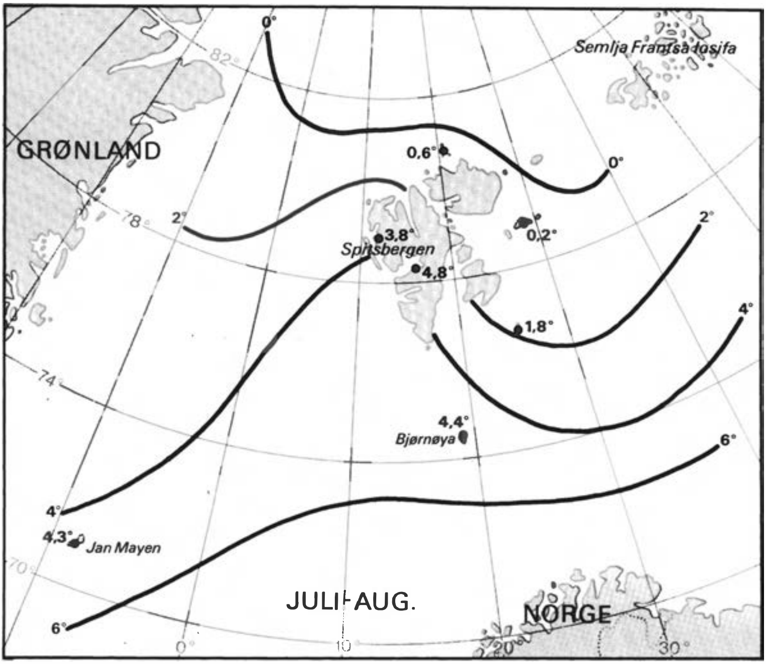

Fig. 34. The maps for July-August show the same general pattern in the distribution of temperature, but the variations are significantly less. Thus, the drop in temperature from Bjørnøya to Phippsøya is only 4°C. As might be expected from this 'flat', energy-poor temperature field, the average air flow is also far weaker at this time of year.

mer. Arctic fog generally forms when relatively mild air brushes lightly over snow- or ice-covered surfaces, or cool seas. The lowest air layers are cooled by the cold surfaces and are therefore able to retain less water vapour. Some of the vapour condenses as minute drops of water, which drift away in the light air. Eventually, there may be so many that visibility is drastically reduced, and fog (visibility less than 1 km) becomes a reality.

Arctic fog is not particularly thick, often only a few tens of metres. Offshore and coastal areas, where mild air from the south frequently encounters ice or cold sea water, are most exposed. Bjørnøya and Hopen have a fog frequency of well over 20% in July, whereas it is a mere 1% to 2% in January.

Weather fronts frequently sweep over Svalbard, and rain or snow are therefore common in most areas, though amounts are small. The lowlands on the west coast of Spitsbergen receive an average of well under 500 mm annually. The main reason for this low precipitation is that the cold air is

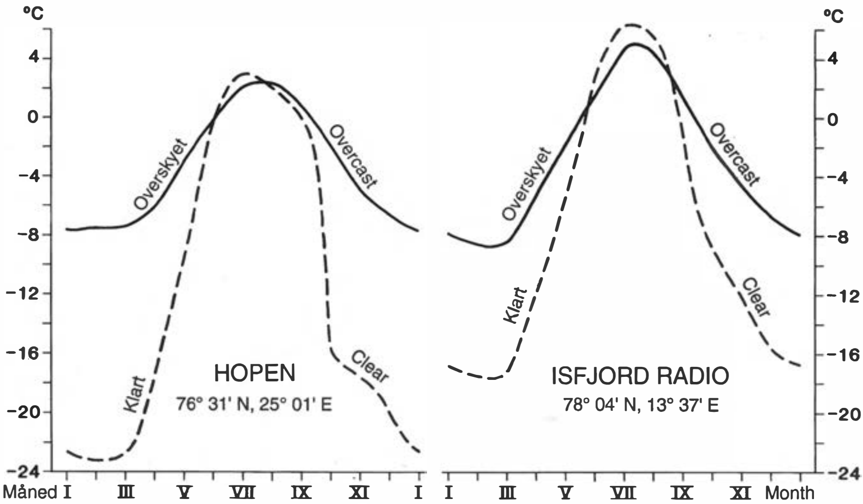

Fig. 35. Curves showing the average annual temperature variations at Hopen and Isfjord Radio for 1956–1976. The variations for overcast days (on average more than 80% of the sky cloud covered) and clear days (on average more than 80% of the sky clear) are shown separately. The annual variation in temperature for clear days is far greater than for overcast days, mainly because of the considerably higher temperatures on overcast days in winter, when the cloud cover reduces the radiation loss from the ground to space. Overcast weather is, moreover, frequently linked with the passage of depressions and northward transport of mild air. (Data from Steffensen (1982)).

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*Fig. 36. In polar regions, the content of water vapour in the atmosphere is often close to saturation point. When air is forced to rise over mountains, it expands and cools. Relatively limited uplift and chilling may then be sufficient to bring the water vapour to the dew point, causing condensation to take place in the form of tiny water droplets (or ice crystals at low temperatures). In this way so-called orographic clouds form over mountains, as seen on this photograph. Because these clouds are closely associated with the topography below, they remain virtually stationary. New droplets are continuously forming on the windward side of the mountains, where the air is ascending, whereas the 'old' ones evaporate on the leeward side where the air sinks and is reheated. In the situation shown in the photograph, the glaciers in the passes below will also help to cool the air. The lens-shaped clouds higher up are another kind of orographic clouds (*altocumulus lenticularis*), and are formed in a similar manner along the crests of stationary waves created in higher layers in the atmosphere above mountain ranges. (V.H.)*

Fig. 37. A fog bank on the west coast of Spitsbergen. Relatively mild, moist air brushes over a colder sea surface and some of the water vapour condenses as fog droplets. Note the limited thickness of the fog and its sharply defined upper limit. (V.H.)

unable to retain much water vapour. Svalbard rain typically falls as small drops, often fine drizzle. The heavens rarely open, as they can at lower latitudes. As was pointed out earlier with respect to the temperature, the weather sometimes forgets which season it is. Snow in summer and rain in winter are by no means unknown.

Of course, the average precipitation varies with time and place. Spring and early summer are usually driest, and the east side of the islands is clearly most prone to precipitation, especially mountainsides and glacier slopes which force easterly air currents to rise. This is the typical direction that brings precipitation in these tracts. When measurements of the depth of snow high up on glaciers in the east have been recalculated, an annual precipitation amounting to well over 1000 mm of water has been revealed, more than the average in Oslo.

Least precipitation seems to fall in central Spitsbergen, from Van Mijenfjorden northwards. This area lies in the rain shadow of the precipitation-bearing winds. After crossing the mountains, the air sinks, thereby becoming warmer, which causes the clouds to dissolve. The snow falls are barely sufficient to maintain smaller glaciers, preferably in shady locations and on high ground.

Fig. 38. Orographic cloud over Retziusfjellet on Kongsøya, the largest island in the small Kong Karls Land archipelago. The extremely even and well-defined outline of the cloud is due to the great stability of the air flow over the ice-covered sea (the photograph was taken in April) and the smooth, well-rounded contours of the mountain. There is a slight drift of snow over the sea ice in the foreground. (J.A.)

Light is a fundamental quality of our environment. It is a necessary condition for our ability to see, and for many other important biological processes. This is obviously the case everywhere on Earth. Nevertheless, light conditions in polar regions differ so much from those at lower latitudes that certain peculiarities should be mentioned. Since most of this description applies to high latitudes in general, reference will be made to polar regions or the Arctic, rather than Svalbard specifically.

Variations of the light

The closer we approach the pole, the greater is the annual variation of the light conditions, and the less the diurnal variation. The length of time the sun remains above the horizon in summer (the midnight sun), or below the horizon in winter (the polar night), increases steadily from the Arctic Circle to the North Pole, until both periods attain a length of about half a year at the pole itself.

Table 2 shows the periods when the sun remains above or below the horizon night and day at the degrees of latitude covering the Svalbard area, provided you have a free view to the horizon in the north during the midnight sun period, and to the south during the polar night. It is seen that the duration of the midnight sun, or the polar night, increases by almost six weeks from 74° to 81°N, which amounts to about six days for each degree of latitude northwards.

The table also shows that the midnight sun period is about two weeks longer than the polar night. The reason for this is that the rays of the sun are curved downwards slightly during their passage through the atmosphere, enabling us to see the sun even though it is located slightly below the horizon.

The ability of the atmosphere to raise the sun depends very much on the variation of the air temperature with height (or, more correctly, of the density of the air), and is just one of many effects of the natural phenomenon called *refraction*. At 'normal' temperatures, refraction will result in a celestial body at the horizon being raised approximately 0.6°. However, in polar regions the temperature distribution in the atmosphere, and hence the refraction, may be highly abnormal, for instance when there is an extremely cold layer of air at the earth's surface. This may give rise to unexpected peculiarities. For example, the sun occasionally returns like a ghost, appearing in a dark red, deformed state around noon, several days after astronomical calculations prove that the polar night has set in.

In addition to the severe climatic conditions, it is no doubt primarily the perpetual winter darkness that makes long stays in polar regions less attrac-

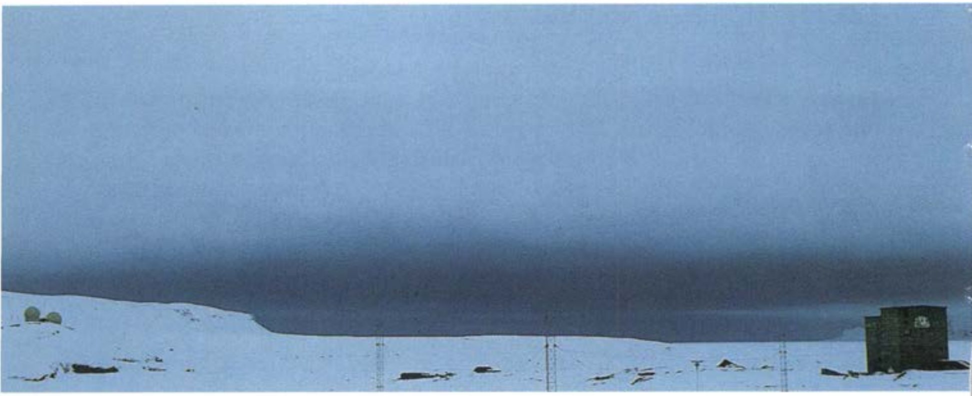


Fig. 39. The dark sky over the mouth of Kongsfjorden represents clouds above open water ('water sky'). Here, the underside of the cloud cover receives much less reflected light from below than it does from a snow-covered surface. The narrow, light stripe just above the horizon to the right is due to reflection from the snow-covered Kapp Mitra peninsula. (V.H.)

Fig. 40. View of Longyearbyen during the polar night. An almost full moon hangs above the mountains in the north. (B.Ly.)

tive for many people. The midnight sun has just the opposite effect and is a great inducement for large numbers of tourists each summer. However, we shall see that the picture of the polar night is less black than it is often painted.

Twilight

As long as the sun is not too far below the horizon, its rays will continue to hit the higher layers of the atmosphere and be partially dispersed and reflected down to the earth's surface. This is what produces twilight at dusk and dawn.

It is usual to divide the twilight period into three intervals, depending on how far the sun is below the horizon:

1. *civil twilight*, when the sun is between 0° and 6° below the horizon,
2. *nautical twilight,* when the sun is between 6° and 12° below the horizon,
3. *astronomical twilight*, when the sun is between 12° and 18° below the horizon.

According to the traditional definition, it should still be possible for a person with normal sight to see to read a newspaper at the transition between civil and nautical twilight, provided the sky is cloudless. When the sun is more than 18° below the horizon, the last traces of daylight should have faded.

Twilight is specially important in polar regions, not just because any trace of daylight is most useful, but the duration of twilight is so much longer than at lower latitudes. This is because the sun's daily path forms a

Table 2. *Length of periods when the whole solar disc stays continuously above the horizon (Midnight sun) for a person with free horizon towards the north, or stays continuously below the horizon (Polar night) for a person with free horizon towards the south.*

	Midnight sun			Polar night		
Lat. north	*First night*	*Last night*	*Numb. of nights*	*First day*	*Last day*	*Numb. of days*
74°	3. May	9. Aug.*	99	10. Nov.	1. Feb.	84
75°	30. Apr.	12. Aug.	105	6. Nov.	5. Feb.	92
76°	27. Apr.	15. Aug.	111	3. Nov.	8. Feb.	98
77°	24. Apr.	18. Aug.	117	31. Oct.	11. Feb.	104
78°	21. Apr.	21. Aug.	123	28. Oct.	14. Feb.	110
79°	18. Apr.	24. Aug.	129	25. Oct.	17. Feb.	116
80°	15. Apr.	27. Aug.	135	22. Oct.	20. Feb.	122
81°	12. Apr.	30. Aug.	141	19. Oct.	23. Feb.	128

* The night from 3 to 4 May and the night from 9 to 10 Aug. and so on.

smaller angle with the horizon here, and therefore spends longer in the 'twilight zone'.

The duration of twilight in the Arctic can be illustrated by considering the conditions at 78°N which is approximately the latitude of Longyearbyen. Table 2 shows that here the sun remains continuously below the horizon from 28 October. However, that day has more than seven hours of civil twilight and nearly twelve hours of nautical twilight. The duration of civil twilight around noon decreases continuously to zero on 13 November, and does not return before 29 January. Nautical twilight, on the other hand, is present around noon even in midwinter, but only lasts a couple of hours at winter solstice.

For comparison, at 50°N (central Europe) the maximum duration of civil twilight is only about one and a half hours (dawn and dusk combined). Moreover, it occurs at night in midsummer and is therefore of little practical significance.

Moonlight

The moon is, nevertheless, the great master of light during the polar night. During the period from one new moon to the next, about 29.5 days, the moon moves through more or less the same area of the sky as the sun does in a year. This means that the full moon in winter stands approximately as high in the sky at midnight as the midday sun does in summer. Hence, in polar regions, the moon in winter remains above the horizon for several days around the time when it is full, just as the sun does for several weeks around the summer solstice. Similarly, the moon remains below the horizon for some days when it is new, which really is no great loss, since its value as a source of light is anyway greatly reduced in that state.

When the moon is full, or virtually full, during the polar night, it thus makes a heroic attempt to imitate the path of the midnight sun. At such times it is an extremely important, if modest, compensation for the sun. The low level of light is to some extent balanced by the fact that the light rays from the moon have a preferred direction, thereby creating shadows and contrasts that make it easier to orientate oneself. In foggy weather, for example, the level of light may be very high, but the light itself is diffuse and the lack of contrasts impairs visual conditions.

Light emanating from stars and other less precise sources (nightglow, etc.) is extremely weak, but a strong display of northern lights (*aurora borealis*) may have some value, even though it can by no means equal a full moon. Table 3 gives the approximate value of the illuminance levels of some of the light sources mentioned above. The huge range of variation from full daylight to the weakest twilight that is adequate to permit some outdoor activity, illustrates the amazing sensitivity and adaptability of the human eye.

Table 3. *Some typical illuminance values measured on a horizontal surface (clear sky)*

Light source	Illuminance in lux
Sun and sky (sun 30° above horizon)	55 000
Sun and sky (sun 10° above horizon)	15 000
Sun 6° below horizon (lower limit of civil twilight)	1.5
Full moon 30° above horizon	0.2
Half-moon 30° above horizon	0.02
Sun 12° below horizon (lower limit of naut. twilight)	0.01
Stars, nightglow, etc. (moonless night)	0.002

Light and clouds

The above description was based on cloudless conditions and a free horizon, so that the full effect of the light sources is not reduced by clouds, fog, hillsides, etc. A truly black polar night exists when the moon is new and a dense cloud cover prevents the meagre light from the rest of the sky from reaching the ground. Moreover, such a description obviously depends on the sensitivity of a 'normal' eye that is optimally adapted to darkness. It has been shown that attaining maximum sensitivity in the dark takes significantly longer than previously assumed, particularly if the eye has just become adapted to a far higher level of illumination, for instance produced by artificial light.

