Geology of Svalbard

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Content

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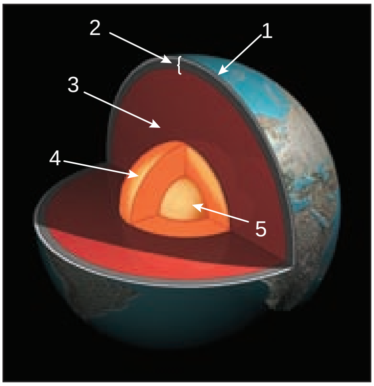
What is geology?

The science of the Earth

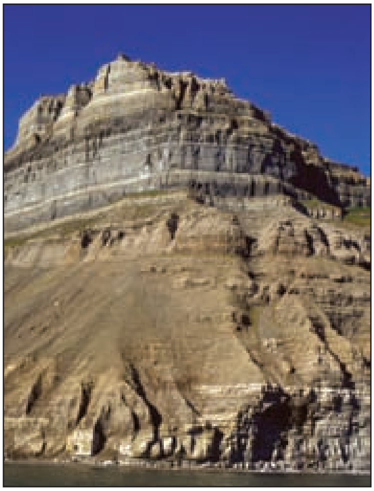
Geology is the study of the Earth, its structure and composition and its evolution from its formation about 4.6 billion years ago to the present. Geology topics range from volcanoes and earthquakes to dinosaurs and gems. More precisely, geology is the study of rocks, minerals, fossils and unconsolidated deposits, and is where chemistry, physics and biology are integrated in order to describe, explain and understand the processes and features of the Earth.

A schematic section through the Earth reveals layers of different composition. In the centre is the core, which is made up of metallic iron and nickel. The inner core is solid whereas the outer core is assumed to be liquid. The middle layer is the mantle which is viscous, and the outer layer is the cool solid crust which consists of rocks. The crust can be subdivided into continental and oceanic crust.

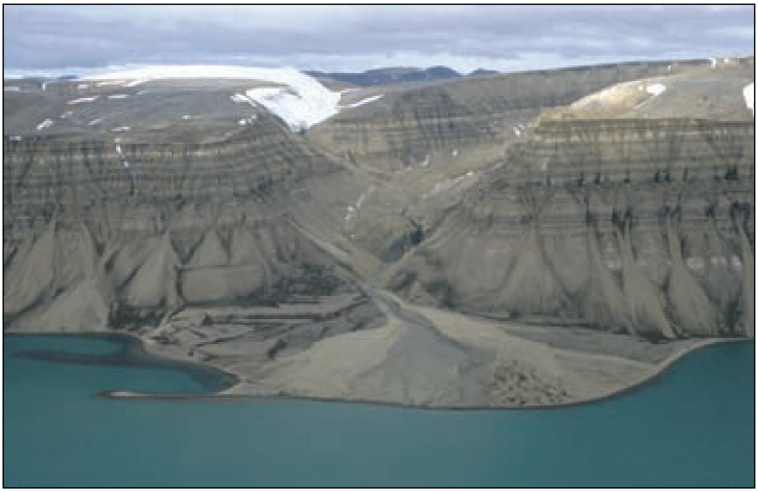


1. Crust
2. Lithosphere
3. Mantle
4. Outer core
5. Inner core

Fossil leaf impression in Tertiary siltstone. Fossil leaves from deciduous trees are found in the end moraine of the Longyear glacier in the vicinity of Longyearbyen. Photo: D. Blomeier



Layered Palaeozoic (Permian) sedimentary rocks in the Billefjorden area. Photo: W. Dallmann



