

# Outline of the geography and geology of Svalbard

by

Ólafur Ingólfsson, professor of Quaternary geology, University of Iceland and UNIS

## GEOGRAPHY

Svalbard is an archipelago in the Arctic Ocean, located about midway between Norway and the North Pole. Svalbard comprises all islands between latitude 74° North and latitude 81° North and between longitude 10° East and longitude 35° East. The principal islands are Spitsbergen, Nordaustlandet, Barentsøya, Edgeøya, Kong Karls Land, Prins Karls Forland, and Bjørnøya (Bear Island). The total area of Svalbard is 62,160 km<sup>2</sup>. With the exception of some coastal lowlands, the landscape is mountainous with many large and small glaciers. The Spitsbergen landscape is characterized by rugged mountains, with steep flanks, as well as large, glacially eroded fjord systems. The highest mountain peak is *Newton toppen* (1717 m asl.) in north-eastern Spitsbergen.



A characteristic feature of the coastal landscape is the strandflat. It is a low-land plain along the coast, partly covered by marine deposits and presumably formed due to the combined actions of frost weathering and abrasion by the sea during interglacial periods. It may be more than

10 km wide in places. Raised beaches and post-glacial marine terraces commonly occur along the coast.

**Climate** – The present climate of Svalbard is arctic, with mean annual air temperature of about  $-6^{\circ}\text{C}$  at sea level and as low as  $-15^{\circ}\text{C}$  in the high mountains. In Longyearbyen, the coldest month is February with  $-15.2^{\circ}\text{C}$ , the warmest month is July with  $6.2^{\circ}\text{C}$  and the mean annual air temperature is  $-5.8^{\circ}\text{C}$  (average 1975-2000). Precipitation measured at sea level is low, only about 200 mm w.e. in central Spitsbergen and somewhat higher, about 400-600 mm w.e., along both the western and eastern coasts of the island. Usually April-May is dry. The periods February-March and August-September tend to be comparatively humid. Very large inter-annual differences in mean precipitation and temperatures do occur. Also December-January may see heavy snowfalls in some years. Snow is the dominant type of precipitation. The border-zone between cold arctic air from the Polar Basins and mild maritime air from the oceans to the south occurs around Svalbard. Meteorologically, this border zone at times is very active with cyclones generating unstable, often stormy weather. There may be very windy periods during winter, and fogs are common during the summertime in the coastal areas. April-May are often calm and sunny.



*The Fridtjovbreen glacier in Van Mienfjorden.*

**Glaciers** – About 60% of Svalbard is glacier-covered, with many outlet glaciers terminating in the sea. In central Spitsbergen, most glaciers are comparatively small due to the dry climate, but large valley glaciers and ice caps are frequent along both the west and east coasts of Spitsbergen. Several large ice caps exist on the eastern islands, Edgeøya, Barentsøya and Nordaustlandet. Most glaciers in the dry interior of Spitsbergen are cold-based, and move only 1-2 m per year, but in the more humid regions along the coasts, glacier velocities frequently are more than 10-30 m per year, causing large crevasses to form.

The Equilibrium Line altitude (ELA), or what used to be called the climatic snow line, rises on a transect from west to east across Spitsbergen, reflecting very well the distribution of precipitation: on Prins Karls Forland and along the central west coast it lies at 200-300 m a.s.l., but reaches >800 m in the highlands of north-eastern Spitsbergen. North-eastern Spitsbergen is a very dry area, and can be described as a polar desert.

A significant number of glaciers in Svalbard are surging-type glaciers. This means that from time to time they advance with extraordinary high velocity, up to several km during a period of 3-6 years. This behaviour is characteristic for at least 30% of all glaciers in Svalbard. Possibly, up to 60% of all Svalbard glaciers surge from time to time, with a recurrent interval of 50-100 years. A 30 km wide sector of the large ice cap on Nordaustlandet, Austfonna, experienced a surge advance of more than 20 km between 1936 and 1938. The mass balance of many glaciers in Svalbard is partly controlled by snowdrift during the winter and many glaciers for that reason face downwind, that is, towards NNW and NW. Glaciers along the east coasts presumably receive huge amounts of snow drifting across from the sea ice during the winter, driven by south-easterly winds.

**Permafrost** – Svalbard falls within the zone of continuous permafrost and periglacial and permafrost-related terrain features are widespread in areas not covered by glaciers. At the coasts