A low, even cloud cover can produce some extraordinary light phenomena, not least in polar regions. A *white-out* is a relatively common situation. It arises when the light reaches the eye with approximately the same intensity from all directions, owing to repeated reflections between a cloud cover and snow-covered ground or ice. All contrasts are drowned in a diffuse mass of light, giving poor visibility and sense of direction and distance. Another well-known optical phenomenon is *water sky,* a term applied to the dark underside of a cloud layer over open water some distance away. This is particularly marked for an observer on a snow-covered area, where the clouds overhead receive much more reflected light than over water. It is particularly useful for sailors who are surrounded by ice and are anxious to find a way to open water. The term *land sky* is similarly applied if the dark appearance of the clouds is caused by the low reflectivity of snow-free land.

Iceblink, in contrast, is a whitish glare some distance away, caused by reflection from a low cloud layer over an ice-covered area, usually sea ice. *Snowblink* is even stronger, and arises if ice or land is completely covered

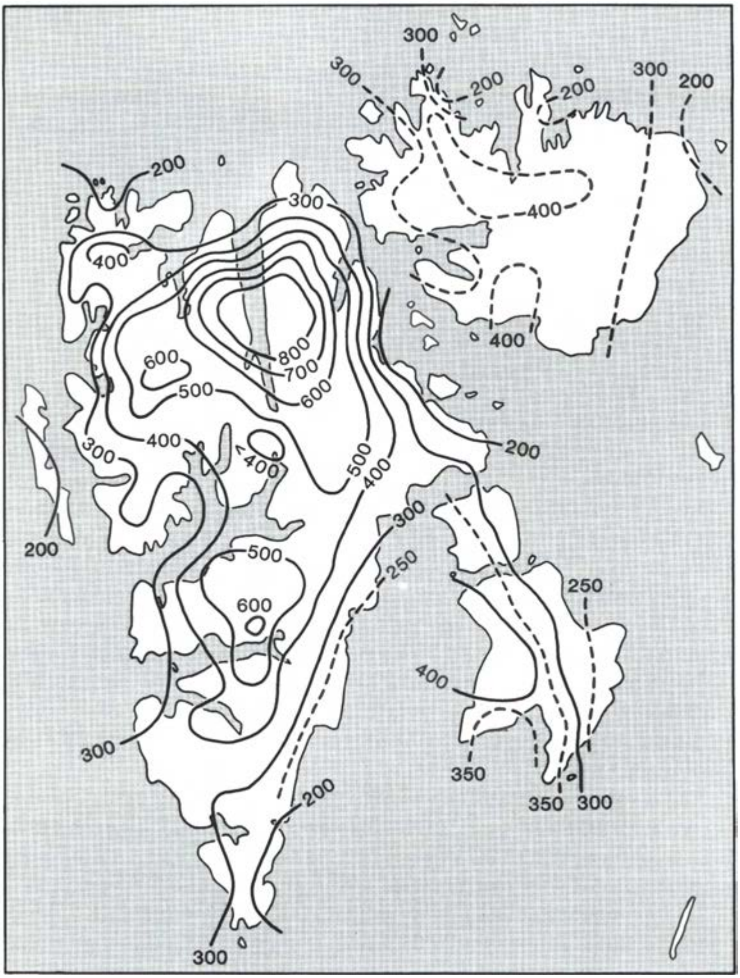


Fig. 41. This map shows the height in metres of the so-called climatic equilibrium line of the glaciers. Above the lines there is, on average, an annual net accumulation of snow. Below the lines, melting of snow and ice in summer exceeds the amount of snow falling annually, and the glaciers show a deficit. The height of the equilibrium line depends on several factors. Heavy snowfall brings the line down, high summer temperatures and intensive solar radiation raise it. The 'desert region' of Svalbard is, without doubt, situated around the central part of Wijdefjorden, where the equilibrium line is located above 800 m. Furthest east, on Kvitøya (beyond the map), the corresponding height is estimated to be barely 100 m. (The map was compiled by Liestøl & Roland in the 1980s.)

by newly fallen snow. Snow, of course, reflects light far better than ice. Vivid accounts exist of how a uniform cloud cover acts as a kind of screen reflecting light from the earth's surface with varying intensity and spectral composition, drawing an image of the ground beneath. However, it may safely be said that this requires unusually favourable conditions, and, moreover, considerable experience on the part of the observer to interpret such a 'cloud map'.

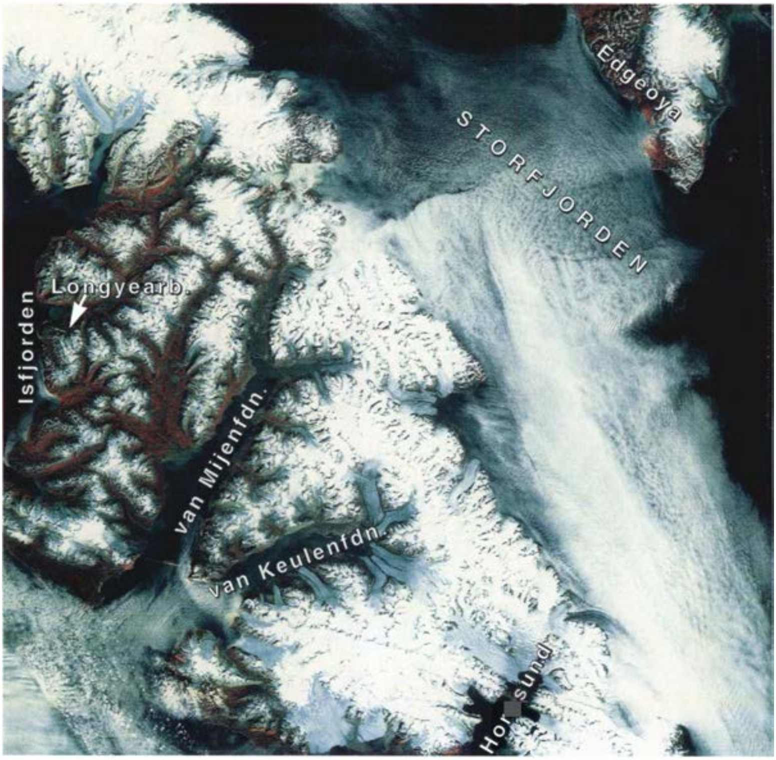
We know that light is vital to a great many biological processes. In plants and animals inhabiting polar regions, these processes are adapted to an extreme annual variation, from a summer without darkness to a winter without daylight. Their 'biological clock' therefore has to be regulated in a manner quite different from that of corresponding species living at lower altitudes. We know too little about the extent to which this form of adaptation has taken place in people who have lived for a long time in the Arctic, or how important the problem is for human beings.

People coming from lower latitudes can to some extent simulate the light cycle to which they are accustomed, by covering their windows when they want to sleep in summer, and using artificial lighting indoors in winter. However, this simulation is far from perfect. Above all, they have to live for comparatively long periods in artificial light, which is usually much fainter than daylight, and also has a completely different spectral distribution. In addition, such light can mostly only be used indoors. Consequently, in winter people in polar regions live in light that differs substantially from that to which Man has become adapted through practically the whole of his evolution.

Recent research suggests that these special conditions do not only have practical and psychological consequences, they may also affect the health of people in many more ways than we have been aware of. The results of future studies of such 'extrasensory effects of optical radiation' will obviously be of special interest for people living at high latitudes.

The vast ice sheets from the last Ice Age have long since disappeared. In Svalbard, however, there is still sufficient ice left for it to dominate large parts of the landscape. Only 40% of the archipelago becomes bare land by late summer. The rest is covered by glaciers of various types and size.

Fig. 42. A photo image of the southern part of Spitsbergen and adjacent areas taken in July by the American LANDSAT satellite. Clouds cover most of the open sea, but the land and fjords are practically cloudless. The snow line is indicated by the boundary between the white and light blue on the glaciers. This boundary is far higher along the fjords and the valleys in the west than in eastern districts, where more snow falls and the thawing effect of the sun's rays is more frequently reduced by clouds. Light patches can be discerned in a few places in the fjords. They represent fine-grained material which meltwater rivers have transported into the sea from the glaciers. (The picture was made at the Chr. Michelsens Institute in Bergen.)



Different types of glaciers

Northeastern Spitsbergen and, above all, Nordaustlandet have some large *ice caps* (also somewhat misleadingly called *plateau glaciers*), which are so thick that they entirely or partially mask the underlying bedrock relief. They often reach the sea over long stretches. By far the largest is Austfonna on Nordaustlandet, which ends in an almost 200 km long and 10 m to 40 m high ice wall facing the sea. Glaciers of this kind, but considerably smaller, are also found on Edgeøya, Barentsøya and Kvitøya.

If the glaciers are not quite so huge, or there are sufficiently high mountains in the area, they will just fill the lower parts of the terrain and the mountains will project above, often as isolated peaks in the ice field (*nunataks*). Such glaciers are particularly characteristic for northwestern Spitsbergen, where they cover large areas. They are usually called *glaciers of the Spitsbergen type*, also in an international context.

The most common types of glacier are *outlet glaciers* and the closely related *valley glaciers*, which flow from elevated ice fields down towards low ground, often all the way to the sea. Among the largest of these are the Hinlopenbreen and Negribreen glaciers in northeastern Spitsbergen. If two or more outlet glaciers merge over large areas in the lowlands, huge cake-like formations are created, called *strandflat glaciers* or *piedmont glaciers*. A good example is Murraybreen on Prins Karls Forland.

Geographical distribution

Glaciers are far from evenly distributed on the archipelago. Differences in topography and weather conditions are important. Whereas Bjørnøya, furthest south, has no glaciers whatsoever, Kvitøya, in the extreme northeast, is almost entirely concealed by an ice cap. This is doubtless mainly explained by cooler summers with less insolation in the north, and by more of the precipitation falling as snow.

As a glance at a map shows, large parts of Spitsbergen have few glaciers, especially the central region from Van Mijenfjorden northwards. It was pointed out earlier that this area is sheltered from the air streams that bring most precipitation, that is, those from directions between east and south. Too little snow falls to maintain a widespread cover of glaciers. However, the sparse snowfall cannot take all the blame. Where there is little precipitation, there is often a lot of clear weather, too, and the sun will have good opportunities to attack and melt the snow in summer.

The central part of Wijdefjorden has the poorest conditions for glaciers. We have to climb to 800 m to find snow that survives the summer here. That is a high snow line considering that we are at 80° N. The snow line on the west coast of Spitsbergen is, on average, around 300 m above sea level, but rises to more than 500 m in the interior, before gradually dropping

Fig. 43. Magdalenefjorden and its surroundings, near the northwest corner of Spitsbergen. The mountains, which consist of strongly metamorphosed igneous rocks, have been shaped into typical, jagged alpine forms by glacial erosion and frost action. This small fjord is considered to be one of the most beautiful ones in Svalbard, and is often visited by cruise ships. The area is also well known as an arctic paradise for ice and rock climbers. Several regions of Spitsbergen have been much visited by climbing expeditions, particularly in recent years. Many peaks, nevertheless, still remain untrodden by human feet. (B.L.)

Fig. 44. At the head of Van Keulenfjorden, several glaciers coalesce with the largest one, Nathorstbreen, before reaching the sea. This picture was taken in 1936. Since then, the glacier front has retreated several kilometres. The many medial and lateral moraines are easily recognised as dark trails of rock debris along the glacier surface, making it easy to envisage the glacier as a conveyor belt transporting material from the mountains to the sea. By far the greater amount of the debris, however, is dragged along by the ice or swept forward by meltwater rivers down the glacier bed, where it acts as sandpaper rubbing down the rocks beneath. (B.L.)

Fig. 45. The Freemansbreen glacier flows down from the ice cap covering the central part of Barentsøya and terminates in the sound separating that island from Edgeøya. The glacier had behaved calmly for many years, probably ever since last century, until shortly before this photograph was taken in 1956, when it suddenly advanced rapidly (surged), creating the huge, fan-shaped tongue in the foreground. (V.H.)

again further east (Fig. 41), to reach a minimum of barely 100 m on Kvitøya.

Glacier fluctuations

Glacier mass budgets are determined by the local topography and climate. Glaciers are fed by snowfalls, and even though precipitation in Svalbard is only moderate, most of it falls as snow, particularly in more elevated areas.

The radiant heat received is chiefly responsible for the melting, the debit side of the budget. Most of this derives from solar radiation, but long-wave radiation from clouds is also important. Provided the underside of a cloud cover is warmer than the surface of the glacier, the snow cover will receive more radiant heat than it emits.

The air temperature is another significant erosive agent. Mild air streams give off heat when they are in contact with a glacier. Radiation and air temperature are, however, so closely linked that detailed study is required to distinguish the effects of these two factors on the melting.

Svalbard glaciers have largely been retreating during this century. Both direct measurements, comparison with old photographs, and the presence of moraines far beyond present-day glacier snouts clearly demonstrate this. However, this is a long-term trend, not a continuous recession. Glaciers tend to fluctuate, periodically advancing and retreating.

A more long-term reduction of the glaciers must mean that the climate

Fig. 46. Kvitøya, the easternmost island in the Svalbard archipelago, is almost completely ice covered. This photograph of the west coast, taken from a height of 3000 m, gives the impression of a quite depressing and rather hostile glacier landscape. (V.H.)

Fig. 47. Fractured ice cliffs facing the sea, this is how many Svalbard glaciers end their life. Large and small blocks of ice frequently crash into the sea. The glacier is calving. However, this does not seem to worry the small flock of black guillemots swimming calmly in the foreground. (V.H.)

has become less glacier-friendly. The amount of snowfall seems to have been reduced. Moreover, the average temperature in Svalbard rose from the beginning of the century until the mid-1920s, although in summer this only amounted to a few tenths of a degree. Otherwise, we know little about just which changes in the weather conditions have had most to say, or about the interplay between these changes and the glacier fluctuations. The popular notion that cold winters cause glaciers to grow is incorrect. Cold winters in Svalbard generally mean little snowfall.

For many glaciers in Svalbard, the link with the weather conditions is so indistinct that it is difficult to perceive. As at lower latitudes, glaciers increase their mass on their highest parts (the *accumulation area*), and melt lowermost (the *ablation area*). However, in Svalbard, glaciers are far too cold and ice movement is too slow for all the surplus to be transported down. After several decades, occasionally more than a hundred years, de-

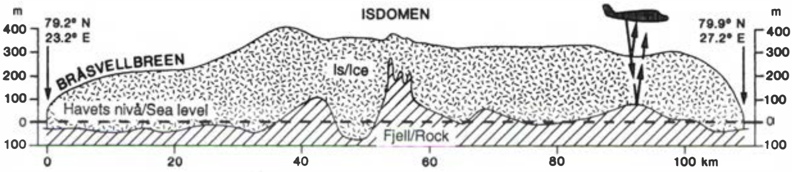


Fig. 48. Airborne instruments transmit radar waves down towards a glacier and receive echoes from the ice surface and underlying bedrock. This provides a continuous profile of both the surface of the glacier and its sole, thereby enabling the thickness of the ice to be measured. In spring 1983, a group from the Scott Polar Research Institute in Cambridge and the Norwegian Polar Institute used this technique to measure the thickness of glaciers over a large part of Svalbard. The measurements made on Austfonna on Nordaustlandet were particularly detailed. This diagram shows the contours of both the glacier surface and the concealed bedrock topography beneath, and is the result of one of the flights across the southeastern part of this huge ice cap. The maximum thickness measured on this particular traverse was 430 m, but the greatest thicknesses found during the entire project were between 600 m and 700 m. As the diagram shows, some of the sub-glacial topography is below sea level (but the ice obviously prevents the sea from inundating it). On the other hand, there are several high ridges and summits, especially in the central part of the diagram, even though it must be taken into account that the vertical scale is greatly exaggerated relative to the horizontal one.

pending upon the extent of the growth and the underlying terrain, the glacier becomes too top heavy. It becomes so steep and unstable that the ice begins to move down like a gigantic wave. The relatively high velocity produces greater frictional heat along the sole, and the temperature there can reach the melting point. Water along the sole will obviously radically reduce the friction and the velocity will increase further. The glacier snout, which has been extremely passive for a long time, suddenly advances, breaking up into a pile of ice blocks which are pushed forward with immense force. This kind of dramatic forward thrust of a snout is called a *surge*.