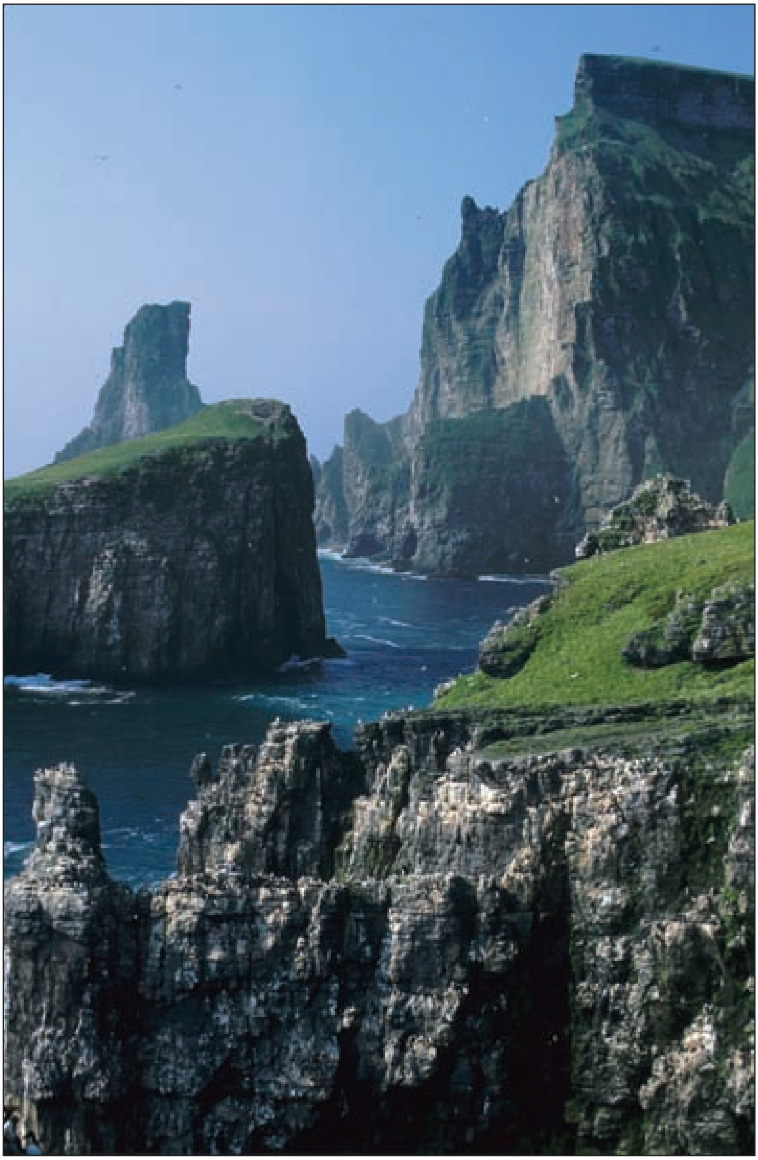
The landscapes in Svalbard are strongly sculpted by glaciers and rivers. The rivers transport eroded rock material, which is subsequently deposited in fan-shaped deltas. Photo: D. Blomeier

Geology in the society

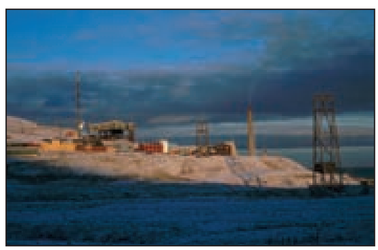
Geology is all around us and is, quite simply, about the ground on which we live. Geological processes have formed the bedrock, deposited the superficial sediments and modified and sculpted landscapes. Some of these processes are global and very slow measured on a human time scale. Other geological processes of local character may be rapid and violent. Among the hazardous Earth's processes are volcanic eruptions, floods, earthquakes and landslides.

Resources represent another important focus of geology that is of great practical value to people. Humans have utilized geological resources throughout history. The Stone Age, Iron Age and Bronze Age are named after geological resources. Craftsmen of the Stone Age used flint for tools, and later the Vikings discovered how to extract iron from minerals such as hematite. Geological resources also form the very foundation of modern civilization. In Norway, society has developed in relation to the exploitation of ore resources on land and petroleum resources offshore on the continental shelf. In Svalbard, the history and the development of the local settlements is the result of the geological occurrence of coal.

Geology is also of importance for ecosystems. In Svalbard, for example, there are many sheer cliffs where hundred of thousands of sea birds gather to nest. The bird cliffs represent special habitats where the steep mountainsides provide the basis for bird colonies. Safe ledges for nesting result from the nature of the bedrock and different geological processes that have formed the cliffs. Tourism and outdoor activities are important for Svalbard's economic basis, and the geology of the archipelago forms part of the nature experience enjoyed by tourists.