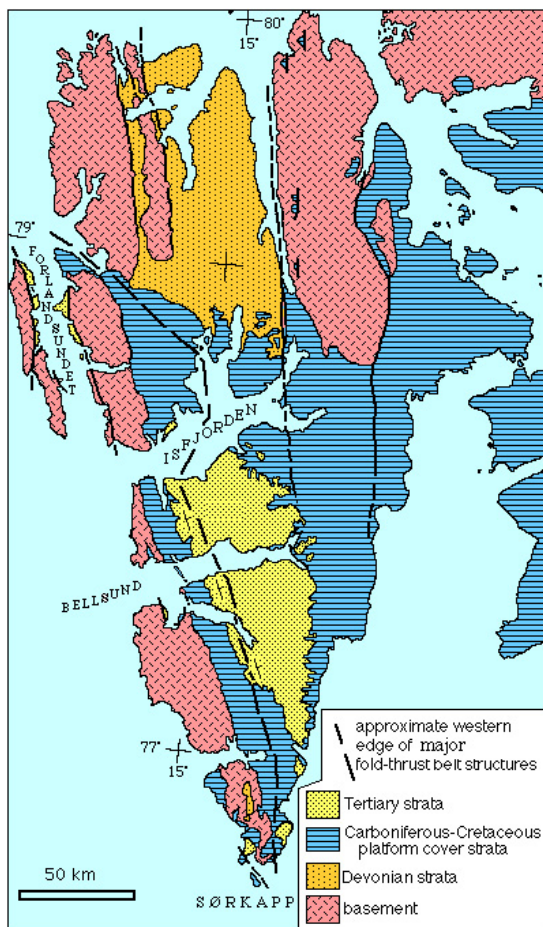
the thickness of permafrost is 10-40 m, but increases to more than 450 m in the highlands. Terrain phenomena such as pingos, ice wedges and rock glaciers are widespread, especially in the dry central regions of Spitsbergen. Snow avalanches are frequent, especially on downwind slopes. Periglacial features such as solifluction lobes occur primarily in the more humid western regions. Various forms of patterned ground, such as stone circles and stripes are widespread and well developed.



*Stone polygons on Kvadehukslette*

**Fluvial and eolian activity** – Fluvial activity is important, especially during the spring melt, but remains so for most of the summer as well. All Svalbard rivers are short-lived summer phenomena. Large braided river systems draining glaciers occur in most major valleys, transporting large amounts of sediments into the fjords. When these riverbeds dry up during the autumn, wind erosion of fresh fine-grained sediments lead to deposition of eolian sediments (loess) downwind from the rivers. This process comes to a stop when the winter snow cover is firmly established in October-November.

**Lakes** – with the exception of Bjørnøya, there are relatively few lakes on Svalbard. Most lakes occur on the strandflat. They are usually small and shallow, and many bottom-freeze in winter. The best known and studied lake on Svalbard is Linnévatnet, just south of the entrance to Isfjorden. It is more than 5 km long. Its sediments contain an archive on environmental changes on Svalbard during the last >10,000 years. There are also several ice-dammed lakes, containing varved sediments, but few have been studied so far.



*Simplified geological map of Spitsbergen*

## GEOLOGY

Svalbard has a very rich, diverse and long geologic history that makes it somewhat of a 'mecca' for geologists; a place where a great variety of geology can be studied and where much can be learned about the development of tectonic features and sedimentary environments

through time as well as the drift of continents across the Earth's surface. The oldest till deposits on Svalbard were probably deposited when Spitsbergen was situated close to the South Pole, some 600 million years (MY) ago, and the red Devonian sandstone of northern Spitsbergen was deposited when Svalbard was close to the Equator, some 350-400 MY ago. Since the vegetation cover is so sparse and the glacially eroded landscape so fresh, there are continuous bedrock sections that span more than 11 km and that are more than 1 km high! Even students of Quaternary geology should be familiar with the outlines of the bedrock geology of Svalbard – it makes it so much more fun to be in the field!

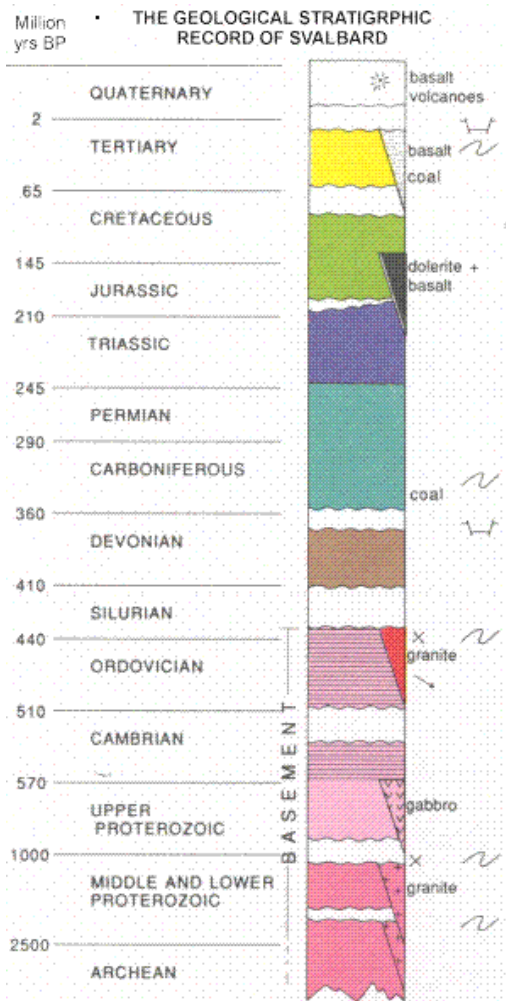
**The Basement** - The large-scale features of the Svalbard geology are relatively simple. The oldest formations, the so-called *Basement*, including *Precambrian*, *Cambrian* and *Ordovician* rocks, occur as a belt along the west-coast of Spitsbergen, in a large area between Wijdefjorden and Hinlopenstretet in the north, as well as in the northern part of Nordaustlandet and in the southern part of Bjørnøya. The Precambrian bedrock of Svalbard is more than 570 MY old, and there is evidence of repeated mountain-building and metamorphic episodes (orogenies) dating from ca. 1700, 1000 and 600 MY ago. The mountain chains have long time ago disappeared due to erosion, and what remains are rocks from their deeper, inner parts. The Precambrian rocks on north-western Spitsbergen are generally very strongly metamorphosed. This means that they have once been buried deep in the crust, and high pressure and temperatures have caused them to partially melt and re-crystallize. The oldest rocks dated on Svalbard are zircon minerals from NW-Spitsbergen, giving the age of 3200 MY! Precambrian tillites, bearing witness to glacial coverage about 600 MY ago occur both on the west- and north-coasts of Spitsbergen. Other Precambrian rocks include volcanic rocks found on both sides of Forlandsundet.