The Negribreen glacier in inner Storfjorden achieved the most rapid surge observed in Svalbard. In less than one year, in 1935–36, the glacier front advanced more than 12 km. Hence, the average speed was about 35 m per day, but the maximum speed was certainly considerably higher.

Calving

Even the largest glaciers terminating in the sea in Svalbard do not venture so far into deep water that they float. They calve before getting that far. Making tremendous cracks and splashes, large and small ice blocks break off and are

Fig. 49. An aerial photograph looking southeast showing the snout of Abrahamsenbreen in Woodfjorddalen. A small arm of this glacier, approximately in the centre of the photograph, has undergone a powerful surge. Ice and gravelly debris deriving from this surge have been transported down by the main glacier and can be recognised as a dark embayment in the upper edge of the glacier. (V.H.)

Fig. 50. During the summer thaw, a very distinct, regular pattern of crevasses often appears on the surface of glaciers, like we see here on Blomstrandbreen in Kongsfjorden. Prins Karls Forland is visible in the far background. (V.H.)

Fig. 51. Following a persistently cold winter, the fjord ice may be so solid that it poses a hindrance to shipping well into the summer. Here, a sealer, specially strengthened to penetrate ice, is breaking a lane for a passenger ship on its way to Longyearbyen. (V.H.)

Fig. 52. Long-lasting onshore winds may press the drift ice in the ocean towards land, to form a dense belt of pack ice along the coast and in the fjords. (V.H.)

Fig. 53. The southeast coast of Nordaustlandet, the second largest island in Svalbard. Ice covers about three-quarters of the island. The huge Austfonna ice cap rises to a height of nearly 800 m, the highest area on the island. The glacier reaches the sea in the east, as this photograph shows, forming an ice wall that extends for about 200 km along the coast. The western and northern parts of the island, however, are deeply incised by fjords. The headlands separating these fjords are largely ice-free lowlands, or hills rising to well above 600 m. This aerial photograph was taken in 1938, when the glacier in the foreground, Bråsvellbreen, was advancing rapidly (surging) and is therefore heavily crevassed. (B.L.)

sent adrift at the mercy of the wind and the currents. This mostly takes place in summer and autumn when the sea is not frozen. The largest blocks have the rank of icebergs and are feared for their enormous underwater mass, around 90% of the ice being concealed below water level, where its shape is indiscernible. They are usually irregular in shape, in contrast to the flat-topped icebergs that break away from the floating ice shelf in the Antarctic. Antarctic-type icebergs, but of moderate size, can occasionally be observed

Fig. 54. Aerial photograph taken off the coast of Nordaustlandet (just visible in the background). It provides a typical example of sea ice broken up by wind, currents and waves into floes of various size, which have subsequently become frozen together again. The largest floes on the picture are a couple of kilometres across. The density of sea ice is usually denoted on a scale from open pack ice, which covers 1–3 tenths of the surface, to compact pack ice, which covers the entire surface (10 tenths). The most impenetrable kind of drift ice is formed when winds and currents press the floes together, often piling them up on one another to give rise to pressure ridges and hummocks (screw ice). (B.L.)

in the waters east of Svalbard. However, they have drifted a long way, mainly from the Znamenityj glacier in Zemlja Franca Iosifa.

Icebergs have the regrettable property that they are unpredictable. They melt on all sides, both above and below the sea level, fracture and split apart. When pieces break off, the iceberg may overbalance and turn over. Obviously, a large iceberg that rolls over may be disastrous for boats that are too close. The smaller growlers, peacefully bobbing on the surface, seem more harmless, but if you hit them with a small boat you get a sharp reminder of their considerable underwater mass.

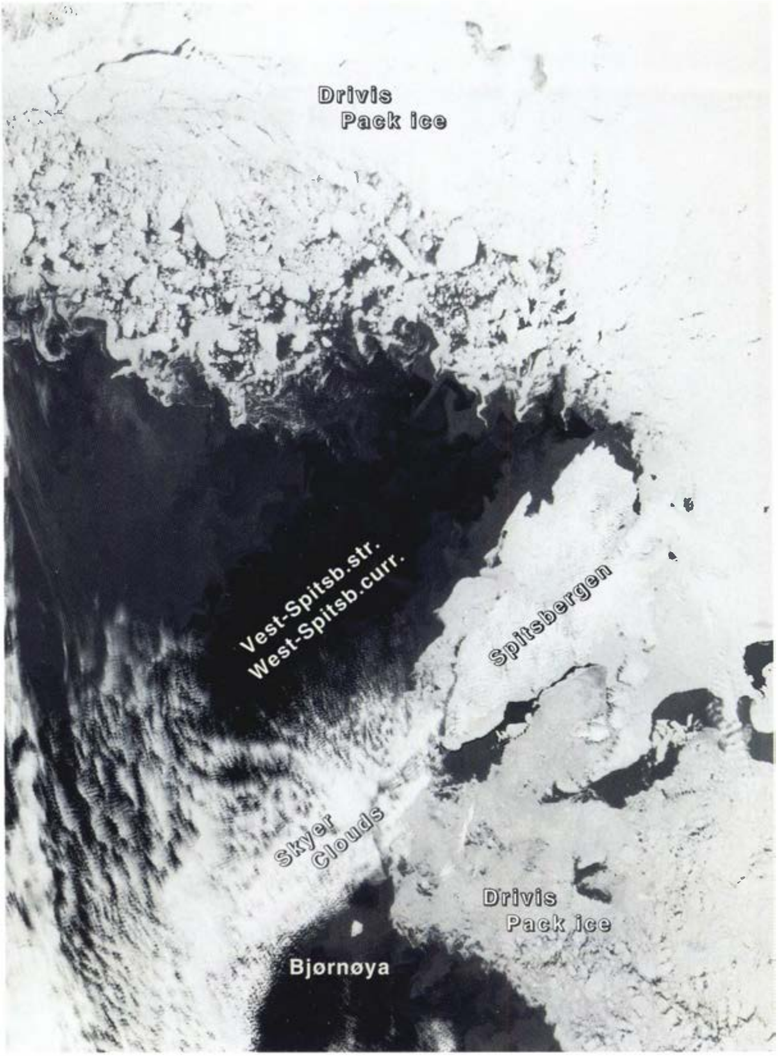


Fig. 55. This is a combination of two NOAA satellite photographs taken simultaneously, one in the visible and the other in the infra-red portion of the spectrum. Good light reflectors, such as clouds and snow cover on land and sea ice, show up as light areas, whereas the open sea is dark. The darkest portions of the open sea are warmest, and vary from about 2°C to 4°C. The lightest grey shades predominate the sea close to land or sea ice, and indicate temperatures ranging from -2°C to 0°C. The West Spitsbergen Current, which transports →

Icebergs are packed with tiny air bubbles under pressure, because the ice is formed deep down in a glacier through the gradual pressing together of layers of airy snow that were once on the surface. Melting icebergs therefore emit a pleasant rustling sound as the bubbles burst.

When the wind and current are adverse, fjords with large, calving glaciers may be filled with a dense queue of icebergs yearning to escape to the ocean. Hornsund, Kongsfjorden and Krossfjorden on the west coast of Spitsbergen are among the fjords where this typically arises. However, it seldom poses a serious obstacle for navigation, at any rate for long at a time. It is the sea ice that causes major problems for shipping in these waters.

Sea ice

The waters surrounding Svalbard are covered with ice to a varying extent, depending on the time of year and shifting meteorological and oceanographical conditions. When the temperature in the surface layer of the sea drops to between 1 and 2 degrees below freezing, depending on how saline the water is, conditions are right for ice to form.

The sea may cool down and freeze throughout the winter, and the ice normally has its greatest extent in March–April. At that time, the ice limit in the Barents Sea generally runs westwards to Bjørnøya, before turning north-northwest towards Spitsbergen, where it lies quite close to the west coast of the island. Off the northwest corner of Spitsbergen it turns southwest (Fig. 58).

There is therefore a huge bay of open sea west of Spitsbergen. This characteristic trait in the distribution of ice is closely related to the northward drift into this area of relatively warm Atlantic water, popularly referred to as the last branch of the Gulf Stream.

The sea ice is usually at its minimum in August–September. The ice limit then generally approaches the islands east of Spitsbergen from the north, describing a wide arc north of Nordaustlandet before swinging southwestwards towards Greenland (Fig. 58).

On the open sea, the sea ice is more or less broken up, drifting around at the whim of the winds and currents (*drift ice, pack ice*). The largest ice floes may be several kilometres across. In more protected waters, however,

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relatively warm Atlantic water northwards, can be seen as a black tongue in the middle of the photograph. The vortex-shaped formations on the boundary between black and grey shades show that the mixing of cold and warmer water masses is not a simple, smooth process. The picture also clearly demonstrates that the ice limit may be extremely diffuse and irregular. In this example, this is especially conspicuous between Spitsbergen and Greenland. (The photograph is based on data from Tromsø Satellite Station.)

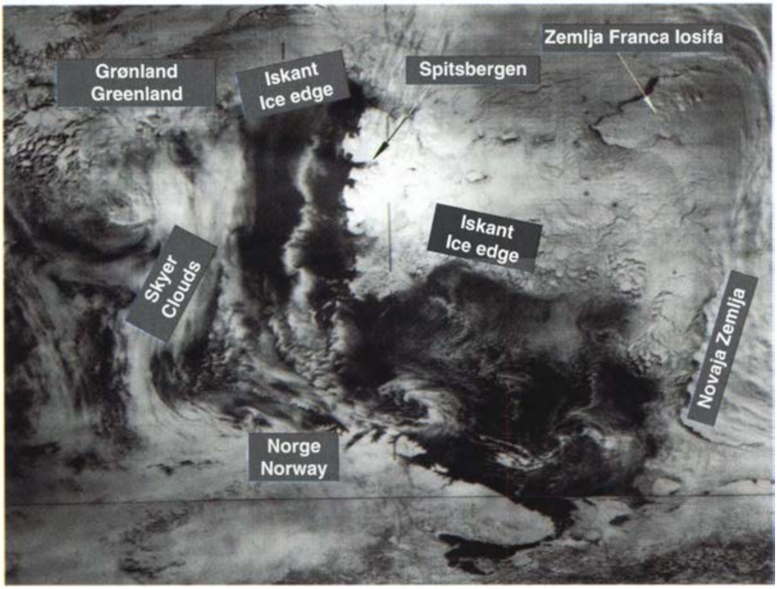


Fig. 56. A photograph of the Barents Sea and adjacent areas taken in the visible part of the spectrum by a NIMBUS satellite in April. The considerable extent of sea ice in the northern Barents Sea, in contrast to the dark, ice-free areas west of Spitsbergen, is clearly visible. Clouds appear as more or less diffuse, white patches, some having a fine, regular pattern. The cloud cover is often so compact that it is difficult to determine the extent of the sea ice by means of visible radiation. Satellite imagery made on the basis of radar waves, which 'see' through the clouds, then gives valuable information about the extent of the pack ice, even in the dark or in overcast weather.

the ice may form an unbroken carpet (*fast ice*), a typical feature of fjords and sounds in the late winter and spring.

It is normally possible to reach the west coast of Spitsbergen with ordinary vessels from the end of May or the beginning of June, until well into the autumn. This is a remarkably long period compared with other waters at this latitude, and is obviously of great importance for the transportation of coal from the mines.

However, it is by no means unusual for ice conditions to differ completely from this average situation. Thus, the west coast of Spitsbergen may have drift ice problems even in late summer. A current flowing from the area east of Spitsbergen turns north to follow the west coast as a cold, coastal current landward of the warmer Atlantic water. If this current is aided by a strong wind blowing in the right direction, it may take with it large quanti-

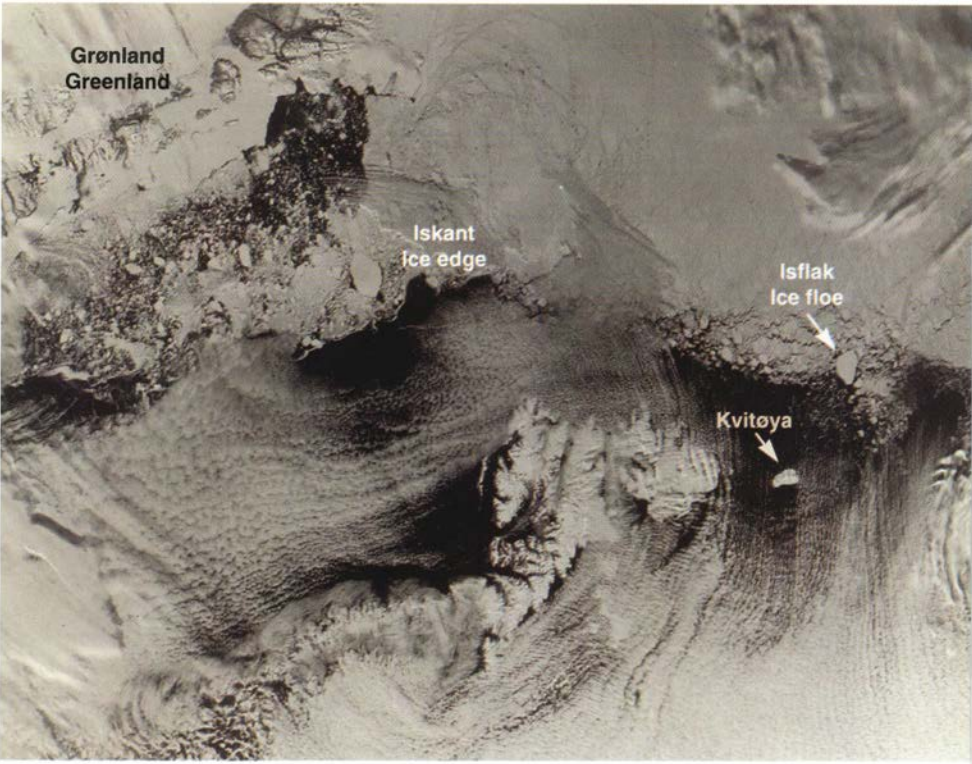


Fig. 57. A NOAA satellite photograph showing an area somewhat northwest of that shown in the preceding figure, and taken in mid-September. The drift ice boundary is now located significantly further north. Spitsbergen, moreover, looks much 'thinner' at this time of year, because both the fjord ice and much of the snow on the ground have melted. Note that the size of the largest ice floe exceeds the area of Kvitøya (700 km²). On this particular day, cold polar air was flowing southwards and swept out over open water, where it was heated, became more humid, and ascended in stripes parallel to the wind direction. This gave rise to the long, narrow bands of clouds visible in the picture.

ties of heavy pack ice, which can make the west coast partially or entirely inaccessible to shipping.

On the other hand, in favourable years, ice conditions may be so good that it is possible to circumnavigate the entire archipelago with a small vessel. Nevertheless, in most summers it is difficult or impossible for ordinary boats to reach the northeasternmost parts of Svalbard.