The spectacular cliffs on the southern tip of Bjørnøya consist of dolomite and carbonate rocks that erode easily and create ledges suitable as nesting sites. Photo: H. Strøm



The geology of Adventdalen forms the basis for the development and history of Longyearbyen. Photo: I. L. Næss

Minerals and rocks

A rock is made up of one or more minerals. Minerals such as quartz, feldspar and mica are quite common, whereas others are present in lesser amounts. Rocks can be divided into three major types based on how they are formed:

Sedimentary rocks

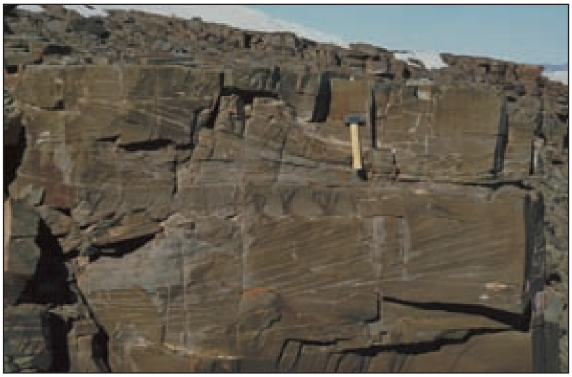
Weathering of existing rocks produces clay, sand and pebbles, which are transported by running water, wind, waves or glaciers to a new location and deposited. Following deposition, the sediments undergo lithification and become solid sedimentary rocks. Examples of sedimentary rocks are sandstone, shale, limestone and conglomerate.

Igneous rocks

Igneous rocks are formed when magma (molten rock) forms deep beneath the Earth's surface, rises, cools and solidifies. When the magma solidifies at depth within the crust, plutonic rocks such as granite and gabbro are formed. Dykes and sills are formed when magma is injected into fractures or along sedimentary bedding surfaces. Dykes and sills in Svalbard commonly consist of dolerite. Extrusive rocks crystallize from magma that rises all the way to the surface where it solidifies. Lava, most commonly basalt lava, is an example of an extrusive rock.

Metamorphic rocks

Metamorphic rocks form when sedimentary or igneous rocks are subjected to great pressure and/or intense heat. The result is recrystallization, often accompanied by development of a schistosity. Examples of metamorphic rocks are gneiss, marble and mica schist.

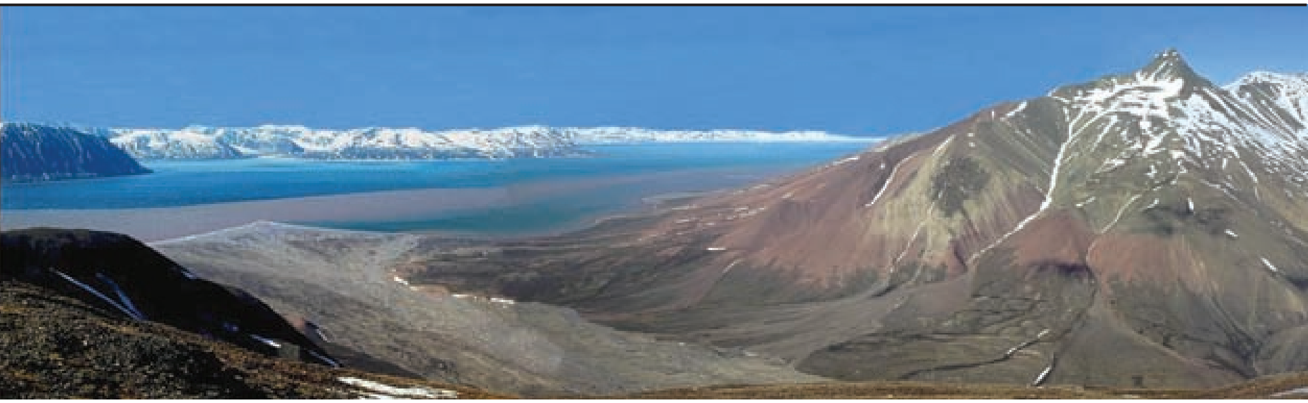


Sedimentary rock: cross-bedded sandstone. Photo: D. Blomeier

Igneous rock: granite with large feldspar crystals. Photo: S. Elvevold

Metamorphic rock: strongly folded gneiss. Photo: S. Elvevold

The diversity of geology



Svalbard presents an exceptional geological diversity within a relatively small area. Although most of the land area is covered by glaciers, Svalbard is one of the few places in the world where sections representing most of the Earth's history are easily accessible for study. Svalbard is thus both a natural geological archive and a laboratory where past and present geological processes are particularly well displayed. Another aspect of the geology of Svalbard is the presence of sedimentary successions that are rare or do not exist in other places in northern Europe.