The Cambrian and Ordovician calcareous and limestone strata of Svalbard often contain fossils of marine creatures that once upon a time lived in the so-called Lapetus Ocean. These were

primitive invertebrates, such as trilobites and graptolites.



Example of an Ordovician trilobite. Scale bar: 1 cm



A stratigraphic column for Svalbard

**Silurian: mountain building** - During the Silurian, two continental plates collided, causing large-scale folding and faulting in what is now the North Atlantic region (the Caledonian Orogeny). All rocks on Svalbard that are older than late-Silurian (see the stratigraphic column) are therefore folded and metamorphosed. Granites intruded in the older rocks during late Silurian. The highest peak on Svalbard, *Newtontoppen* (1714 m), consists of late Silurian granite. Palaeomagnetic research has shown that at this time Svalbard was located at the Equator. The system of metamorphic and igneous rocks, which was the result of the Caledonian Orogeny, is traditionally called the *Heckla Hoek series*. The name Spitsbergen, meaning the Pointed Peaks, comes from the wild and rugged Heckla Hoek terrain on north-western Spitsbergen.

**Devonian: erosion and sedimentation** -During the Devonian Period, northern Svalbard began sinking and rivers eroded down the Caledonian mountains. A total of more than 8000 m thick sandstones, conglomerates and shales were deposited in near-shore environments, deltas and lakes. The Devonian beds often consist of characteristic red sandstone. The red color implies periods of dry, desert-like climate. At this time, 360-400 MY ago, Svalbard was located just north of the Equator. The Devonian is called “the Age of Fishes”, and fossils of primitive fish – the first known vertebrates – have been found on Svalbard. As have fossils of primitive plants.



A coal-swamp from the Carboniferous Period

**Carboniferous: tropical swamps** - During the early part of the Carboniferous, Svalbard was a relatively flat and undulating terrain, with lakes, lagoons and alluvial plains. The Svalbard plate

was drifting from the desert climate of Devonian time, entering wetter, more tropical climate. Carboniferous sandstones in the central parts of Spitsbergen – which were mined by the Russians in the settlement of Pyramiden until a few years ago - contain coal seams with plant fossils, showing a luxurious swamp vegetation. Life on Earth was developing rapidly: this was the Age of the Amphibians, and the swamps teemed with life. Amphibians were common, but fish, insects and scorpions were also numerous. The swamps of Carboniferous Svalbard have no modern analogue anywhere in the world: not only were seedless plants and ferns extremely important in this community, but there were no birds singing or insects with humming wings. The first birds did not emerge in the evolution of life until in Jurassic times, more than 100 million years later, and all insects of the Carboniferous swamps had fixed wings.

Later, during Middle and Upper Carboniferous, Svalbard was subject to alternating deposition on land and in shallow marine seas. Strong evaporation in a dry, temperate climate caused deposition of gypsum, anhydrate and dolomite. Typical rocks from this time in Svalbard's history are breccias, limestone and dolostone (containing fossil mollusks and snails), and beds of gypsum or anhydrite.

**Permian: sub-tropical shallow seas** - The Permian beds on Svalbard resemble the uppermost Carboniferous, with shallow-water marine deposits in areas that periodically became dry. Intense evaporation during dry periods resulted in renewed formation of gypsum, anhydrate and dolomite. The Permian beds contain numerous fossils of shells, as well as siliceous sponges and bryozoans. These beds can be seen e.g. along the north-coast of Isfjorden, in Linnédalen and at Axeløya in Bellsund.

**The Mesozoic: Age of the Reptiles** – During the *Triassic*, *Jurassic* and *Cretaceous* Periods, Svalbard drifted from about 45°N to about 65°N. The Mesozoic was a “greenhouse world”, considerably warmer globally than at present, and with higher sea levels. The Svalbard climate throughout this time was temperate and humid.

The Mesozoic deposits on Svalbard are mostly marine, but they alternate with terrestrial deposits, and volcanic intrusions towards the latter part of the Era. Among fossils from the Triassic Period found on Svalbard are bivalves and ammonites, but reptile remains also occur in the Lower Triassic strata.



*A fossil ammonite*

During the Jurassic and lowermost Cretaceous, most of the Svalbard area was covered by a shallow sea. The sedimentary rocks consist mostly of marine shales, often very rich in fossil ammonites, belemnites (squids) and bivalves. Remains of Plesiosaurus, a swan-necked marine reptile that swam the Jurassic seas have been found in the Isfjorden area and on Kong Karls Land.