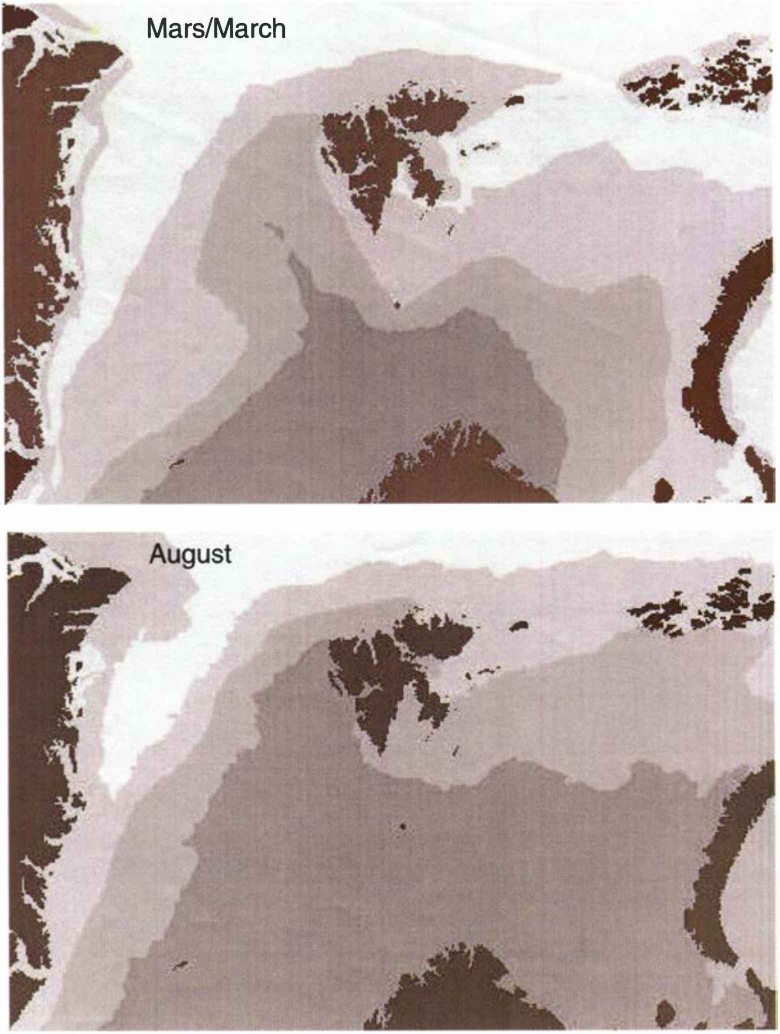


Fig. 58. The sea ice boundary in March and August, usually the months with most and least ice, respectively. The darkest grey area signifies open sea. If we move into the medium-grey zone, the chances of meeting ice increase from 0% to 50%. Correspondingly, the chance of meeting ice rises from 50% to 100% inwards within the lightest grey zone. Observation data indicate that ice should always be present in the white areas. (The map is based on data from 1966–89, derived from various sources and digitised at the Norwegian Polar Institute.)

The extent, movement and thickness of the sea ice depend entirely on the prevailing meteorological and oceanographical conditions and are equally capricious. The major ocean currents change quite slowly and result in correspondingly slow shifts in the ice conditions. Strong winds, and the resulting waves and intermittent surface currents, break up the ice and set it in motion. Strong winds are chiefly responsible for the large and rapid changes sometimes observed in the location of the ice.

Temperature and wind conditions during the winter determine the extent to which the sea freezes. Winter-old ice seldom becomes more than a couple of metres thick. However, when the ice is broken up by winds and currents and the floes pile up on one another to form huge masses of *screw ice*, the thickness may become substantial. This is particularly the case for perennial ice from the Polar Basin that has experienced several episodes of screwing. Heavy pack ice of this type may drift southwards in the waters east of Svalbard and occasionally swing northwards along the west coast of Spitsbergen, as mentioned previously.

If the wind is sufficiently strong, and consistently blows from the northwest, it is not unknown for heavy ice from the waters off northeast Greenland to drift right onto the west coast of Spitsbergen, but this is fortunately a seldom event. Generally, it fails to reach beyond the north coast of the archipelago.

Only the uppermost layer of the ground thaws in summer, down to a depth varying from a few decimetres to a couple of metres, depending on the weather conditions, the aspect and the nature of the soil. It is only this relatively shallow layer that is biologically active.

The permafrost results in poor drainage, and the water table is often close to the surface, particularly in flat or only gently sloping areas, which

Fig. 59. Among the most hostile places for vegetation in Svalbard must be the ground in front of some glaciers. During the thaw, such an area will often be a porridge of water and clay, mixed with coarser rock debris. Not even the hardiest of plants can find a footing here. It is not particularly hazardous to walk across such an area, since solid permafrost is only a few decimetres below the surface, but it can be very exhausting as boots continually become stuck in the mud. (V.H.)

may become extremely waterlogged, especially during the thaw. The vegetation will therefore generally have adequate moisture. The minimum factor is usually the short growing season, which lasts only 6 to 10 weeks.

The short growing season makes it particularly important for the plants to get a flying start as soon as conditions are right. Many species flower only a few days after the snow has thawed. Preparations for flowering therefore have to be made far in advance, and buds are often already fully developed the year before. Several species also form brood buds and runners, giving them a chance to reproduce vegetatively, even if they do not have time to produce mature seeds.

Characteristic species

Almost 170 species of vascular plants have been found in Svalbard. This is nearly four times as many as under the harsher conditions in Zemlja Franca Iosifa to the east, but obviously far fewer than we find when we travel south to northern Norway. The flora is particularly rich along the central fjords in western Spitsbergen, not least Van Mijenfjorden and Isfjorden. More than three-quarters of the vascular plants occur in the inner parts of these fjords. Only a few characteristic species will be mentioned here.

Above all, it is the relatively favourable climatic conditions that make the vegetation in Svalbard more virile and varied than in most areas at a corresponding latitude. Trees and shrubs, as such, lack a basis for existence. The dwarf birch (*Betula nana*) is found in a few places in inner Isfjorden, although it only occurs as a low, creeping shrub whose branches reach some centimetres above the ground. Polar willow (*Salix polaris*) is much more common, again as a low shrub. It is, indeed, a characteristic feature of the vegetation in these regions that the plants grow close to the ground, or densely clustered together in tussocks or cushions. This gives them the best possible protection from the wind, and also maximum benefit of the life-giving power of the sun's rays.

Like everywhere else, the origin and evolution of the plant communities in Svalbard can be partly traced back to historical causes, partly to the local growing conditions. These, on their part, embrace many different factors, such as the local climate, including insolation, exposure to wind and the influence of the snow cover. In addition comes the influence of the texture, composition and moisture of the substratum. The individual species place different demands on these factors. Together with the fact that the plants are living under marginal conditions, this often leads to great differences in the composition of the vegetation over short distances.

On well-drained, calcareous soils with a moderate snow cover in winter (heathland and morainic ridges), large areas may be dominated by mountain avens (*Dryas octopetala*), often along with rock sedge and cushion sedge (*Carex rupestris* and *C. nardina*), or belts of the white arctic bell

Fig. 60. Brightly coloured purple saxifrage may paint large areas of the tundra. (V.H.)

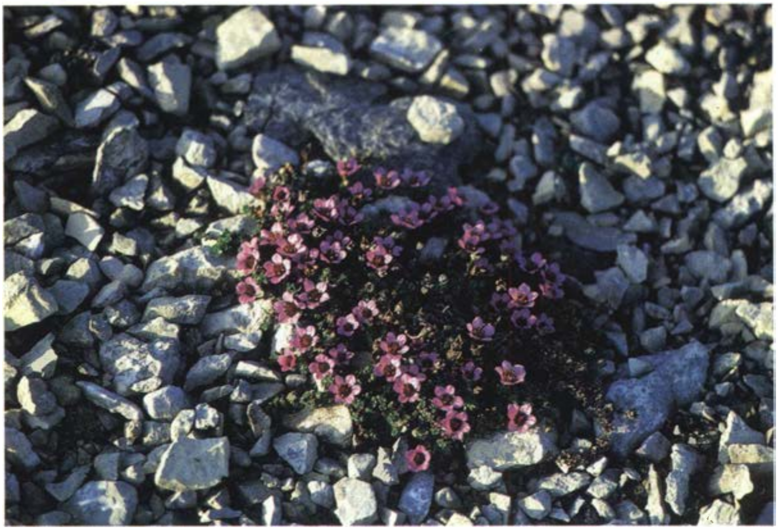


Fig. 61. A close-up of purple saxifrage. This is a very hardy plant, which flowers as soon as the snow disappears, all the way from the seashore to high on the mountains. An occurrence on the north coast of Greenland gives it the record of being the northernmost flowering plant in the world. (V.H.)

Fig. 62. Lowland plains with a high water table may be richly vegetated by mosses and higher plants which thrive in wet places. A vigorous arctic cotton-grass community is seen in the foreground. (A.B.)

Fig. 63. The Svalbard poppy occurs in two forms, with white or yellow flowers. Many people consider it the most beautiful plant in the archipelago. It is very common and is also the highest-growing flowering plant found in Svalbard.

Fig. 64. A plant community containing mountain avens. This flower is widespread throughout Svalbard, but prefers dry, calcareous soils that become snow free early in spring. (B.Ly)

Fig. 65. Lush polar scurvygrass near a bird cliff on Bjørnøya. The juicy leaves are rich in vitamin C, and the plant has for a long time been renowned as an efficient cure for scurvy. (B.Ly.)

Fig. 66. Frost may create a network of narrow depressions in the ground where water gathers, providing good growing conditions for thick moss carpets, often in beautiful colour compositions. (T.L.)

Fig. 67. Hillsides beneath bird cliffs are often richly manured by bird droppings from above, giving them the apperance of green hanging gardens. (V.H.)

heather (*Cassiope tetragona*), the only common type of heather in Svalbard.

On the other hand, in moist localities where the water table is high, as is usually the case on valley floors and the strandflat, the vegetation differs completely in type and composition. Here, we can find dense, brightly coloured carpets of mosses, especially tarn mosses and claw mosses (species of *Calliergon* and *Drepanocladus*) and grasses may abound. Tundra grasses (*Dupontia*) and arctic marsh grass (*Arctophila fulva*) are common. A number of flowering plants also thrive in wet localities, including yellow marsh saxifrage (*Saxifraga hirculus*), arctic cotton grass (*Eriophorum scheuchzeri)* and several species of buttercup (*Ranunculus*).

Another conspicuous flower which makes its mark on the vegetation in many places, is purple saxifrage (*Saxifraga oppositifolia*). As soon as the snow thaws, this flower unfolds and may form a deep red carpet over large areas of the tundra. It is a very hardy and adaptable plant and occurs both on seashores and high in the mountains. Purple saxifrage has been found as far north as 83°N (the northern tip of Greenland) and holds the title of the world's northernmost flower.

Other characteristic species that are common in Svalbard include moss campion (*Silene acaulis*), perhaps the best known of the many plants that have a pronounced cushion-shaped form of growth, and Svalbard poppy (*Papaver dahlianum*), which is found in both a yellow and a white variant and is known for its beauty. It also has no fear of altitude, having been found as high as 1100 m, the highest known locality for a flower in Svalbard. Another well-known plant is polar scurvygrass (*Cochlearia groenlandica*). As the name implies, this plant has long been renowned as an efficient remedy for scurvy, and the high vitamin C content of its juicy leaves is reputed to have been the saving of many trappers.

The plant life is particularly rich beneath many bird cliffs, especially those facing south. This is obviously mainly due to the ample supply of fertiliser from the bird colonies. It produces an amazingly luxuriant vegetation, as regards both production and number of species. The bright colours of the plant cover, above all the mosses, contrast sharply with the surroundings and make the slopes beneath the bird cliffs easy to pick out from a long way off, as a kind of hanging gardens.

Vulnerability

The extreme growing conditions mean that external impacts, such as those created by human activities, may easily inflict great damage on the plant life. Rejuvenation takes place extremely slowly in this environment, and is made still more difficult by the fact that the absence of a plant cover facilitates the destructive effects of erosion. This is an important reason why large parts of Svalbard are protected through strict environmental legislation (see Appendix II). The establishment of three plant reserves may be mentioned here. They are found: (1) around the innermost arms of Isfjorden, (2) between Colesdalen and Adventdalen, on the south side of Isfjorden, and (3) on Ossian Sarsfjellet, a mountain at the head of Kongsfjorden. These areas have a specially rich vegetation and are legally protected from the collection and destruction of plants.

Regulations have also been introduced for Svalbard in general, with the intention of protecting the natural environment from the damaging impact of human activities. Protecting the vulnerable ecological systems in the region as well as possible is particularly important in connection with the ever-increasing tourist traffic.

Just like the plant life, the animal life in Svalbard has to be adapted to extreme living conditions. Low temperatures and unusual light conditions are perhaps the first factors that spring to mind. Other important environmental factors are the snow conditions on land and the extent and variation of the sea ice.

The snow generally disappears from steep slopes first, such as bird cliffs, a clear advantage for species nesting there. The amount of snow on the tundra may vary greatly from year to year. If it takes a long time for the ground to become snow free, it may be critical for birds which nest on flat ground. Time may be too short for the young to achieve adequate flying proficiency to tackle the long journey south in the autumn. At worst, egg laying may not take place at all.

Sea birds require open water, or at least gaps in the ice, in order to find food. On the other hand, almost all the seal species in Svalbard are dependent upon sea ice for long periods, using it to rest on between dives to find food and to give birth to their pups. The polar bear also prefers to be on sea ice, because the chance of finding its favourite meal, a seal, is best there.

As in most polar regions, the number of species in Svalbard is not im-

Fig. 68. A pair of Svalbard ptarmigans in spring. The female has already shifted to her brown-mottled summer plumage, while the male keeps his white plumage until late in the summer. The ptarmigan is the only terrestrial bird that remains in Svalbard throughout the year. (F.M.)

Fig. 69. Brünnich's guillemots on a bird cliff. In common with several other birds in Svalbard, its most dreaded enemies are the arctic fox and the glaucous gull. The chicks are particularly at risk when, in an almost helpless state, they leave for the sea for the first time. Brünnich's guillemots and kittiwakes (some are visible on the edge of the picture) often share the same nesting site. (F.M.)

pressive. On the other hand, there may be tremendous numbers of some species, particularly birds.

Birds

The bird life is surprisingly rich, but naturally only in summer. The sole bird that remains on the islands throughout the year is the Svalbard ptarmigan (*Lagopus mutus hyperboreus*). It mostly obtains its food from plants and has to accumulate a sufficiently thick layer of subcutaneous fat during the summer and autumn to have enough to live on when food is hard to come by in winter. Both sexes have white winter plumage, but while the female gets her brown summer plumage already early in spring, the male does not get his before mid-August, only a month before they both return to their winter plumage. They are not at all timid, and have clearly not learnt to look upon Man as an enemy. Ptarmigan are found throughout the archipelago, except the extreme northeast.

As soon as summer approaches, the islands are invaded by millions of birds. Several members of the auk family, the Brünnich's guillemot (*Uria lomvia*), black guillemot (*Cepphus grylle*) and little auk (*Alle alle*), are common, while the puffin (*Fratercula arctica*) is somewhat less abundant.

Fig. 70. The little auk is the smallest member of the auk family, measuring a mere 20 cm, but is the most abundant species in the archipelago. It mostly nests in fissures in cliffs, or in a scree at the foot of a cliff, and lays just one egg. The colonies vary in size from a few pairs to several hundred thousands. Close to large colonies, the air swarms with birds whose whirring wings carry them to and fro between the larder in the sea and the nest. The snow near large colonies of little auks (and several other seabirds) may be painted red with the droppings from the birds, which largely live on small, red crustaceans. (F.M.)

The Brünnich's guillemot nests on bird cliffs all over Svalbard, in contrast to the ordinary guillemot (*Uria aalge*), which almost only occurs on Bjørnøya. These two related species are perhaps most easily distinguished by the former having a conspicuous white stripe along the edge of its upper beak.

The little auk is the smallest of the auks. It prefers to nest in fissures in steep cliffs or screes, occasionally in colonies numbering several tens of thousands of pairs, whose hidden presence is given away by the harmonious humming sound issuing from the feathered choir. Dense swarms of birds, with whirring wings, sweep back and forth between their larder in the sea and their nests. Far less numerous, but certainly far more conspicuous, is the puffin with its characteristic, large, brightly striped red, yellow and blue beak, which earns it the nickname of 'sea parrot'.