Remnants of the 400 million year old Caledonian mountain range in Svalbard comprise a variety of different rock complexes, each with a unique geological history. After the Caledonian orogeny, Svalbard was below sea level for a long portion of its geological history. Mud, sand, gravel, lime etc., were almost continuously deposited and later turned into stratified, sedimentary rocks. There is little soil in Svalbard and no forests or agricultural areas hide the rock formations from view. The naked landscape is cut through by fjords and valleys exposing the bedrock three-dimensionally so that the geological record is presented as in a picture book.

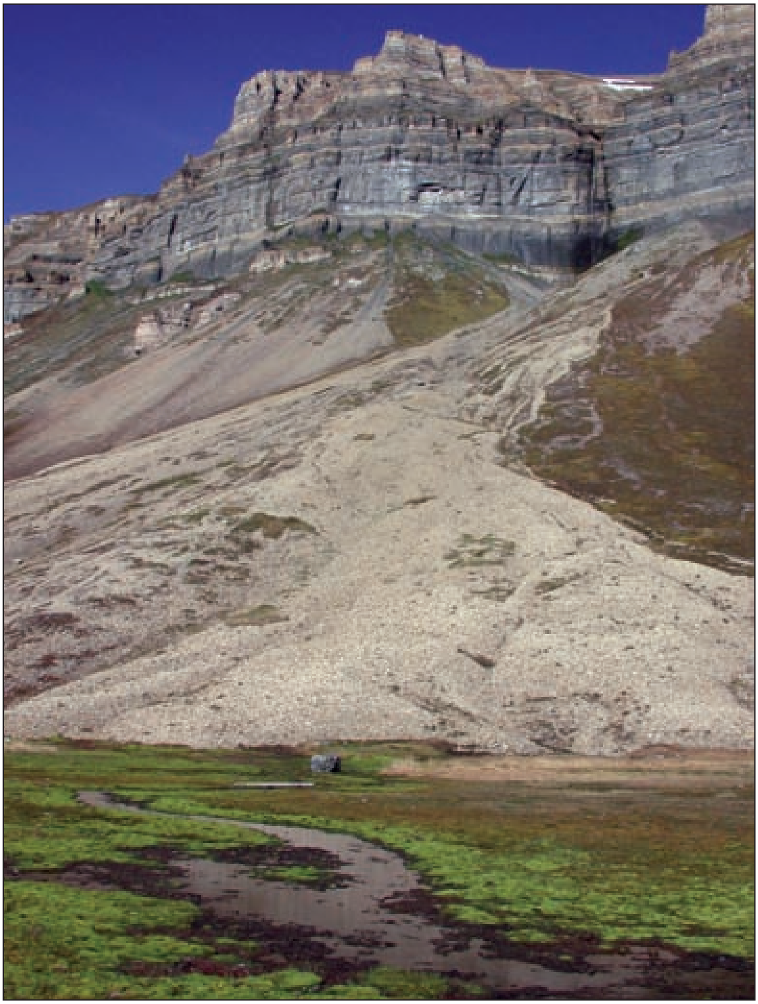
Material eroded from the mountains is transported by rivers and then deposited in a large river delta that runs into the fjord. Photo: W. Dallmann

Crustal movements and erosion can expose rocks that once were deeply buried. The picture shows folded gneisses of the Caledonian mountain belt. Photo: W. Dallmann

Photo: M. Wisshack

Granite, gneiss, schist, sandstone and lava are the names of different rocks that are known to many of us. These rock types, along with many others, make up the bedrock – the solid ground. The age of the rocks varies by several billion years. The oldest rocks found in Svalbard are 3.3 billion years old. As a comparison, the Earth is more than 4.6 billion years old, and the oldest rocks yet found on Earth are 4.03 billion years old.

Surficial deposits of clay, sand and gravel overlie and are much younger than the bedrock. The geological processes that formed these sediments are closely linked to glacial erosion. The large rivers have transported the material out towards the sea. In Svalbard, as in other arctic areas, wind and frost have also had an impact that can be dominant in the landscape.