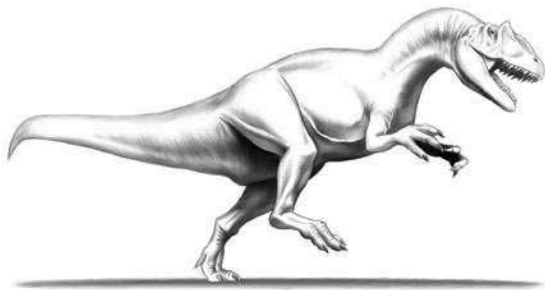
*Reconstruction of swimming Plesiosaurus*

The Plesiosaurus remains from Kong Karls Land, discovered in 1973, are spectacular. The ca. 200 MY old fossil contained the remnants of

its last meal in its stomach: a healthy diet of squids and plants.



*A giant plant-eating Iguanodon, measuring 10-12 m from tail to snout*



*A meat-eating Allosaurus out on the hunt!*

During the early Cretaceous Period, Svalbard had extensive alluvial plains of sand. There are abundant plant remains preserved in the sandstones. Fossilized footprints of the Cretaceous (ca 130 MY) plant-eating Iguanodon were discovered at Festningen, close to Kapp Linné in the outer Isfjorden area. Fossil footprints of the carnivorous Allosaurus were found at Kvalvågen, in south-eastern Spitsbergen. The dinosaur remains suggest that the Cretaceous climate was mild, with luxurious vegetation. 130 MY ago, Svalbard was located between 50° and 60° N. The upper part of the lower Cretaceous is characterized by alternating marine and terrestrial deposits, deposited in shallow seas and deltas. The fossil record contains bivalves, squids, snails and tree-trunks. During the later part of the Cretaceous, Svalbard was subject to a tectonic uplift causing erosion and a hiatus in the sedimentary record.

***The Tertiary: folding and sedimentation*** – At the transition between the Cretaceous and Tertiary periods, some 65-60 MY ago, Svalbard and Greenland collided, causing intense folding of the Svalbard west-coast strata, as well as the formation of a depression basin to the east where sedimentation occurred.



*Heavily folded Permian, Triassic and Carboniferous strata in Bellsund*



*Abandoned coal-mine close to Longyearbyen. The coal was mined from Lower Tertiary coal seams.*

The Central Tertiary Basin dominates the geology of the central-southern part of Spitsbergen, from the Isfjorden area to Storfjorden. Lower Tertiary deposits in the basin mainly consist of sandstones, with numerous coal seams which form the basis for commercial mining of coal in Svalbard today. The vegetation was luxuriant, and beautiful plant-fossils are frequent in the strata. The Longyearbyen glacier today erodes a Tertiary coal seam, and plant fossils can be sampled from its frontal moraine. Towards the latter part of the Tertiary, when the plate pressure started to diminish, Svalbard was

subject to intense faulting and volcanism. Lava flows of basalt occur spot-wise on northern Spitsbergen. The climate of Svalbard was getting successively cooler partly as a consequence of the slow northward drift, and partly because of a late Tertiary global cooling.



*Tide-water glacier on NW-Spitsbergen.*

***The Quaternary of Svalbard: repeated glaciations*** - Svalbard had largely attained its present shape and size by late Tertiary times. The sculpturing of the landscape with its fjords, bays, valleys, cirques, mountains, horns and arêtes was largely carried out by the repeated glaciations during the Quaternary. No one knows how many glaciations have occurred on Svalbard since the onset of the glacial period at these high latitudes some 3 MY ago, but there may have been 50 or more glaciations! The preservation of Quaternary sediments is poor since subsequent glaciations have removed signs of earlier glaciations.



*The sections at Kapp Ekholm in Billefjorden*

During the last glacial cycle, ca. 115,000-10,000 years before present (BP), Svalbard was probably subject to three major glaciations, where a major ice sheet grew in the Barents Sea

and extended over, or confluent with, an ice sheet over Svalbard. During their peak, glaciers extended in fjords and troughs out to the shelf break west of Spitsbergen.