Some gulls also occur in considerable numbers, particularly the kittiwake (*Rissa tridactyla*) which nests on bird cliffs throughout the archipelago. Larger, but far less abundant, is the glaucous gull (*Larus hyperboreus*), which can almost be considered a predator. During the breeding season, it largely lives on the eggs and chicks of other birds. In inhabited areas it also acts as a refuse collector, dealing efficiently with waste food on rubbish dumps. The attractive, but more seldom, ivory gull (*Pagophila*

Fig. 71. The puffin is not one of the most abundant of Svalbard birds. However, because of its unique, colourful beak, which gives it its popular name of 'sea parrot', it attracts our attention. The nest is well concealed in a scree or rock fissure. Outside the breeding season, it generally remains at sea, well away from the coast. (B.Ly.)

eburnea) stands out because of its striking, snow-white plumage. It is a typical arctic species, and is most common far north and in ice-filled waters.

The arctic tern (*Sterna paradisaea*) is the only tern found in Svalbard, but it breeds throughout the archipelago, both on tundra near the sea and on islets. Despite its Latin name, there is little in its behaviour that gives an impression of paradise. On the contrary, it is highly aggressive, screeching at and dive-bombing anyone who dares to venture too near its nesting site. It has many enemies, too, not least the arctic fox.

Arctic terns are also notable for their remarkably long migration. They travel right to the Southern Hemisphere in the autumn, some even as far as the Antarctic, thus experiencing two polar summers each year. This contrasts with many of the other sea birds breeding in Svalbard, which often do not journey far, but can be heard, if not seen, off the coast during the polar night.

Another aggressive defender of its nest is the arctic skua (*Stercorarius parasiticus*), which is the most common of the skuas in the islands. It obtains most of its food by piracy, chasing gulls and auks until they have to drop the food they have found, and also stealing the eggs and chicks of other birds. The fulmar (*Fulmarus glacialis*), a member of the petrel family, is far more peaceful. It is numerous and is frequently seen gliding low over the waves.

The common eider (*Somateria mollissima*) is by far the commonest duck. It nests near the sea, preferably on islets after the ice has melted, preventing

Fig. 72. A colony of breeding kittiwakes. The birds nest close together on narrow ledges in bird cliffs. The kittiwake is the commonest gull in Svalbard and is found on the coast and also far out at sea. Its clutches are small, numbering only one or two chicks. (V.H.)

Fig. 73. The fulmar, one of the most abundant members of the petrel family, is an outstanding flier and enjoys gliding low over the waves with outstretched, almost motionless wings. It is a silent bird, with a somewhat sombre appearance, which has doubtless encouraged all the superstition that is associated with it. (V.H.)

Fig. 74. An attacking arctic tern. It is extremely aggressive during the breeding season, and, issuing harsh screeches, dive bombs anyone which it considers a threat to its eggs or chicks. People who pass close to a tern colony can hold a stick above their heads to avoid being pecked, and should content themselves with this passive form of self-defence. Arctic terns nest on islets and shores, as well as on tundra not far from the sea. They are excellent fliers and are renowned for their long spring and autumn migrations. Some journey all the way between the Arctic and the Antarctic, thus experiencing two polar summers each year. (V.H.)

the arctic fox from reaching it. You can approach very close before a brooding female leaves her nest. However, it is vital that they are not disturbed, and certainly not frightened away, during that period. Because the population was greatly decimated by widespread hunting and the taking of eggs and down from the nests, it was given total protection in 1963. Its colourful relation, the king eider (*Somateria spectabilis*), is considerably more seldom.

Three geese species are found in Svalbard, the pink-footed goose (*Anser brachyrhynchus*), the barnacle goose (*Branta leucopsis*) and the brent goose (*Branta bernicla*). The pink-footed goose is most common and quite widespread, and it is even allowed to be shot for a short period in autumn. The other two species are totally protected. The brent goose, in particular, seems to have suffered a strong decline in numbers, after apparently being the most abundant goose species in the archipelago in the past.

Other important, but less conspicuous members of the Svalbard bird fauna are the red-throated diver (*Gavia stellata*) and some waders, notably the purple sandpiper (*Calidris maritima*) and the grey phalarope (*Phalaropus fulicarius*). The purple sandpiper is, incidentally, a master at feigning injury, persuading intruders to follow it as it drags itself away from the nest. Apart from some chance, rare visitors, the snow bunting (*Plectro-*

Fig. 75. A pair of eiders, the brooding hen closest to the camera. The contrast in their plumage is striking. Eiders nest on small islands which foxes cannot reach, but also along the coast. The risk of a fox or glaucous gull taking the eggs or chick is greatest if the female is frightened from the nest. (F.M.)

Fig. 76. The barnacle goose population was greatly reduced around the end of the Second World War. After protective measures were introduced, its numbers have recovered substantially, and now more than 20,000 individuals spend the summer in Svalbard. They graze on tundra vegetation. (V.H.)

Fig. 77. Apart from sporadic guests, the snow bunting is the only passerine species that nests in Svalbard. It is unbelievably hardy and stays on the islands from early in spring, often well before the snow has melted, until late in the autumn. It is mainly a vegetarian, feeding on seeds and buds, but also takes some insects. (T.L.)

phenax nivalis) is the only representative of the passerine fauna. Even so, it is very common, and a lively, unbelievably hardy little creature.

No birds of prey have been recorded nesting in Svalbard. Although the snowy owl (*Nyctea scandiaca*) is often observed, it is only looked upon as a sporadic visitor. This 'gap' in the bird fauna is probably a result of the almost complete absence of small rodents, an important prey item for such birds.

Many invertebrates inhabit the islands, but naturally they are a well-concealed part of the fauna. Biting mosquitoes may occasionally be bothersome in the inner parts of the fjords on calm, sunny days in summer.

Terrestrial mammals

There are only three indigenous terrestrial mammals in Svalbard, the arctic (or polar) fox (*Alopex lagopus*), the Svalbard reindeer (*Rangifer tarandus platyrhynchus*) and the polar bear (*Ursus maritimus*). Attempts to introduce new species have not been particularly successful. In 1929, 17 musk ox (*Ovibos moschatus*) were brought from Greenland and released near Longyearbyen. As far as is known, the species has never lived in Svalbard earlier. The herd was obviously fully protected and increased somewhat. Following a reduction during the war (illegal hunting), it probably num-

Fig. 78. The arctic fox can be encountered almost anywhere in the archipelago, but of course mostly where access to food is good, such as near colonies of breeding seabirds. (Ø.L.)

bered some 50 individuals in 1959. Subsequently, the population became drastically reduced, probably due to inclement weather and competition with reindeer for grazing. By the mid-1980s, only one survivor was observed, and the species must now be considered as extinct here.

Similar attempts to introduce hares (*Lepus arcticus* and *L. timidus*) in the 1930s were unsuccessful, too. Rats and mice occur more or less sporadically in the settlements. The only species that seems to have gained a foothold and become fairly widespread for a lengthy period, also beyond the settlements, is the sibling vole (*Microtus epiroticus*), which probably reached the islands with vessels from eastern Europe. Like the other small rodents that are sometimes seen, it cannot be considered a genuine member of the fauna.

The arctic fox (polar fox) can be met with all over Svalbard. Two forms occur, a white one (more than 95% of the population) and a blue one. The former is white in winter. In summer, it has a dark greyish-brown back, but a much lighter stomach. The blue type, on the other hand, shows no marked seasonal change in colour. The colour of its coat does not differ much from that of the white variant in summer, but it lacks the light-coloured parts.

Even though the arctic fox can be encountered anywhere, in the lowlands as well as in the mountains, it is naturally most abundant where food is easiest to come by. A favourite site for its den is a scree at the foot of a

Fig. 79. The Svalbard reindeer differs in several ways from its relations elsewhere in the world. It is comparatively small, stockily built and short-legged. It is a miracle that it can survive the harsh conditions under which it lives, with such extremely sparse vegetation. It has to accumulate a substantial layer of fat between spring and autumn to have something to fall back on during the lean period in winter. (H.G.)

bird cliff. Here, both eggs and chicks literally fall from the skies before its very mouth. It also eats the carcasses of larger animals which it happens to come across, and sometimes follows polar bear tracks out across the ice and makes do with finishing up the remains of the bear's meals. Times are hard in winter, and like other animals that spend the winter in polar regions, foxes need to lay up a layer of fat in their bodies during the summer to fall back on when food is scarce. The arctic fox is also renowned for hiding surplus food for later needs. To what it extent it rediscovers these caches is uncertain.

It is important to be aware that many foxes are infested with rabies, although the disease only makes itself apparent in the animal itself when it is greatly weakened for some reason. In 1980, both a reindeer and a ringed seal were found to be infected with rabies, probably after being bitten by foxes.

The Svalbard reindeer differs somewhat from its relations on the tundra further south and is looked upon as a separate sub-species (hence the addition: *platyrhynchus*). It is comparatively small and short-legged, and its coat is thick and specially suited for providing efficient insulation. It also has a highly developed ability to store fat to fall back upon when food is hard to come by. These are just a few of the special adaptations in Svalbard

Fig. 80. The polar bear is in its right element in the pack ice, where it finds its favourite food, seals, as illustrated in this photograph. It is most common in northern and eastern Svalbard. (V.H.)

reindeer that enhance their chance of surviving under the extreme environmental conditions.

Svalbard reindeer spend virtually all day and night grazing and chewing cud. This is also vital, considering the sparse plant cover. In winter, they stay on windy ridges and other places where little snow gathers and it is relatively easy to scrape the snow from the vegetation. However, the winter grazing is obviously far too meagre to balance the animal's loss of energy. The deficit has to be met by its fat reserves, which therefore need to be adequate when winter sets in if the animal is to survive. A great deal of energy is saved by its sedate way of living, and it is essential that people avoid scaring the animals into energy-tapping flight.

Reindeer used to be quite numerous in Svalbard, but excessive hunting during the 19th century and up to 1920 drastically reduced their numbers, even to the risk of extinction. They were then legally protected in 1925, and the population began to increase again. Now it seems to have stabilised at around 10,000 animals. There are several sub-populations in relatively limited areas, which have little mutual contact. The largest numbers are found in Nordenskiöld Land (between Isfjorden and Van Mijenfjorden) and on the eastern islands of Barentsøya and Edgeøya. A herd of 12 animals was released on Brøggerhalvøya on the south side of Kongsfjorden in 1978.

Fig. 81. The small, plump ringed seal, is the most numerous of the seals in Svalbard, and the Arctic as a whole. It only gives birth to a single pup, which is born in March–April, in a protective hollow in a snow drift on the ice. The pup depends upon its mother for almost two months. (C.L.)

Its numbers have increased greatly, even though difficult weather in the winter of 1993–94 brought many deaths when a layer of ice formed on the grazing. The herd is now some 100 animals strong.

The polar bear belongs first and foremost in the drift ice, but can fairly often be encountered on the islands, both in summer and winter. It is most numerous in the east and north. On land, it mostly remains close to the shore, and on islets and small islands. However, there is no doubt that it prefers to be out on the ice where it has the best chance of catching seals, its favourite food. When the ice margin retreats northwards in summer, the polar bear has to follow it. In winter, when the sea ice stretches far south, bears can get as far south as the area around Bjørnøya. Bears that are left stranded by vanishing ice and have to stay on land for a long period, may have difficulty finding sufficient food and can then be aggressively curious – about human beings, too. A well-fed polar bear is usually not keen to attack, provided it does not feel itself threatened.

Pregnant bears dig dens in snow drifts late in the autumn. Favourite locations include hillsides on Kong Karls Land and some other islands in the east. The cubs, usually two, are born around New Year. They leave the den in March or April, and the cubs normally accompany their mother for at least two years before being able to fend for themselves and become independent. Male bears do not den, but occasionally dig holes in the snow and rest for a time if the weather is really bad. However, the excellent insulation provided by their coat and the fat layer helps them to maintain a normal body temperature.

The polar bear population was severely decimated by hunting up to the end of the 1960s. An average of 300 animals were shot each year at that time. Restrictions and quotas were introduced in 1970, and became gradually more strict until 1976, when an agreement on total protection was signed by all the nations which had a polar bear population within their boundaries. Certain exceptions were made for indigenous peoples, for whom polar bear hunting has long been part of their basis for existence.

Svalbard polar bears are thought to belong to a population that roams between East Greenland and the islands of Severnaja Zemlja. Bears may make remarkably long trips within this area. They are known to be capable of covering 50 km to 80 km in 24 hours. They are also excellent swimmers, so open lanes in the drift ice offer no obstacle. Following its protection, the polar bear population has recovered well, and it is now estimated that around 3000 bears live in the Svalbard area.

Seals

The ringed seal (*Phoca hispida*) is by far the commonest seal along the coasts of Svalbard. It is the smallest and also the most abundant seal in the whole of the Arctic. It can reach a length of 1.6 m and a weight of around 120 kg. The dark patches on its skin, surrounded by a lighter ring, explain its name.

It can be very conspicuous in some places in late spring, scattered across the fjord ice, but open water or holes have to be present in the ice in the vicinity. However, it also occurs far out in the drift ice, or can be observed in open water, its head just visible above the surface.

The ringed seal dives to take crustaceans and small fish, and can remain under water for as long as 20 minutes, although it usually comes up to breath far more frequently. It manages to keep a breathing hole open in up to 2 m thick ice by continuously scraping away the newly frozen ice with the claws on its front flippers. Ringed seals give birth to their pups in hollows in snow drifts on the sea ice in March–April, which is the only time of the year when they are protected. However, the hunting of ringed seals has no economic significance. They have several enemies nevertheless, both in the sea and on the ice, the polar bear no doubt being the worst.

The bearded seal (*Erignathus barbatus*) is also common in Svalbard, but far less so than the ringed seal. On the other hand, it is considerably larger and can be as long as about 2.5 m. When it is not in the sea, it likes to lie beside the edge of the ice, or on an ice floe. It is important to be close to open water, which represents both a larder and a means of escape. It lives

Fig. 82. The bearded seal is common in Svalbard, but far less numerous than the much smaller ringed seal. It is often observed alone on the ice, close to open water, or on a floe, and does not seem particularly sociable. (V.H.)

Fig. 83. The walrus, the largest of Svalbard seals, often lives in close-knit flocks. It swims easily in the sea, but on the ice, or the seashore, it is far more helpless and therefore an easy prey for trappers. Ruthless hunting almost brought the walrus to extinction in Svalbard before it was totally protected in 1952, after which the population has recovered well. (I.G.).

on fish and demersal creatures, and prefers feeding in shallow water, preferably no deeper than 50 m.

The bearded seal does not seem particularly sociable, and usually only single individuals are encountered, resting majestically on the ice. The young are born on the ice in March–April and, as with the ringed seal, this is the only time of year when the bearded seal is protected. The pups are able to swim just after they are born, and can manage on their own after 2–3 weeks. The hunting of bearded seals is of no commercial importance, either. Their worst enemies are the killer whale, and above all, the polar bear.

The walrus (*Odobenus rosmarus*) is the largest Norwegian seal. The male is biggest and can reach about 3.5 m in length. One of the most characteristic features of the walrus is its slightly curved tusks, which, in old males, can be as much as half a metre or more in length. Walruses live largely on demersal creatures, which they dig out with their tusks. They like to rest on ice floes or, when the ice is no longer present, on suitable spots on the shore. A favourite haunt is Moffen, a small, ring-shaped island just north of Spitsbergen, which is now a nature reserve with strictly enforced regulations. Walruses are very sociable animals and often lie close together in colonies.

Walruses used to be very abundant throughout Svalbard, but their valuable ivory tusks, as well as their skin and blubber, made them much sought after by hunters. They were also very easy to take. Consequently, the species become almost entirely extinct here. It was not totally protected in Norwegian waters before 1952, and the population has since recovered well. Walruses mainly occur in northern and eastern Svalbard, where around a thousand animals are estimated to be present in summer.

Small numbers of common harbour seals (permanent population on Prins Karls Forland), harp seals and hooded seals are sporadically observed in Svalbard.

Whales and fish

The whale species in the seas around Svalbard will not be described in detail. The populations have been greatly reduced since the heyday of whaling during the 18th to 20th centuries. This applies particularly to the bowhead or Greenland right whale (*Balaena mysticetus*), which was hunted almost to the point of extinction. It was legally protected in 1939, alas too late. The white beluga whale (*Delphinapterus leucas*), which is easy to spot, is probably the species that is most frequently seen along the coasts and in the fjords. It can reach a length of 6–7 m and often swims in schools of 10–20 up to several hundred individuals following one another. Excessive hunting has probably also made the beluga whale a great deal less common than it used to be. It is now totally protected.