Flat lying sedimentary rocks in the Billefjorden area. Large piles of rocks, called talus slopes, are formed at the base of the cliffs. Photo: D. Blomeier

Rock weathering creates soil for the varied tundra vegetation. Photo: S. Elvevold

The geological record of Svalbard can be separated into three broad divisions:

1. The basement, comprising the oldest material, was formed during Precambrian to Silurian times. It consists mainly of igneous and metamorphic rocks that have suffered several episodes of folding and alteration.

2. Unaltered sedimentary rocks were formed in Late Palaeozoic to Cenozoic times. Beds of this age on Spitsbergen form a trough-shaped structure from the Isfjorden area to the south, with the youngest beds in the core and the oldest on the flanks.

3. Unconsolidated surficial deposits from the Quaternary period. These are mostly deposits formed during and after the last ice age: moraines, fluvial and beach deposits, talus and scree.

In the following, we will describe general features of the basement, the sedimentary rocks and the Quaternary deposits and landforms. A generalized geological map of Svalbard is shown on page 34, and two geological cross sections are shown on page 21.

Fieldwork in Svalbard. Photos, lower left: S. Elvevold, others: W. Dallmann

Facts

How do we determine the age of rocks?

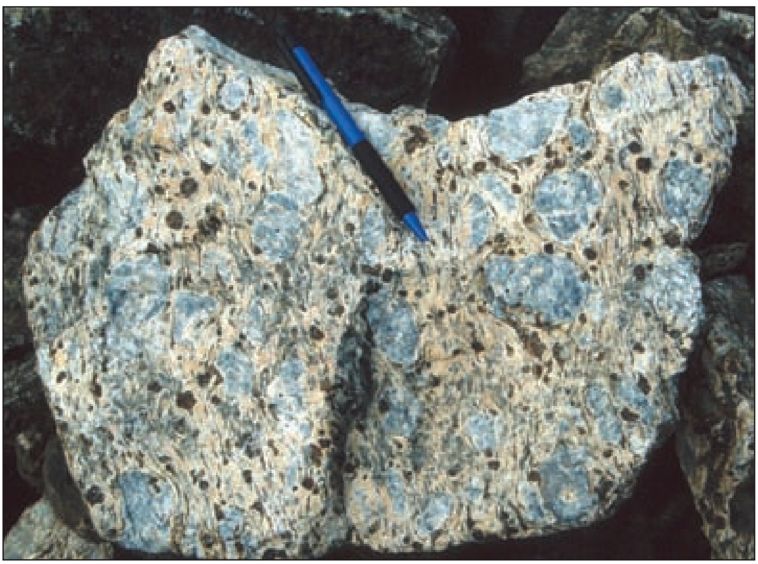
In order to systematize the diverse geological evolution, rocks are subdivided based on age. There are several ways of determining the age of a rock, but not all methods can be used everywhere.

Relative age determination:
The age of a rock can be determined by observing its relation to the surrounding rocks. For instance, the lower beds in an undisturbed succession of beds are older than the upper ones; a granite that has intruded a schist is younger than the schist.

Age determination by fossils:
Some fossils, called index fossils, are limited to certain periods with narrow time limits in the history of the Earth. Because the best preserved fossils are found in Palaeozoic and younger rocks, it is generally in these that dating is done by means of index fossils.

Radiometric age determination:
Radioactive elements, such as uranium (U), can be used for geological age determination. Many elements consist of several isotopes, i.e. variants of the same atom, but with a different atomic weight. When a mineral is formed, a number of elements enter into the crystal structure, including minute amounts of different radioactive isotopes. These radioactive parent isotopes form stable daughter products by radioactive decay. For instance, radioactive decay of uranium produces different isotopes of lead (Pb). The length of time for half the nuclei of a radioactive isotope to decay is called the half-life of the isotope. Two uranium isotopes have half-lives of 4468 and 703.8 million years, and a combination of these two decay rates can be used to determine the age of uranium bearing minerals such as zircon, monazite and sphene. There are many different types of radiometric "clocks"; some are suitable for determining the time of solidification of an igneous rock, others are used to determine the crystallization of a mineral or the metamorphism and deformation of a rock.