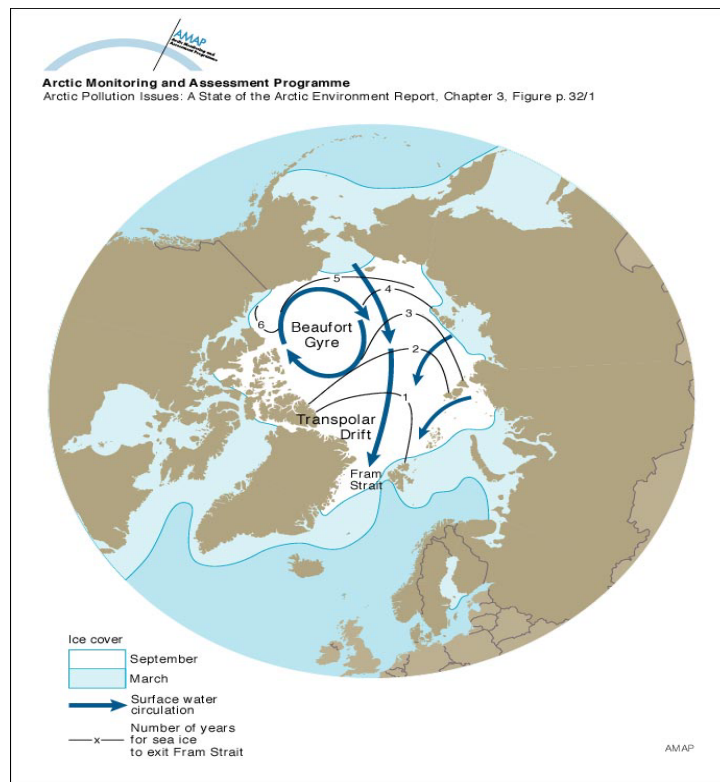
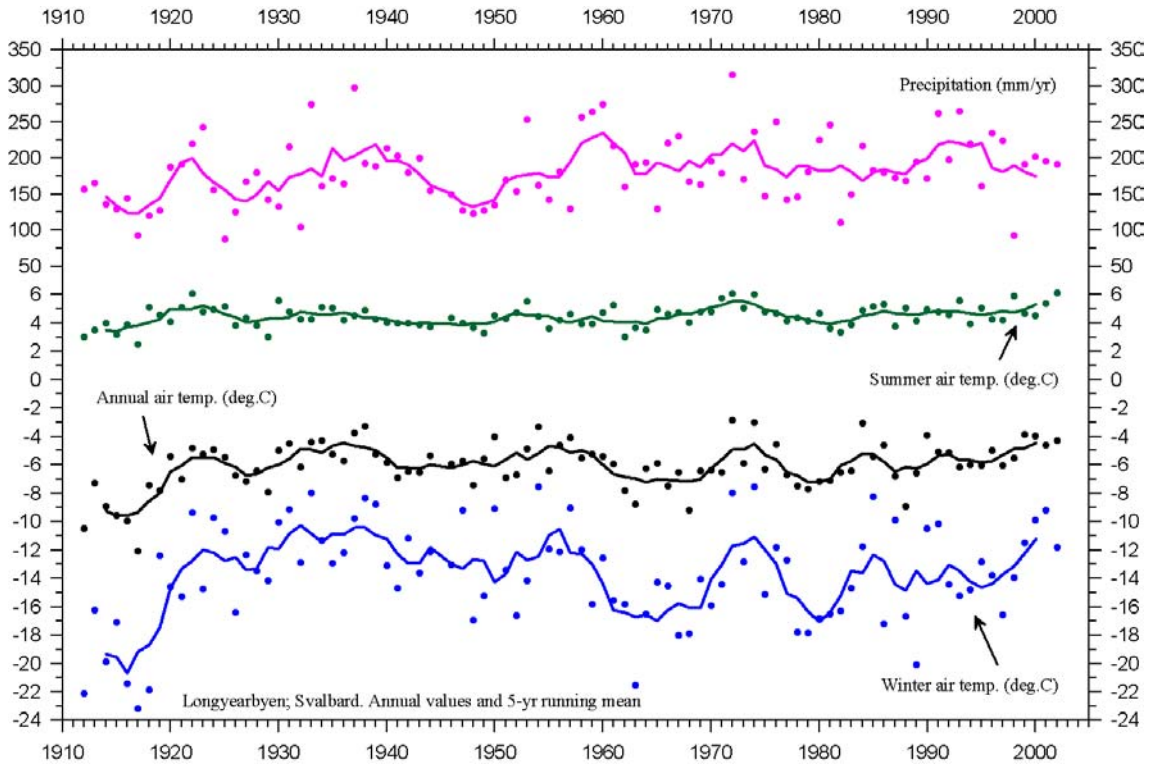
The last major glaciation on Svalbard ended with a rapid deglaciation during the period ca. 14,000-10,000 BP. Transgression by the sea subsequent to deglaciation left marine terraces and flights of raised beaches around Svalbard. The isostatic fingerprinting, as expressed in well-dated relative sea-level curves, suggests heaviest ice-loading over central-northern Barents Sea during the last glaciation. During early-mid Holocene, Svalbard glaciers were probably smaller than at present, and the early Holocene climate was considerably milder. Some of the present cirque- and valley glaciers probably did not exist prior to ca. 2500 BP. Glaciers expanded considerably during the so-called Little Ice Age, which culminated on Svalbard during the first decade of the 20<sup>th</sup> Century. Since then most glaciers have retreated, probably as a consequence of a considerable summer warming occurring in the period after ca. 1915.

***The onward journey*** – Continental drift will continue to move Svalbard northwards and eastwards, and in 50 MY time it *may* lie at or close to the North Pole. Global warming may cause its glaciers to melt away – but again, Svalbard may well plunge into new series of extensive glaciations. Regardless, nothing the future may hold will be more dramatic than the environmental changes through time recorded in the geological record of Svalbard today.

*Recommended further reading:*

- Aga, O.J. (ed.) 1986: *The Geological History of Svalbard*. Stavanger, Statoil, 121 pp.
- Hisdal, V. 1998: *Svalbard. Nature and History*. Oslo, Norsk Polarinstittutt, 123 pp.
- Hjelle, A. 1993: *The Geology of Svalbard*. Oslo, Norsk Polarinstittutt, 163 pp.
- Web-site on geological development through time and the history of life: [www.ucmp.berkeley.edu](http://www.ucmp.berkeley.edu)
- Web site on Plate Tectonics/Continental Drift: [pubs.usgs.gov/publications/text/dynamic.html](http://pubs.usgs.gov/publications/text/dynamic.html)
- An excellent web site on the geological history of Norway: <http://www.toyen.uio.no/>

**The climate in Longyearbyen during the 20<sup>th</sup> Century (data from Ole Humlum):**



Transport of sea-ice across the Arctic Basin.