The arctic char (*Salvelinus alpinus*) is the only species of fish in lakes and rivers in Svalbard. It occurs both in a stationary form that remains con-

*Fig. 84. Even with water temperatures around 0° C, the sea floor around Svalbard is far from lifeless. A typical example is shown in this picture taken by flash photography at a depth of 80 m, approximately 3 km off Bråsvellbreen on Nordaustlandet. The photograph covers about 1.5 x 1.0 m. The floor in these parts typically consists of mud and a scattering of small stones. Meltwater brings the mud from glaciers, while icebergs originating from glaciers or sea-shore ice raft the stones out to sea. A number of organisms in the photograph can be easily identified, including starfish (*Asteroidea*), crinoid (*Crinoidea*), sea urchin (*Echinoidea*) and, scattered everywhere, brittle stars (*Ophiuroidea*). The light-coloured object in the upper right-hand corner is part of the submerged photographic equipment. (A.S.)*

tinuously in fresh water, and in another form, the sea arctic char (Spitsbergen salmon) which spawns in fresh water before swimming down to the sea to gorge itself in summer. Char fishing gradually became too popular relative to the limited size of the stock and its slow rejuvenation. Regulations were therefore introduced to prevent the species from becoming extinct.

The offshore waters may be rich in several kinds of fish, such as cod, Greenland shark and halibut. A significant fishery takes places periodically, particularly on the banks near Bjørnøya. Shrimp trawling has also been successful at times, even as far north as the waters north of Spitsbergen.

Protective regulations have been mentioned in some specific cases of specially threatened species. More general information on the environmental provisions for Svalbard, including the special protection of animal and plant life in specific areas, is given in Appendix II.

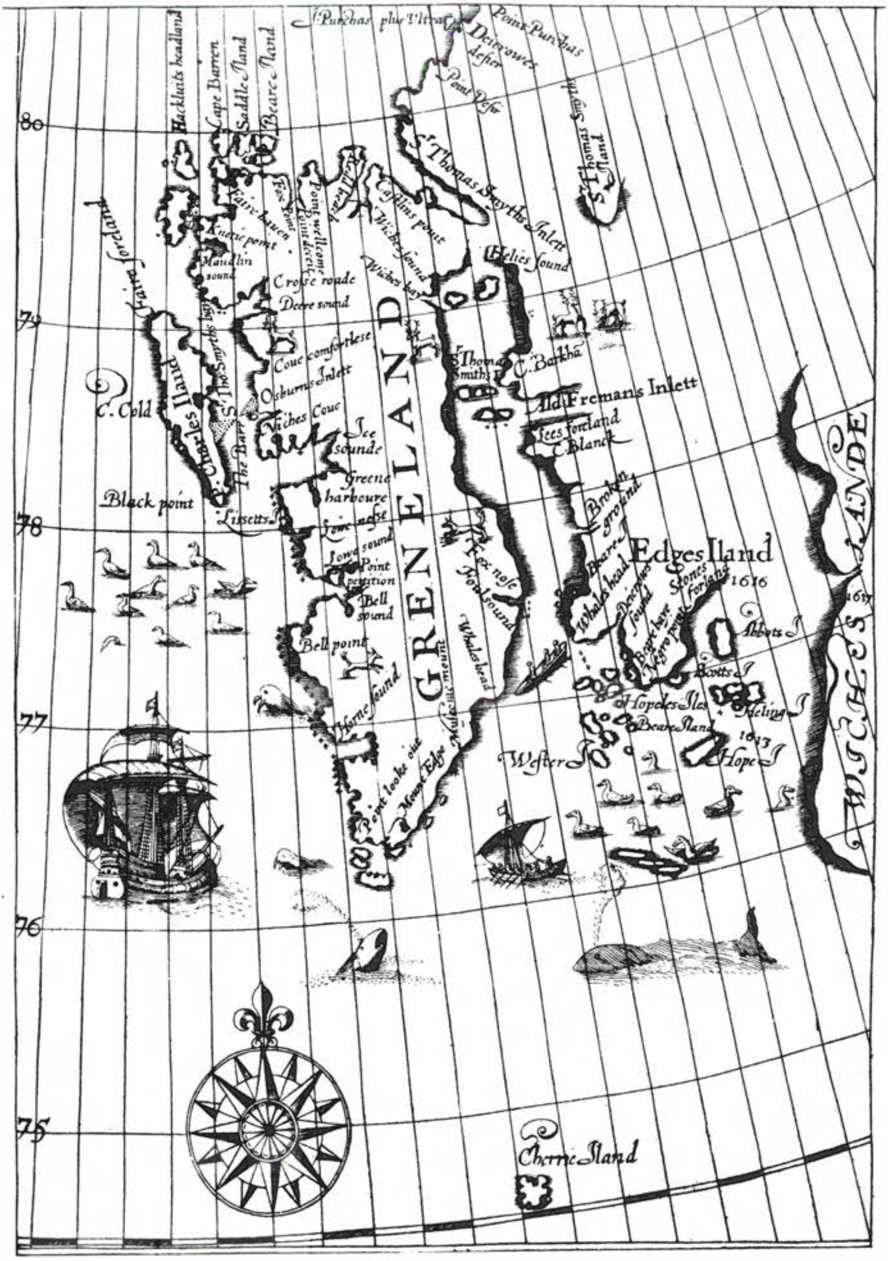
Discovery

The name Svalbard means, or rather is assumed to mean, the cold coast or edge, and is first mentioned in Icelandic annals from 1194 in connection with a brief information, such as *Svalbarði fundinn*. The 13th century Landnámabók gives a little more detail: *frá Langanesi á norðanverðu Islandi er iiii. dægra haf til Svalbarða norðr i Hafsbotn* (from Langanes on the north coast of Iceland, are four days ocean to Svalbard at the northern edge of the ocean). However, it is uncertain whether the geographical locality referred to here was part of what we think of as Svalbard today. Not least, the short duration of the journey gives cause for doubt.

Other more or less plausible evidence of pioneering journeys has been discussed. Discoveries at Isfjorden of fragments of apparently worked flint, and even pieces of rune inscriptions, have been claimed to indicate the presence of people from very early days. However, most experts in this field look upon the evidence as extremely weakly founded. A Russian hypothesis seems to offer a better basis for discussion. It claims that people from the White Sea region (the *pomors*) had huts and hunted on the west coast of Spitsbergen during the 16th century, perhaps even the 15th century. However, so many aspects of the evidence are dubious that most specialists are sceptical, but it is always possible that further research will provide more, and better, clues.

In all events, there is nothing to suggest that Willem Barentsz, or other members of the Dutch expedition that was seeking a northeast passage to China and India, knew anything about the islands when they arrived there in 1596. If we stick to what we really know today, it is therefore those men who have to be given the credit for discovering Svalbard, even though they really only found Bjørnøya and fragments of the west coast of Spitsbergen,

Fig. 85. This early map of Svalbard, published in London in 1625, shows how much of the archipelago was known by that time. Spitsbergen is called Greeneland, even though people were probably already aware that it was a separate island. However, as Conway (1906) writes: It suited the English claims to hold that it was part of Greenland, and they accordingly generally called it by that name down to the end of the eighteenth century. *Bjørnøya is called Cherrie Iland, a name given by an English expedition in 1604. The present name dates from the Dutch discoverers, who called it Beyren Eylandt. The large area of land outlined further east, Wiches Lande, is thought to result from exaggerated impressions of distant glimpses of Kong Karls Land. It must be remembered that 'mirages' and other forms of optical delusions are common in arctic regions, and can have contributed to this false impression of the size of the land seen. Otherwise, it should be noted that several of the names on the map have survived and are still used in a Norwegianised form.*


80
79
78
77
76
75
Hackluits headland
Cape Barren
Saddle Iland
Beare Iland
Point Purchas
Point Desire
St Thomas Smyths Inlett
St Thomas Smyths Iland
Faire foreland
Faire hauen
Maudlin sound
Crosse roade
Deere sound
Wiches bay
Helies sound
Coue comfortlese
Osburns Inlett
C. Cold
Charles Iland
Wiches Coue
Ice sounde
Greene harboure
Black point
Lissetts
Lowe nesse
Lowe sound
Point petition
Bell sound
Bell point
Horne sound
Point looke out
Mount Edge
Muscouie mount
GRENELAND
C. Barkha
Fremans Inlett
Lees foreland
C. Blanck
Broken ground
Edges Iland
1616
Whales head
Fox nose
Fowl sound
Abbots
Scotts
Hopeles Iles
Beare Iland
Heling
1613
Hope
Wester
WICHES LANDE
1617
Cherrie Iland

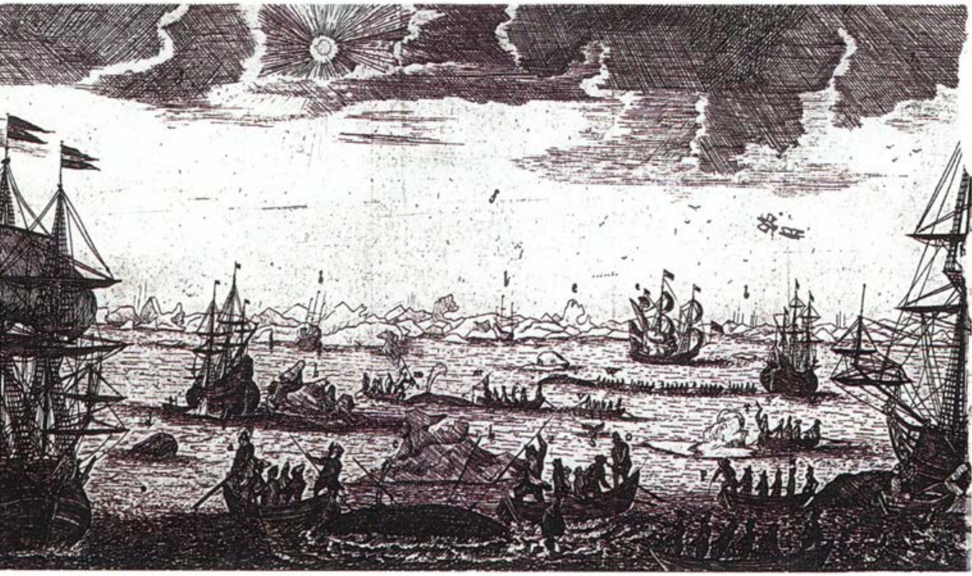
which they assumed had to be part of Greenland. The often employed expression that the Dutch rediscovered Svalbard seems to be based more on nationalistic wishful thinking than actual knowledge.

Hunting and trapping

After the islands were discovered, not many years passed before people with hunting interests directed their attention towards them. The very first expeditions enthusiastically reported huge numbers of seals and whales in the region. The English trading company, the *Muscovy Company*, sent several hunting expeditions, initially to take walruses at Bjørnøya, which they incidentally called Cherry Island after one of the merchants in the company.

In 1610, the hunters turned their main attention to Spitsbergen, still chiefly to take walruses. Whale hunting only became a serious proposition in 1612, and the expertise of Basque whalers was brought to bear. Ships from other nations than Britain also began hunting, not least the Netherlands. At first, commercial interest was mainly directed at the tusks, hide and blubber of the walrus and, to an ever-increasing extent, whale blubber. Oil won by cooking blubber became an important item of trade. The same

Fig. 86. Whaling at Spitsbergen in the latter half of the 17th century. A somewhat trimmed illustration reproduced from F. Martens: Spitzbergische oder Groenlandische Reise Beschreibung gethan im Jahr 1671 *(Hamburg 1675).*



applied to a lesser extent for whalebones, or baleens, for which the Greenland right whale had to suffer most.

Whaling stations were also built on land, the best-known one being the Dutch settlement of Smeerenburg (blubber town). The imaginative tales of the large numbers of people living there and the extent of the activity have, however, been greatly exaggerated, as recent research has demonstrated. From extreme statements of several thousand inhabitants, the figure has now been reduced to a summer complement of some 200 men at the peak of the activity in the 1630s. As time went by, whaling moved further out to sea, and the whales were then dealt with on board the ships.

As more nations became involved, it is natural that the question of sovereignty was taken up. Christian IV, the king of Denmark and Norway, vehemently argued that Svalbard had to be looked upon as part of the ancient Norwegian tributary country of Greenland. This claim was not entirely unfounded. Indeed, for many years after Barentsz' time, it was believed that Svalbard was geographically connected with Greenland. In 1615, the king even sent three naval vessels to the north with the optimistic hope of collecting taxes from the whalers, but without success.

Conflicts arose and fighting even broke out between the expeditions of the various nations and companies. However, after a time agreement was reached to partition the whaling grounds. The Netherlands were, for most of the time, the strongest nation and therefore called the tune. Whaling continued through the 18th century, but the effort and yield fluctuated greatly. It also became more and more obvious that the stock of Greenland whales, by far the most important quarry, was starting to be seriously decimated, chiefly because too many were being taken, and this clearly had an effect on the profitability. By the beginning of the 19th century, so few whales were left in the waters off Svalbard that whaling in the area died a natural death.

Russians entered upon the scene for serious at the beginning of the 18th century. They were pomors from the White Sea region, who had perhaps hunted in Svalbard in earlier times, too. They built stations in which they could spend the winter, and hunted reindeer, foxes, polar bears and seals, not least the walrus. Beluga whales were also taken along the west coast of Spitsbergen. Towards the end of the century, when the activity was at its peak, between 100 and 150 men are said to have been manning the stations. However, Russian whaling and trapping ceased fairly abruptly around the middle of the 19th century, in response to several tragic events and poor profitability.

Norwegians gradually took over from the pomors. From a modest start in the 1790s, many Norwegian summer and winter expeditions were equipped as the succeeding century progressed. Those who wintered there built small, often rather primitive shacks, scattered over most of the archipelago. As long as the stock lasted, the walrus was still the prime quarry, but polar

Fig. 87. A trapper's hut at Krosspynten (Wijdefjorden) photographed by Adolf Hoel's expedition in August 1912. Two trappers had spent the previous winter there. One had died of scurvy and was found by the expedition members, the other had just managed to struggle to Longyearbyen. The main hut is built of logs derived from driftwood, and resembles the huts which Russian trappers had constructed earlier.

bears and foxes became increasingly important. However, the basis for this trapping began to falter.

The walrus population had become so decimated already in the mid-19th century that it gave a poor yield. Other wildlife was clearly also being excessively hunted, the slaughtering of reindeer reaching particularly catastrophic proportions. The most economically important animals are now protected, and the few trappers wintering in Svalbard today are driven more by an interest for polar tracts and outdoor life in general than the hope of an economic yield.

Coal mining

The commercial interest for Svalbard during the 20th century has chiefly centred around coal. The presence of substantial coal deposits had been known for a long time, but it was first around 1900 that they began to attract serious attention. In addition to the needs linked with domestic heating, Europe was a huge market for coal for industry, the growing fleet of steamers and the ever-expanding railway network. By degrees, several mining companies were established, both Norwegian and foreign ones, with the aim of exploiting the coal resources in Svalbard.

The largest Norwegian undertaking of this nature was based on an American initiative. Two American businessmen from Boston, Frederic Ayer and John M. Longyear, purchased the rights to coal deposits in Adventdalen from a Trondheim-based company. In 1906, they founded the *Arctic Coal Company* and began mining operations at Longyearbyen. Their plant was taken over in 1916 by Norwegian businessmen who renamed the company the *Store Norske Spitsbergen Kulkompani A/S* (SNSK). Mining continued, and the amount of coal extracted gradually increased. The same company, though entirely state-owned since 1976, is still working the deposit.