Facts



Gneiss from Biscayarhalvøya. Dating by the U-Pb method has revealed that the rock is ca. 965 million years old. Photo: S. Elvevold

The oldest rocks

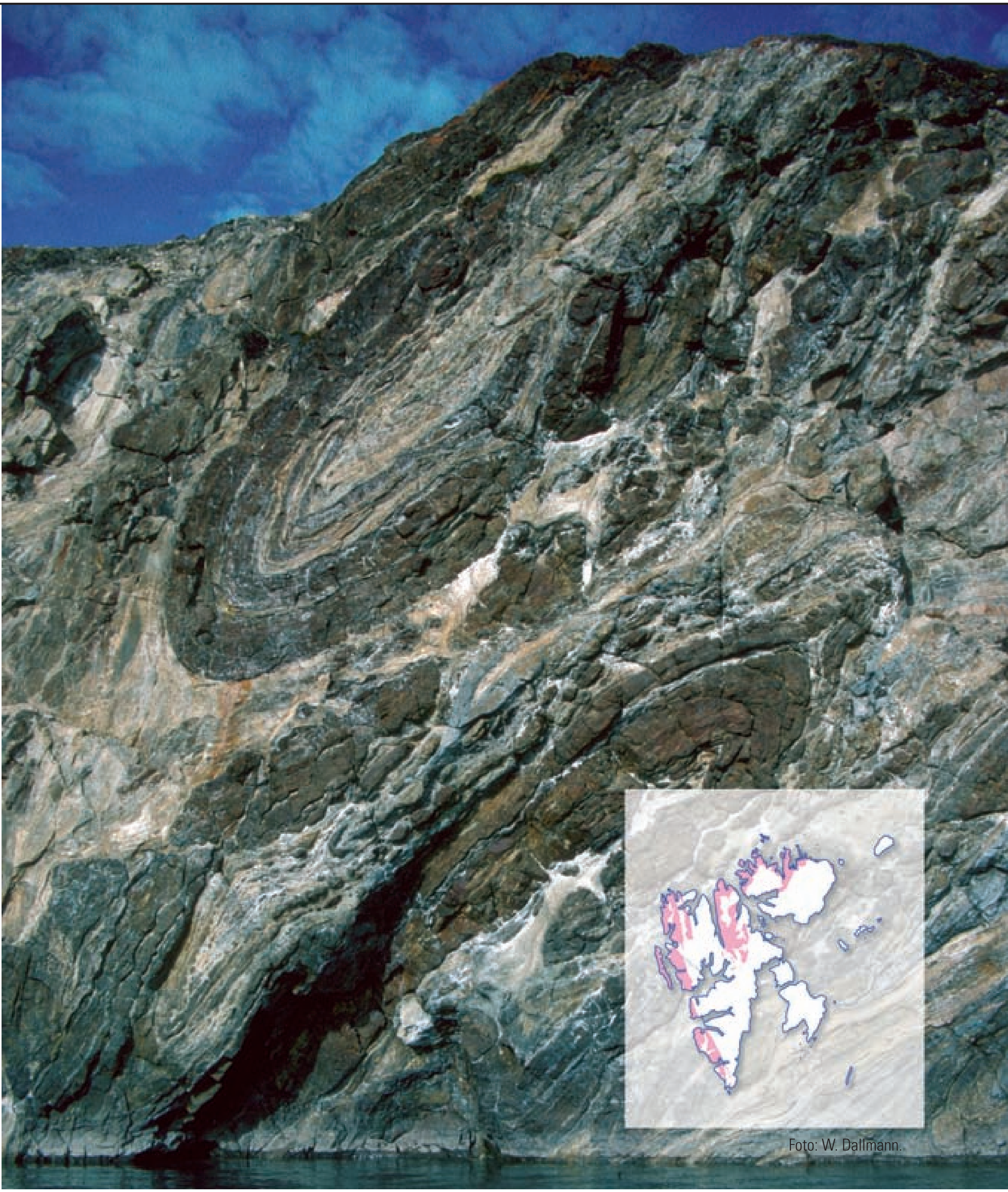


Foto: W. Dallmann.

The basement

Rocks from the older part of the Earth's history are called basement because the oldest rocks usually form a substratum for younger rocks.

The basement of Svalbard formed during Precambrian to Silurian time. Age determinations have shown that the basement in Svalbard has experienced several periods of folding and metamorphism. The last large-scale folding and metamorphism took place during the Caledonian Orogeny, a major mountain building episode in the Silurian, i.e. about 400 million years ago. Because of weathering and erosion, only the eroded remnants of the ancient, folded and metamorphosed basement can be seen today.