## KEY-REFERENCES ON SVALBARD GLACIAL HISTORY

### ***Basic literature on the Late Quaternary Svalbard-Barents Sea ice sheet:***

- Houmark-Nielsen, M. & Funder, S. 1999: Pleistocene stratigraphy of Kongsfjordhallet, Spitsbergen. *Polar Research* 18, 39-49.
- Landvik, J.Y., Bolstad, M., Lycke, A.K., Mangerud, J. & Sejrup, H.P. 1992: Weichselian stratigraphy and paleoenvironments at Bellsund, western Svalbard. *Boreas* 21, 335-358.
- Landvik J.Y., Bondevik S., Elverhøi A., Fjeldskaar W., Mangerud J., Salvigsen O., Siegert, M.J., Svendsen J.I. & Vorren T.O. 1998: The last glacial maximum of the Barents Sea and Svalbard area: Ice sheet extent and configuration. *Quaternary Science Reviews* 17, 43-75.
- Mangerud J., Dokken T.M., Hebbeln D., Heggen B., Ingólfsson O., Landvik J.Y., Mejdahl V., Svendsen J.I. & Vorren T.O. 1998: Fluctuations of the Svalbard-Barents Sea Ice Sheet the last 150,000 years. *Quaternary Science Reviews* 17, 11-42.
- Miller, G.H., Sejrup, H.P., Lehman, S.J. & Forman, S.L. 1989: Glacial history and marine environmental change during the last interglacial-glacial cycle, western Spitsbergen, Svalbard. *Boreas* 18, 273-296.
- Mienert, J; Weaver, P., 2003. European Margin Sediment Dynamics- Side Scan Sonar and Seismic Images, Springer Verlag Berlin Heidelberg New York, 309pp.
- Svendsen, J.I., Elverhøi, A. & Mangerud, J. 1996: The retreat of the Barents Ice Sheet on the western Svalbard margin. *Boreas* 25, 244-256.
- Forman, S. 1990: Post-glacial relative sea-level history of northwestern Spitsbergen, Svalbard. *Geological Society of America Bulletin* 102, 1580-1590.
- Feyling-Hanssen, R.W. 1955: Stratigraphy of the marine Late-Pleistocene of Billefjorden, Vestspitsbergen. *Norsk Polarinstitutt Skrifter* 107, 1-186.
- Landvik, J.Y., Mangerud, J. & Salvigsen, O. 1987: The Late Weichselian and Holocene shoreline displacement on the west-central coast of Svalbard. *Polar Research* 5, 29-44.
- Salvigsen, O. 1984: Two observations of pumice levels from the west coast of Spitsbergen. *Polar Research* 2, 115-116.
- Salvigsen, O. 1984: Occurrence of pumice on raised beaches and Holocene shoreline displacement in the inner Isfjorden area, Svalbard. *Polar Research* 2, 107-113.
- Salvigsen, O., Elgersma, A., Hjort, C., Lagerlund, E. Liestøl, O. & Svensson, N-O. 1990: Glacial history and shoreline displacement on Erdmannflya and Bohemanflya, Spitsbergen, Svalbard. *Polar Research* 8, 261-273.

### ***Prins Karls Forland - Late Quaternary stratigraphy and glacial history:***

- Andersson, T. 2000: Raised beach deposits and new 14C ages from Pricepynten, Prins Karls Forland, western Svalbard. *Polar Research* 19 (2), 271-273.
- Anderson, T., Forman, S.L., Ingólfsson, Ó. & Manley, W. 1999: Late Quaternary environmental history of central Prins Karls Forland, Svalbard. *Boreas* 28, 292-307.
- Andersson, T., Forman, S.L., Ingólfsson, Ó. & Manley, W.F. 2000: Stratigraphic and morphologic constraints on the weichselian glacial history of northern Prins Karls Forland, western Svalbard. *Geografiska Annaler* 82 A (4), 455-470.

### ***Sea level history:***

- Forman, S.L., Mann, D. & Miller, G.H. 1987: Late Weichselian and Holocene relative sea-level history of Brøggerhalvøya, Spitsbergen. *Quaternary Research* 27, 41-50.

Bergsten, H., Anderson, T. & Ingólfsson, Ó. 1998: Foraminiferal stratigraphy of raised marine deposits, representing isotope stage 5, Prins Karls Forland, western Svalbard. *Polar Research* 17, 81-91.

Forman, S.L. 1989: Late Weichselian glaciation and deglaciation of Forelands- sundet area, western Spitsbergen, Svalbard. *Boreas* 18, 51-60

### ***Kapp Ekholm - Stratigraphy and environmental history:***

Forman, S.L. 1999: Infrared and Red Stimulated Luminescence Dating of Late Quaternary nearshore sediments from Spitsbergen, Svalbard. *Arctic, Antarctic and Alpine Research* 31, 34-49.

Mangerud, J. & Svendsen, J.I. 1992: The last interglacial-glacial period on Spitsbergen, Svalbard. *Quaternary Science Reviews* 11, 633-664.

Mangerud, J. & Salvigsen, O. 1984: The Kapp Ekholm section, Billefjorden, Spitsbergen: a discussion. *Boreas* 13, 155-158.

### ***Nordenskiöldbreen - Proglacial processes and morphology:***

Hambrey, M.J. & Huddart, D. 1995: Englacial and proglacial glaciogenic processes at the snout of a thermally complex glacier in Svalbard. *Journal of Quaternary Science* 10, 313-326.

Huddart, D. & Hambrey, M.J. 1996: Sedimentary and tectonic development of a high-arctic, thrust-moraine complex: Comfortlessbreen, Svalbard. *Boreas* 25, 227-243.