The mining operations led by the Americans had not taken place without problems, not least in relation to the Norwegian workers and authorities. Conflicts also soon arose with other companies over the rights to finds and occupied fields. The need for some regulatory authority was urgent, and the old question of sovereignty once more came to the forefront. Several conferences prior to the First World War failed to solve the problem, but after peace was concluded, the matter finally reached its solution. *The Svalbard Treaty*, signed on 9 February 1920, acknowledged Norway the sovereignty of the entire archipelago, in other words all the islands between 74°N and 81°N, and 10°E and 35°E, but it was not formally enacted until 14 August 1925.

A total of 41 nations have now acceded to the treaty. It embodies a number of limitations with regard to Norwegian supremacy. For instance, all citizens of signatory nations are guaranteed equal treatment with respect to commercial activity. Apart from Norway, only Russia is still mining coal. Svalbard is, moreover, to be looked upon as a demilitarised area.

This latter provision was naturally ignored during the Second World War, which also hit Svalbard hard. The mining plant was decommissioned in the summer of 1941, and the population was evacuated. The islands achieved military significance, chiefly in connection with the vital convoy traffic to the ports of northwest Russia, both as a potential base for planes and warships and as a link in a chain of meteorological stations necessary for preparing weather forecasts. From the summer of 1942 until the end of the war, the allies maintained small groups in Svalbard. They were chiefly comprised of Norwegians and had their main bases in Barentsburg and Longyearbyen. Substantial losses were suffered during German attacks from the air (May 1942) and the sea (September 1943).

By the time the war ended, most of the mining plants had been destroyed, but it soon began to be rebuilt. SNSK modernised and extended its plants in Longyearbyen and in Sveagruva, the mine at the head of Van Mijenfjorden, and began producing coal again. Mining in Sveagruva soon ceased, but its development was taken up again in 1970, and trial working began with a view to having a mine ready for full production as the coal reserves in Longyearbyen diminished. The shipping of coal from Sveagruva

Fig. 88. Evacuating Longyearbyen on 3 September 1941. A British naval vessel moored at the quay helped to transfer the inhabitants to the Canadian troop transport ship Empress of Canada *anchored further out in Isfjorden, near the entrance to Grønfjorden. (G.Aa.)*

is, however, seriously hampered by the difficult ice conditions in the fjord. Plans for a road to Longyearbyen have existed for a long time, but this is a very controversial project because of fears for the negative consequences a road will have on the environment.

Considerable interest surrounds large coal deposits just north of Sveagruva, called *Sentralfeltet* (the Central Field). A number of drill cores have recently been acquired there with a view to determining the basis for future working. For a long time, SNSK extracted around 400,000 tons of coal a year, but from the end of the 1980s production dropped to about 300,000 tons, and was only just over 200,000 tons in 1996.

The *Kings Bay Kull Comp.* was founded in 1916 and immediately began developing and eventually working deposits at Ny-Ålesund. Several accidents and poor profitability led to operations ceasing in 1929. The company became state-owned in 1933, and after the war the plant was renovated and coal production began again. However, several major explosions, some of them incurring heavy loss of life, brought a temporary halt in production in 1953. A lengthy period of development and trial working followed, and the plant was again in full production in 1961. However, as early as November the following year, another major explosion took place in the mine, resulting in the loss of 21 lives. This led to a parliamentary decision in summer 1963 to cease mining operations, on account of the excessively dangerous conditions. In the years that followed, Ny-Ålesund became the centre for a new form of activity, which will be described later.

The Russian mines in Barentsburg, Grumantbyen and Pyramiden were also rebuilt and put into production again after the war, in this case by the Russian state-owned mining company *Trust Arktikugol*. The mine at Grumantbyen ceased to be worked in 1962. In recent years, the two remaining Russian mines have together produced about 500,000 tons of coal annually.

There was considerable interest during the 1960s for possible oil deposits in Svalbard, and several companies secured prospecting rights. The activity probably peaked in 1965–66 when a bore hole was drilled down to a depth of 3.5 km at Van Mijenfjorden. However, neither that nor other bore holes have so far revealed exploitable discoveries, and there is now little activity in this field.

From exploration to research

The exploration of Svalbard naturally increased gradually, in pace with the mounting activity in the area. Hunters returned with information about the

Fig. 89. In the mid-1960s, American Overseas Petroleum Ltd. drilled for oil at Blåhuken on the north coast of Van Mijenfjorden. A depth of 3.3 km was reached, but no oil was encountered, just traces of gas of no commercial interest. Several other attempts have been made to find oil in Svalbard, all in vain. (H.G.)

shape and location of the islands, and the environment in general. Even though only a small proportion of this information was written down, and then often only as brief notes in vessel log books, the hunters certainly helped to improve our knowledge of the geography of the area.

We came a step closer to what can be classed as research when people with more scientific training began to join the hunting expeditions. One of the pioneers here was a German named Friderich Martens, who in 1671 was the physician ('Shiffs-Barbierer') on board a whaler from Hamburg. He made a number of detailed observations of the natural environment, which were published in a book a few years after he arrived home. As time went by, systematic observations were undertaken by expedition participants from several nations, both Swedish, Russian and English. Some had a sound background in natural sciences, but they were on expeditions which had completely different aims in mind, whether these were to reach as far north as possible, find new hunting grounds, or discover other commercially viable resources.

The investigations undertaken by the geologist Baltazar M. Keilhau during a voyage to Svalbard in 1827 must be characterised as the first purely scientific effort on the part of Norway. As the 19th century advanced, an increasing number of expeditions journeyed north with more or less solely scientific intent. One of the best known is the Recherche Expedition from France in 1938–39, which had several participants from the Nordic countries. The fine lithographies from Svalbard which illustrate the report from this expedition, are among the outstanding aspects for which it is remembered.

Swedish scientists put considerable effort into Svalbard research during the latter half of the 19th century, particularly in the fields of natural science and cartography. They travelled with expeditions led by Otto M. Torell and Adolf E. Nordenskiöld, backed by rich sponsors in Sweden. Their extensive research is reflected in the many Swedish names on present-day maps of Svalbard. The ambitious, joint Swedish-Russian meridional expedition at the turn of the century must also be mentioned. It undertook detailed measurements of the length of the meridian from a point far south in Svalbard to another in the far north. The principal aim was to acquire better knowledge about how far the Earth deviated from a spherical shape, but the project also brought a great deal of new geographical knowledge, particularly about inland parts of Spitsbergen.

Norway first came seriously onto the scene at the start of the present century. At first, the activity mainly concerned the northern lights, cartography and geology. The first permanent station for weather observations was connected to the first radio station in Svalbard, established in 1911 at Grønfjorden, close to the present Russian mining town of Barentsburg.

A pioneer in this early period was Gunnar Isachsen, an army officer and surveyor, who led four expeditions to Svalbard between 1906 and 1910.

Fig.90. Finneset in Grønfjorden photographed in 1924. Norway built a large radio station here in 1911, which also operated as a weather station until 1930, when both were abandoned. Isfjord Radio took over these functions in 1934. All the buildings on the photograph have been demolished long ago. The locality was earlier much used by trappers, who spent the winter here, and as a harbour. Norwegians had a large whaling station here from 1905 to 1912. (P.B.)

However, it was the geologist Adolf Hoel who was to have the greatest impact during the early part of this century. Up to the time of the Second World War, he organised a series of summer expeditions, from 1928 as head of the new Government institution *Norges Svalbard- og Ishavs-undersøkelser*. The activities of these expeditions spanned over both mapping and a wide range of natural science topics. A marked increase in the activities came in 1948 when the institution was expanded to include both Arctic and Antarctic reseach, and renamed *Norsk Polarinstitutt* (the Norwegian Polar Institute), headed by the geophysicist Harald U. Sverdrup.

From Svalbard to the North Pole

As mentioned previously, the early expeditions viewed it as imperative to get as far north as possible. The dream was naturally not just to set a new record in this respect, but to reach the North Pole itself. The most favourable route seemed to be via the west coast of Spitsbergen. It was there the expedition vessels normally had open water much further north than anywhere else. Several unsuccessful attempts, however, clearly showed that forcing a way through the pack ice in the Polar Basin itself was beyond the capabilities of the vessels that existed at that time. The long-lasting notion that the Polar Basin held large areas of open water, which could permit vessels to sail right to the North Pole, had to be definitively laid to rest.

Several attempts were made to continue the journey from the edge of the drift ice, using various kinds of dual-purpose boat sledges. However, battling against pressure ridges of drift ice, poor sledging conditions and opposing ocean currents carrying the ice southwards, proved too much in the area north of Svalbard. The British explorer William Parry made what was perhaps the most successful of these desperate attempts as early as 1827 in the area north of Nordaustlandet. Yet he reached no further than 82°40' N.

The arrival on the scene of aircraft obviously brought new opportunities for reaching the Pole, sweeping high above ridges of drift ice and the opposing ocean currents. Svalbard played a key role here, too, because for many years the planes required a base for supplies as far north as possible.

A foolhardy attempt to reach the Pole was made in 1897 by the Swede, Salomon A. Andrée. With two companions, he intended to drift with a hydrogen-filled balloon across the North Pole from Virgohamna, near the northwest tip of Spitsbergen. From what we now know of the atmospheric conditions in the area and defects in the equipment he used, the chances of completing the journey were microscopic. It ended disastrously, too. Thwarted with problems, after an almost three-day long flight they crash-landed on the drift ice at about 83°N on 14 July. After unimaginable toil, they eventually succeeded in reaching land on Kvitøya at the beginning of October, only to die shortly afterwards. Their camp was found by chance 33 years later, with legible notebooks and film that was able to be developed.

Walter Wellman, an American, also used Virgohamna as his base for two resolute attempts to reach the Pole with the airship *America* in 1907 and 1909. Partly because of unfavourable winds, he was forced to give up both times after only short flights. Wellman was the first to use a motor-powered aircraft in the Arctic.

After the First World War, planes had become sufficiently advanced that the chances of reaching the Pole by plane began to be quite good. In May 1925, Roald Amundsen led a group intending to leave Ny-Ålesund to try to attain the Promised Point using two well-equipped flying boats. But the engine of one of the planes failed and both had to land on the drift ice at around 88°N. With a combination of skill and luck, they succeeded in getting one of the planes into the air again with everyone aboard. They reached the north coast of Nordaustlandet, where they happened to meet a sealer, which took them on the final lap of the journey back to Ny-Ålesund. On their arrival four weeks after their departure, they were regarded as having retreated from the realms of the dead.

Fig. 91. Roald Amundsen is congratulating Richard Byrd at Ny-Ålesund on 10 May 1926, following his return from the dubious flight over the North Pole. Byrd's pilot, Floyd Bennett, is standing on his left, alongside Amundsen's faithful sponsor and assistant Lincoln Ellsworth.

The first who, according to his own claim, succeeded in reaching the North Pole by air was the American Richard Byrd in 1926, piloted by Floyd Bennett. Both the start and the landing took place in Ny-Ålesund. However, subsequent calculations of the craft's cruising speed and the duration of the flight showed that it was virtually impossible for them to have been above the Pole. Ny-Ålesund was also used by Roald Amundsen, the Italian Umberto Nobile and the American Lincoln Ellsworth as the base for a flight over the North Pole to Alaska with the airship *Norge*. They took off a couple of days after Byrd, and accomplished the flight without significant difficulties.

Two years later, Nobile left Ny-Ålesund on another polar flight, this time with the airship *Italia*. The expedition reached the North Pole, but on its return flight it encountered serious icing problems, failed to maintain sufficient lift and fell onto the drift ice. Half the 16-man crew perished. Nobile no doubt suffered more criticism than he deserved in the huge media coverage that followed, not least because Amundsen died during a flight northwards to join the search for the missing expedition members.

The first tourists

Tourism began to make its mark on the summer activities in Svalbard as early as the second half of the 19th century. Englishmen with an interest for outdoor life and hunting, and at the same time financially well situated, were in the majority. Some sailed their own yacht there, others travelled as paying passengers on Norwegian sealers, some of which completely ignored their sealing aspirations because the income from the tourists was much more reliable.

It was not least all the press reports and hullabaloo surrounding the dramatic attempts to reach the North Pole from Svalbard that made the area well known and sought after as a tourist attraction. Larger, more comfortable passenger vessels were set in and the first foreign tourist steamers were already visiting the coasts of Svalbard before the turn of the century. In 1896, *Vesteraalens Dampskibsselskab* (Vesterålen Steamship Company) from north Norway began to send its ship *Lofoten,* which normally plied the Norwegian coast, on cruises to Svalbard. The company also built a large tourist lodge in Adventfjorden, just northwest of Longyearbyen. This offer of accommodation was not particularly successful, however, and was abandoned after two seasons. It nevertheless gave rise to the name Hotelnesset for the headland which is now occupied by Svalbard Airport. The activities briefly described here can be said to have sown the seed for the extensive tourist traffic we are now experiencing in Svalbard.

Present-day activities

Longyearbyen, the 'capital' of Svalbard, has most of the facilities that belong naturally in a small town: schools, a church, a hospital, a post office, a bank, hotels, restaurants and cafes, a range of shops, a cinema, a museum and so on. In addition to the existing overnight accommodation, a large, modern hotel has been erected partly based on building elements moved from Lillehammer after the winter olympic games were over. It significantly improved the capacity in Longyearbyen for both tourists and conferences. The Norwegian Polar Institute has a small office in Longyearbyen, manned by scientists and technical personnel.

Longyearbyen, as a whole, has evolved enormously during the last couple of decades, from being a male-dominated mining community administered largely by the company SNSK, to become a more normal urban community whose functions have mostly been taken over by the Norwegian Government. This is reflected, among other ways, by the large number of family houses and the greater variety of social and cultural benefits. However, there are certain abnormal features. One is the almost total absence of an older generation, senior citizens, among the permanent population.

The large radio station, Isfjord Radio, at the mouth of the fjord, can now be remote-controlled from a telecommunications centre in Longyearbyen (Svalbard Radio) and has been linked with the mainland via satellite since 1978. This radically improved telephone links with the outside world, and enabled the yearned-for television programmes to be received directly since 1984.

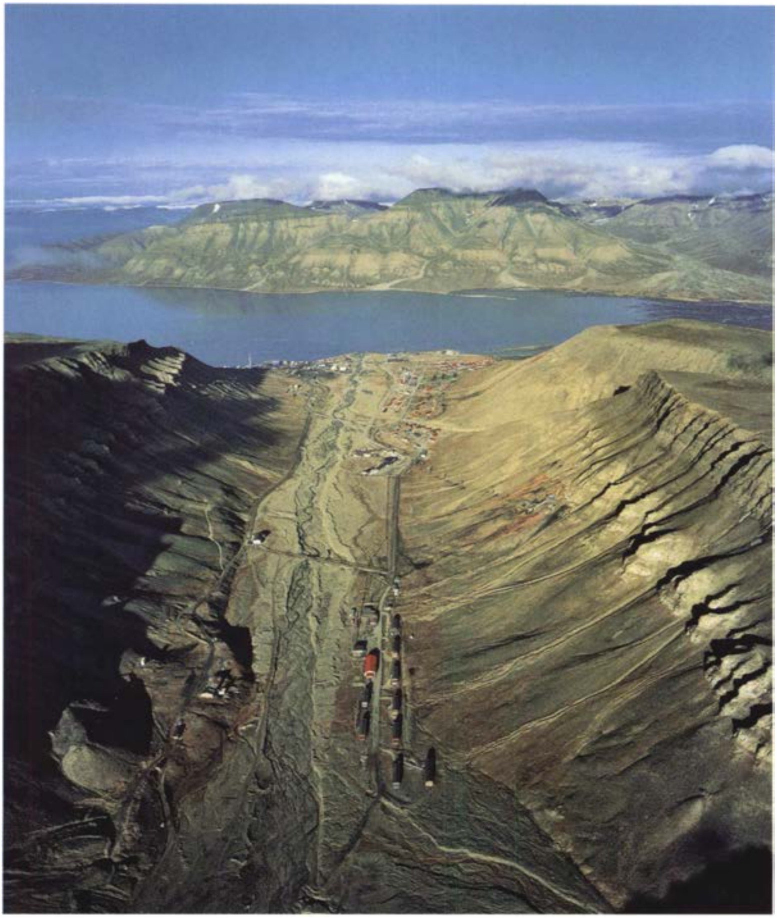


Fig. 92. An aerial photograph of Longyearbyen, looking northeast. This settlement, looked upon as the 'capital' of Svalbard, was originally solely a mining community. It is situated in the valley at the head of Adventfjorden, a short arm of Isfjorden. As the picture shows, the buildings are mostly placed in isolated groups, which is a bonus in the event of fire, but creates certain internal communication problems. The offices of the Governor, and the church, are on the west side of the valley (to the left in the picture, close to the sea), while the new commercial centre, housing shops, offices, cafes, restaurants and hotels, along with the hospital, school and university building, are on the opposite side of the valley, where most of the new dwellings have also been built. The buildings in the foreground, referred to as Nybyen (the new town), were mostly erected shortly after the war and now belong to the older part of the town.