Basement rocks are present along the west coast and the northern part of Spitsbergen, on Prins Karls Forland, Nordaustlandet, and a small area of Bjørnøya. The basement areas are frequently characterized by alpine landscapes with high, sharp, tooth-edged mountains. When Willem Barents saw this land in 1596, he named it Spitsbergen because of its sharp, jagged peaks.

Southern Spitsbergen

Between Sørkapp and Isfjorden, the basement consists of phyllite, quartzite, limestone, dolostone and conglomerate, and minor amounts of volcanic rocks. There are both ordinary conglomerates with well-rounded clasts and tillites. Tillite is consolidated moraine, glaciofluvial deposits and drop deposits from melting icebergs, derived from glaciers which covered Svalbard around 600 million years ago. These beds form an important key horizon for relative age determination. Beneath the tillites are beds of limestone or dolostone containing stromatolites, which are fossil algae colonies. Stromatolites are among the oldest fossils found in Svalbard. Sørkapp Land is underlain by Cambrian and Ordovician strata in which trilobites and brachiopods have been found (see chapter on fossils, page 22-23). Hornsundtind, which at 1431 m is the highest mountain in southern Spitsbergen, consists of similar rocks.

Conglomerate deposited in Proterozoic time. The rock has suffered strong deformation. Pebbles that were originally round are now stretched and folded. Photo: W. Dallmann

Northwestern Spitsbergen

The rock types in Prins Karls Forland and Oscar II Land strongly resemble those found south of Isfjorden, with shale, limestone, dolostone and tillite as the most common. Folding and faulting of Tertiary age left its mark on the area along the west coast of Spitsbergen.

The basement north and north-east of Kongsfjorden consists of gneiss, migmatite and granite, commonly with inclusions of schist, marble and quartzite. East of Magdalenefjorden is the Hornemantoppen granite, which forms steep cliffs and mountainsides. Radiometric age determination of the granite shows that it formed about 411 million years ago.

An area south of St. Jonsfjorden contains blueschist and eclogite. These rocks were formed at extremely high pressures at great depth in the crust. Several millions of years of unloading and erosion brought the rocks up from great depth to the surface.

The sharp, darker ridges in the background consist of metamorphosed carbonate rocks belonging to the basement, whereas the tilted rocks in the foreground are composed of younger Devonian sandstones. Hornsund, Sørkapp Land. Photo: W. Dallmann

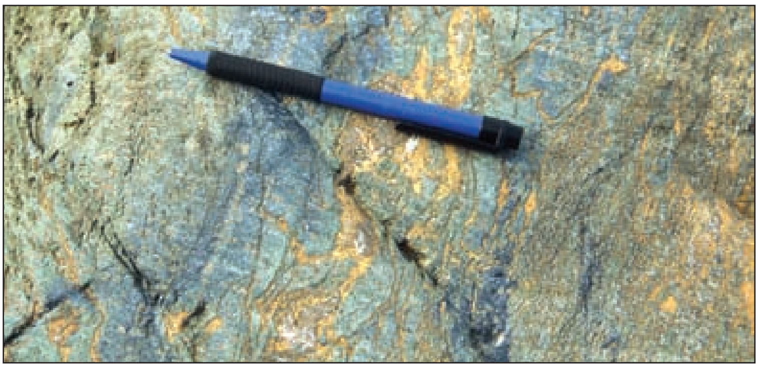
Folded carbonate rocks, Hornsund. Photo: W. Dallmann

Ny-Friesland

The basement along the east coast of Wijdefjorden consists of schist, amphibolite, gneiss and granite. The rocks can be subdivided into a pile of five fault bounded sheets or thrust sheets. Each thrust sheet is comprised of ca. 1750 million year old granitic gneisses and overlying, younger schists. The thrust stack is folded into a large fold, the north–south trending Atomfjella Antiform, which extends the 150 km length of Ny-Friesland.

In the eastern part of Ny-Friesland and in the area between Lady Franklinfjorden and Hinlopenstretet, north-western Nordaustlandet, a thick sedimentary succession consisting of sedimentary rocks from the later parts of the Precambrian, Cambrian and Ordovician is exposed. The succession consists of limestone, sandstone, quartzite and shale and is moderately folded around north–south trending fold axes.