Krüger, J. 1993: Moraine-ridge formation along a stationary ice front in Iceland. *Boreas* 22, 101-109.

Lawson, D.E. 1989: Glacigenic resedimentation: Classification concepts and application to mass-movement processes and deposits. In Goldthwait, R.P. & Matsch, C.L. (eds): *Genetic Classification of Glacigenic Deposits*. 147-169. Balkema, Rotterdam.

Bennett, M.R., Hambrey, M.J., Huddart, D. & Ghienne, J.F. 1996: The formation of a geometrical ridge network by the surge type glacier Kongsvegen, Svalbard. *Journal of Quaternary Science* 11, 437-449.

Bennett, M.R., Huddart, D., Hambrey, M.J. & Ghienne, J.F. 1996: Moraine development at the high-arctic valley glacier Pedersbreen, Svalbard. *Geografiska Annaler* 78, 209-222.

### ***Holocene environmental change on Svalbard:***

Birks, H.H. 1991: Holocene vegetational history and climatic change in west Spitsbergen – plant macrofossils from Skardtjørna, an Arctic lake. *The Holocene* 1, 209-218.

Birks, H.H., Paus, A., Svendsen, J.I., Alm, T., Mangerud, J. & Landvik, J. 1994: Late Weichselian environmental change in Norway, including Svalbard. *Journal of Quaternary Science* 9, 133-145.

Landvik, J.Y., Mangerud, J. & Salvigsen, O. 1987: The Late Weichselian and Holocene shoreline displacement on the west-central coast of Svalbard. *Polar Research* 5, 29-44.

Mangerud, J. & Svendsen, J.I. 1990: Deglaciation chronology inferred from marine sediments in a proglacial lake basin, western Spitsbergen, Svalbard. *Boreas* 19, 249-272.

Salvigsen, O. 2002. Radiocarbon-dated *Mytilus edulis* and *Modiolus modiolus* from northern Svalbard: Climatic implications. *Norsk Geografisk Tidsskrift* 56, 56-61.

Salvigsen, O., Forman, S. & Miller, G.H. 1992: Thermophilous molluscs on Svalbard during the Holocene and their paleoclimatic implications. *Polar Research* 11, 1-10.

Snyder, J.A., Werner, A. & Miller, G.H. 2000: Holocene cirque glacier activity in western Spitsbergen, Svalbard: sediment records from proglacial Linnévatnet. *The Holocene* 10, 555-563.

- Svendsen, J.I. & Mangerud, J. 1997: Holocene glacial and climatic variations on Spitsbergen, Svalbard. *The Holocene* 7, 45-57.
- Svendsen, J.I. & Mangerud, J. 1992: Paleoclimatic inferences from glacial fluctuations on Svalbard during the last 20,000 years. *Climate Dynamics* 6, 213-220.
- Marine geology:**
- Boulton, G.S. 1990. Sedimentary and sea level changes during glacial cycles and their control on glacial marine facies architecture. In: Dowdeswell and Scourse, J.D. (Eds.): *Glacial marine environments: Processes and sediments*. Geological Society Special Publication. 15-52.
- Dowdeswell, J.A., O Cofaigh, 2002. Glacier-Influenced Sedimentation on High-Latitude Continental Margins, Geological Society of London, Volume 203.
- Elverhøi, A., Liestøl, O. & Nagy, J. 1980: Glacial erosion, sedimentation and microfauna in the inner part of Kongsfjorden, Spitsbergen. *Norsk Polarinstitutt Skrifter* 172, 33-61.
- Elverhøi, A., Lønne, Ø. & Seland, R. 1983: Glacial marine sedimentation in a modern fjord environment, Spitsbergen. *Polar Research* 1, 127-149.
- Hald, M. & Korsun, S. 1997: Distribution of modern Arctic benthic foraminifera from fjords of Svalbard. *Journal of Foraminiferal Research* 27.
- Hald, M., Steinsund, P.I., Dokken T., Korsun, S., Polyak, L. & Aspeli, R. 1994: Recent and Late Quaternary distribution of *Elphidium excavatum* f. *clavatum* in Arctic seas. *Cushman Foundation Special Publication* 32, 141-153.
- Hebbeln, D., Dokken, T., Andersen, E.S., Hald, M. & Elverhøi, A. 1994: Moisture supply for northern ice-sheet growth during the last glacial maximum. *Nature* 370, 357-360.
- Liestøl, O. 1988. The glaciers in the Kongsfjorden area, Spitsbergen. *Norsk geografisk tidsskrift*, 42, 231-238.
- Osterman, L.E. & Nelson, A.R. 1989: Latest Quaternary and Holocene Paleooceanography of the eastern Baffin Island continental shelf, Canada: Benthic Foraminiferal Evidence. *Canadian Journal of Earth Science* 26, 2236-2248.
- Sexton, D.J., Dowdeswell, J.A., Solheim, A. & Elverhøi, A. 1992: Seismic architecture and sedimentation in northwest Spitsbergen fjords. *Marine Geology* 103, 53-68.
- Vilks, G. 1981: Late Glacial-Postglacial Foraminiferal Boundary in Sediments of Eastern Canada, Denmark and Norway. *Geoscience Canadian* 8, 48-56.
- Important papers, not covered by the themes above:**
- Forman, S.L. 1990: Post-glacial relative sea-level history of northwestern Spitsbergen, Svalbard. *Geological Society of America Bulletin* 102, 1580-1590.
- Forman, S.L. & Miller, G.H. 1984: Time dependant soil morphologies and pedogenic processes on raised beaches, Brøggerhalvøya, Svalbard archipelago. *Arctic and Alpine Research* 16, 381-394.
- Forman, S.L. & Ingólfsson, Ó. 2000: Late Weichselian glacial history and postglacial emergence of Phippsøya, Sjuøyene, northern Svalbard: a comparison of modelled and empirical estimates. *Boreas* 29I, 16-25.
- Forman, S.L., Lubinski, D., Miller, G.H., Snyder, J., Matishov, G.G., Korsun, S. & Myslivets, V. 1995: Postglacial emergence and distribution of late Weichselian ice-sheet loads in the northern Barents and Kara seas, Russia. *Geology* 23, 113-116.
- Ingólfsson, Ó., Rögnvaldsson, F., Bergsten, H., Hedenäs, L., Lemdahl, G. & Sejrup, H.P. 1995: Late Quaternary glacial and environmental history of Kongsøya, Svalbard. *Polar Research* 14, 123-139.
- Lambeck, K. 1995a: Constraints on the Late Weichselian ice sheet over the Barents Sea