Fig. 93. View of some of Longyearbyen's new buildings. Recently built homes in Lia in the foreground, with the town centre behind. On the opposite side of the valley, the museum and church stand on the left, and closer to the sea, on the right, is the Governor's office and the power station with its tall chimney. (V.H.)

Two important facilities linked with arctic research have recently been completed. In 1995, an impressive building was opened in Longyearbyen to house an educational center for arctic studies called *UNIS* (University Studies in Svalbard). This is run jointly by the Norwegian universities. In addition, *EISCAT* (European Incoherent Scatter Scientific Association) constructed a large radar antenna on the mountain above Mine 7 in Adventdalen, to facilitate upper atmosphere research. It was officially opened in 1996. A state-of-the-art facility to download satellite data (*Sval Sat*) is currently being completed on Platåberget, a mountain top just west of Longyearbyen. It will be operated by *Tromsø Satellite Station* on the mainland, which is also planning to erect a system of antennas on the same site during the next few years.

Ny-Ålesund is, nevertheless, the 'research metropolis' of Svalbard. Following the disastrous explosion in 1962, and the consequent abandonment of mining there, activities connected with various research projects have provided the main basis for the community. The 'Kings Bay' mining company actually still formally owns the site, and therefore lets the buildings and is responsible for the everyday running of the facilities. This little community is able to boast a landing strip and an impressive new quay, where small cruise vessels can moor, if necessary.

Fig. 94. Longyearbyen's main street, lined by shops, the post office, bank, restaurants, cafes and offices. Hiorthfjellet, across Adventfjorden, is seen in the background. (V.H.)

In 1967, *ESRO* (European Space Research Organisation) opened a large station in Ny-Ålesund to download satellite data. However, a few years later it was no more of current interest and ceased to function in 1974. The Norwegian Polar Institute had already been gradually building up a research station, which gained official approval in 1968. This has now developed into an extensive, versatile station involving several cooperating institutions. The research taking place there concerns such fields as the continuous recording of incoming and outgoing radiation energy, upper atmospheric phenomena, magnetism and seismology. During the summer, many more people are involved in a wider range of activities, where fields such as glaciology, botany and zoology achieve a more prominent position.

A mountain station served by a cable car was opened in 1989, at a height of about 470 m on Zeppelinfjellet, close to Ny-Ålesund. It is run by the Norwegian Polar Institute, but *NILU* (Norwegian Institute for Air Research) is responsible for most of the measurements being carried out there, which involves recording data on atmospheric chemistry. *Statens kartverk* (Norwegian Mapping Authority) began operating an observatory in the old ESRO building in 1994 to provide precise measurements of horizontal and vertical movements in the Earth's crust, using signals from satellites and a variety of reference stars. Close by, *Norsk Romsenter* (Norwegian Space

Fig. 95. Ny-Ålesund, looking north from the mountain station at a height of 470 m. The place shows obvious signs of having been a mining settlement, even though coal mining ceased in 1962, after a disaster down the mine. A telemetry station run by the European Space Research Organisation (ESRO) was recording satellite data here from 1967 to 1971, and in 1968 a permanent research station was put in operation under the auspices of the Norwegian Polar Institute. Over the years, the research activity has expanded greatly, and several nations are now involved, some operating year-round scientific programmes. The Kings Bay Kull Comp. still owns the settlement and is responsible for its everyday running. A glimpse of the new quay can be seen approximately in the centre of the picture. Ny-Ålesund was the point of departure for several expeditions aiming to reach the North Pole, including the flights of the airships Norge *(1926) and* Italia *(1928). The mast to which they were anchored remains intact as a historical monument. (V.H.)*

Centre) is constructing a launching pad for rockets equipped with instruments to study the upper atmosphere and adjacent parts of outer space. It should be mentioned in this connection that the structure of the geomagnetic field over Svalbard makes this area especially favourable for studying the so-called 'dayside northern lights'.

Ny-Ålesund has, indeed, been found to be so favourable for research related with high latitudes that several foreign institutions have been involved in projects there for many years. Only the *Alfred-Wegener-Institut* in Germany, which opened its *Koldewey-Station* here in 1988, has operated a year-round manned facility. It is mainly concerned with meteorological and related geophysical observations. Other nations are currently largely active here in summer, winter observations, if any, being automated. British, French, Japanese and, recently, Italian teams have been at the forefront. This

Fig. 96. The central part of Ny-Ålesund viewed towards Zeppelinfjellet. The mountain station is situated just left of the summit, but is barely visible. The light green building on the extreme left at the back, houses the canteen, lounge and library. The darker green building a little to the right is the research station of the Norwegian Polar Institute. (V.H.)

Fig. 97. The new quai in Ny-Ålesund was built as a fortress of heavily reinforced concrete, to make it resistant against attacks from drifting icebergs in the fjord. (V.H.)

Fig. 98. The Russian mining town of Barentsburg stands on the hillside on the east coast of Grønfjorden, and is the centre for Russian activities in Svalbard. The Russians bought the plant and the mining rights from the Dutch in 1932. (V.H.)

Fig. 99. One of the main streets in Barentsburg at the beginning of April. (B.Ly.)

Fig. 100. Pyramiden, the other Russian mining settlement in Svalbard, is in Billefjorden, one of the innermost arms of Isfjorden. This coalfield was originally Swedish, but was bought by the Russians in 1926. The settlement is named after the mountain in the background. (V.H.)

Fig. 101. Lenin gazes out over the centre of Pyramiden from his high plinth, against a background of fjords, glaciers and mountains. (V.H.)

Fig. 102. Modern mining machinery excavating coal in Sveagruva. The seams here are significantly thicker and working conditions therefore much simpler than in the mines at Longyearbyen. There the seams to a large extent are less than 1 m thick and work often has to take place lying down or kneeling. (S.H.)

Fig. 103. A topographer from the Norwegian Polar Institute making measurements at Newtontoppen, which at 1713 m is the highest peak in Svalbard. (B.Ly.)

extensive, multinational research has required better co-ordination for a long time, and a committee (*NySMAC*) has now been appointed to attend to this.

The Russians have also carried out a good deal of research at Barentsburg, where they have a geophysical institute. The community also provides a base for field work. Poland, too, has for a great many years been operating a research station at Hornsund, far south on the west coast of Spitsbergen, where about ten persons spend the winter.

Population and administrative system

At present, about 1300 Norwegians live in Svalbard during the winter, more than 90% of them in Longyearbyen, and the rest in Ny-Ålesund, Isfjord Radio, Sveagruva and the weather stations on the islands of Hopen and Bjørnøya. However, those who work at Isfjord Radio and Sveagruva often have their permanent homes in Longyearbyen. Only a few trappers live on the islands nowadays and, as mentioned earlier, they are driven more by an interest for outdoor life than the prospect of financial gain.

Summer visits by researchers and their assistants, and tourists, have increased greatly in recent years, not least because opportunities for travelling between Svalbard and the mainland have substantially improved. The most important step here was the opening of Svalbard Airport, near Longyearbyen, for regular traffic in 1975. Internal transport is, however, both difficult and costly. It takes place with small planes and helicopters, and also small vessels when the coastal waters are not impassable due to ice. These vessels are a major bonus in allowing tourists the chance to experience more of Svalbard than just the vicinity of Longyearbyen.

Large numbers of 'summer guests' mean that the Svalbard population fluctuates greatly between summer and winter. A typical example is Ny-Ålesund. Whereas its population in recent winters has been around 30, in summer it sometimes rises to more than 100. If a cruise ship ties up, the numbers briefly explode of course.

The recent developments have naturally resulted in a significant shift in the distribution of occupations among the population. Only about a quarter of the Longyearbyen population is now directly involved in coal mining. Most of the remainder are engaged in a variety of service occupations, government jobs, research or purposes of study, or they are spouses and children.

Activity in the Russian mining communities of Barentsburg and Pyramiden has been substantially reduced in recent years. Their schools and kindergartens closed in 1994, and practically all the children and mothers went home to Russia. Just over 800 people now live in Barentsburg during the winter, and some 600 in Pyramiden. Coal production continues, though at a lower level than earlier. Financial reasons lie behind current plans to cease mining at Pyramiden. To provide a modest compensation, the Russians, too, are beginning to pave the way for a certain amount of tourism in

Fig. 104. The camping grounds of Longyearbyen, viewed here from the southwest, are located near the airport, about seven kilometres from town. (V.H.)

their mining towns.

Svalbard is administered by a *Sysselmann* (Governor), appointed by the King, whose authority is on a level with the County Governors on the mainland. The Sysselmann also has the role of Notary Public, Chief of Police and even Judge for minor infringements. However, for more important legal matters, Svalbard is under the jurisdiction of the appropriate authorities in Tromsø. A central administration, which is under several Government ministries, is co-ordinated and advised by an Interministerial Polar Committee. The Minister of Justice chairs this committee, and the polar department in the Ministry of Justice acts as its secretariat. An Inspector of Mines ensures that the special mining ordinance for Svalbard is adhered to.

In 1971, a local Svalbard Council was set up, which is elected by the Norwegian population of the islands. It has the task of considering and commenting on Svalbard matters that are of importance for the population and the authorities. There is still no local government administration on the lines of that on the mainland.

The Russian Consul in Barentsburg is responsible for administering Russian activities in the archipelago. The Russians are required to abide by the laws and regulations laid down by Norway with respect to Svalbard, within the framework of the Svalbard Treaty. It is true to say that this has often been practised tactfully on the part of Norway, but on the whole co-operation has functioned well.

Fig. 105. Most tourists come to Svalbard on cruise ships, which are fully provisioned. The photograph showes that the landing facilities are also well though out. This form of mass tourism probably brings little income to the local community. The postal authority no doubt has the most reliable income, selling stamps postmarked from 'The world's northernmost community'. (V.H.)

Taxes and dues are mostly lower than on the Norwegian mainland. In principle, the income derived from them is to be used for the benefit of Svalbard, and there is a separate Svalbard budget. The Norwegian Government is, however, compelled to provide a considerable additional sum to balance the budget. The Norwegian sovereignty necessitates a certain measure of Norwegian settlement. The size and type of this settlement can obviously be discussed, and is, too. A major problem at present is whether to continue the coal mining. The question of whether to develop the Sveagruva and Central coalfields, and build roads to serve them, will then arise, which will doubtless create great opposition on the part of environmentalists.

Virtually all the modern maps of Svalbard have been prepared by the Norwegian Polar Institute. The main series is intended to comprise 62 topographical maps on a scale of 1:100,000 and one on a scale of 1:50,000 (Bjørnøya), which will cover all the islands. So far, 22 of these have been published in colour. The remainder are for the moment available as black-and-white copies. A few of the maps have a satellite- photo map printed on the back. A separate map covering the area between Isfjorden and Van Mijenfjorden (Nordenskiöld Land) has been published on a scale of 1:200,000, primarily for the benefit of those who roam in the most densely populated part of Svalbard.

Small-scale maps, Svalbard 1:2,000,000, Svalbard 1:1,000,000 and Svalbard 1:500,000, depict the broad features of the entire archipelago. The last-mentioned map is divided into four sheets called: 1. Spitsbergen, southern part; 2. Spitsbergen, northern part; 3. Nordaustlandet; and 4. Edgeøya. The first of these is also available as a satellite-photo map.

Many special maps have also been published, above all thematic maps, which are geological maps, coastal maps (carrying information on geomorphology and fauna), and vegetation maps. The Norwegian Polar Institute also has a large archive of aerial photographs of Svalbard.

Numerous articles and scientific papers dealing with various aspects of Svalbard have been published. Many of these are printed in various Norwegian Polar Institute series, and are listed in a bibliography entitled *Norsk Polarinstitutt Publikasjonsoversikt.*

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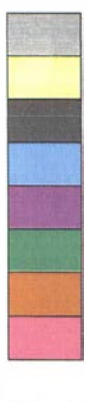
Geologisk kart over Svalbard
Geological map of Svalbard



Tertiær basalt
Tertiary basalt

Paleogen
Paleogene

Mesozoisk doleritt og basalt
Mesozoic dolerite and basalt

Mellomjura til tidligkritt
Middle Jurassic top Early Cretaceous

Trias til mellomjura
Triassic to Middle Jurassic

Senpaleozoikum
Late Paleozoic

Devon og senestesilur ("Old Red"-lagene)
Devonian and Latest Silurian (Old Red)

Grunnfjell eldre enn "Old Red"-lagene
Pre-Old Red basement

Viktig forkastning eller forkastningssone
Major fault or fault zone

APPENDIX I

APPENDIX II

Position of different types of protected areas in Svalbard. The numbers on the map refer to the following Bird Sanctuaries:

1. Sørkapp
2. Dunøyane
3. Isøyane
4. Olsholmen
5. Kapp Linné
6. Boheman
7. Gåsøyane
8. Plankeholmane
9. Forlandsøyane
10. Hermansenøya
11. Kongsfjorden
12. Blomstrandhamna
13. Guissezholmen
14. Skorpa
15. Moseøya.

The nunber 16 farthest to the north indicate Moffen Nature Reserve, one of the most important resting places for walrus in Svalbard (see list of literature).


NORDVEST-SPITSBERGEN
NASJONALPARK
NORDAUSTLANDET
NORDAUST-SVALBARD
NATURRESERVAT
Kvitøya
SPITS-
BERGEN
Prins
Karls
Forland
FORLANDET
NASJONALPARK
Kong Karls Land
Barentsøya
EDGEØYA
SØRAUST-SVALBARD
NATURRESERVAT
SØR-SPITSBERGEN
NASJONALPARK
Hopen
SVALBARD
0 50 100
KM
Nasjonalparker, naturreservat
National parks, Nature reserves
Plantefredingsområder
Plant protected areas
Fuglereservat
Bird sanctuaries
Naturreservat
Nature reserves
Bjørnøya
NORSK POLARINSTITUTT, OSLO 1987

POLHAVET
NORSKE-HAVET
BARENTS-HAVET
SVALBARD
MÅLESTOKK 1 : 2 000 000
10 0 20 40 60 80 100 KM
Høgder i meter
Heights in metres
Ekvidistanse 300 meter
Contour interval 300 metres
Busetnad
Settlement
Radiostasjon
Radio station
Fyr
Lighthouse
Gammal gruveby eller fangststasjon
Old mining settlement or hunting base
Flyplass
Airfield
Isfritt land
Ice-free ground
Bre
Glacier
NORSK POLARINSTITUTT
OSLO 1983
Prenta av Statens kartverk
3. 15 000. 97
NORSK-POLARINSTITUTT
NORDAUSTLANDET
AUSTFONNA
VESTFONNA
SPITS-BERGEN
KONG KARLS LAND
BARENTSØYA
EDGEØYA
Hopen
Bjørnøya
Kvitøya
Prins Karls Forland
ISFJORDEN
STORFJORDEN
HINLOPENSTRETET
ERIK ERIKSENSTRETET
OLGASTRETET
STORFJORDBANKEN
STORFJORDRENNA
SPITSBERGENBANKEN
HOPEN-BANKEN
Longyearbyen
Sjuøyane
Kapp Platen
Hornsund
Sørkapp
Sørkappøya
Kong Ludvigøyane
Tusenøyane
Wilhelmøya
Svenskøya
Kongsøya
Storøya