from observations of raised shorelines.  
*Quaternary Science Reviews* 14, 1-16.

Lambeck, K. 1995b: Limits on the areal extent of the Barents Sea Ice Sheet in Late Weichselian time. *Global and Planetary Change* 12, 41-51.

Lehman, S.J. & Forman, S.L. 1992: Late Weichselian glacier retreat in Kongsfjorden, west Spitsbergen, Svalbard. *Quaternary Research* 37, 139-154.

Landvik, J.Y., Hjort, C., Mangerud, J., Möller, P. & Salvigsen, O. 1995: The Quaternary record of eastern Svalbard - an overview. *Polar Research* 14, 95-103.

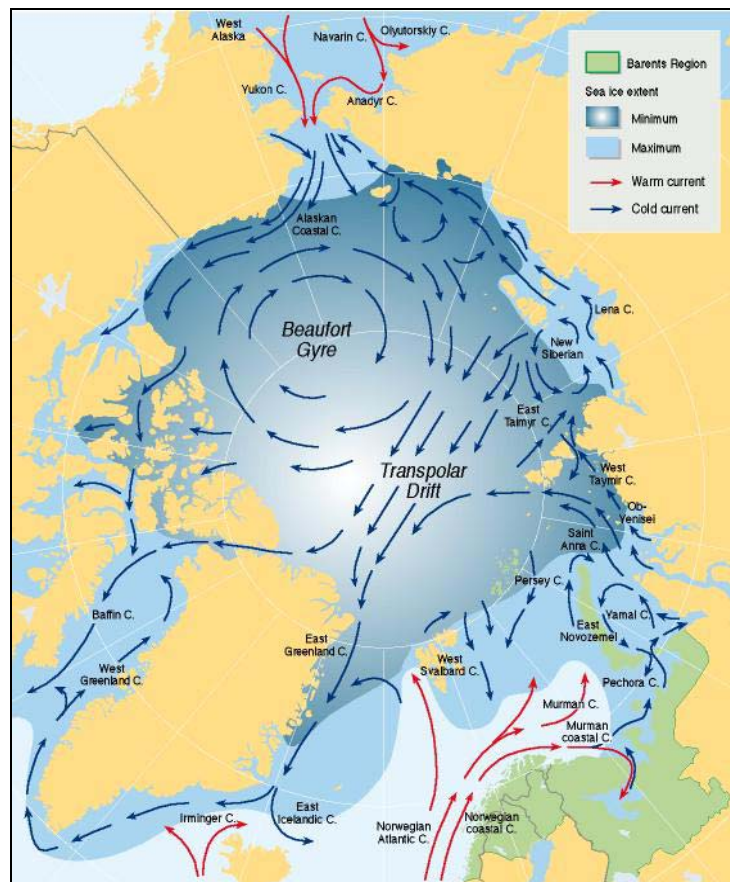
Mangerud, J. & Svendsen, J.I. 1990: Deglaciation chronology inferred from marine sediments in a proglacial lake basin, western Spitsbergen, Svalbard. *Boreas* 19, 249-272.

Mangerud, J., Bolstad, M., Elgersma, A., Helliksen, D., Landvik, J.Y., Lønne, I., Lycke, A.K., Salvigsen, O., Sandahl, T. & Svendsen, J.I. 1992: The last glacial maximum on Spitsbergen, Svalbard. *Quaternary Research* 38, 1-31.

Mangerud, J., Jansen, E. & Landvik, J.Y. 1996: Late Cenozoic history of the Scandinavian and Barents Sea ice sheets. *Global and Planetary Change* 12, 11-26.

Siegert, M.J. & Dowdeswell, J.A. 1996: Topographic control of the dynamics of the Svalbard-Barents Sea Ice Sheet. *Global and Planetary Change* 12, 27-39.

Svendsen, J.I., Mangerud, J. Miller, G.H. 1989: Denudation rates in the Arctic estimated from lake sediments on Spitsbergen, Svalbard. *Paleogeography, Paleoclimatology, Paleoecology* 76, 153-168.



Ocean currents and sea ice in the Arctic Basin