Newtontoppen (1717 m), the highest peak in Svalbard, consists of coarse-grained granite. Radiometric age determination has shown that the granite intruded the surrounding host rocks about 432 million years ago.



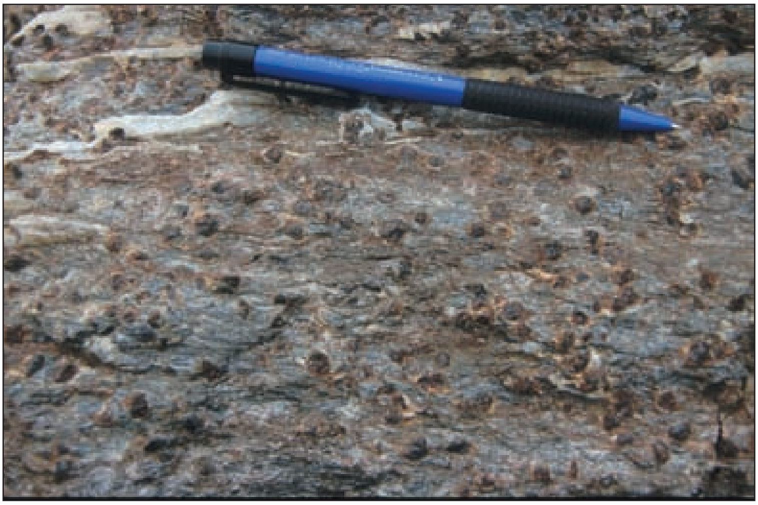
Eclogite is a colourful and very striking rock. Eclogites in the St. Jonsfjorden area were formed at great depth (60-80 km) around 470 million years ago. Photo: S. Elvevold

Garnet-mica schist with amphibolite layers in Ny-Friesland. The rocks were deformed and folded during the Caledonian orogeny. Photo: S. Elvevold

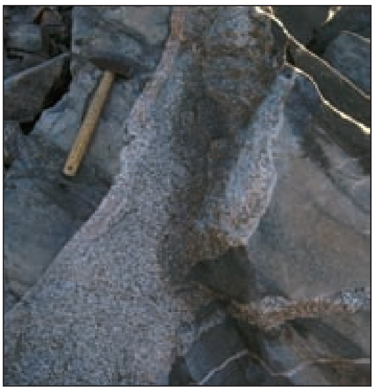
Nordaustlandet

In Nordaustlandet, the basement is exposed in the northern coastal areas and in an area between the two large Austfonna and Vestfonna ice caps. The basement east of Lady Franklinfjorden consists of granite, augen gneiss, migmatite and volcanic rocks. Various types of volcanic rocks, which formed 950 million years ago, are present at Botniahalvøya. The easily recognizable Rijpfjorden granite has intruded the east and southern shore of Rijpfjorden. Bedrock in contact with the intruding granite was heated and metamorphosed.

East of Duvefjorden, the major rock types are migmatite, gneiss and granite. Isispynten is a small but geologically interesting area where four generations of rocks are exposed. The oldest unit is a gneiss that is cut by amphibolite, which is itself intruded by granite and dolerite. The youngest rocks are pink granitic dikes that resemble the Rijpfjorden granite.



Garnet-mica schist, Ny-Friesland. Photo: S. Elvevold



Granitic dyke that has intruded a fine-grained, metamorphosed sandstone, Ny-Friesland. Photo: S. Elvevold

Proterozoic folded gneisses, Ny-Friesland. Photo: W. Dallmann

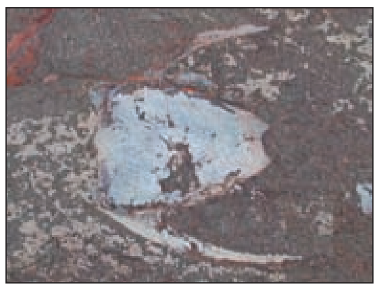
The sedimentary successions

The landscape around Woodfjorden is characterized by red-coloured Devonian sandstones. Erosion of the sediments produces fine-grained material that is transported by rivers into the fjord, colouring the water red, as seen in the inner part of Bockfjorden. Photo: W. Dallmann

When the Caledonian Orogeny ended in the Devonian, erosion of the mountain chain started. Huge quantities of sand, gravel and mud were deposited on alluvial plains and in the sea. Later during the Carboniferous and Permian, new depositional episodes formed limestone successions, and subsequently, during the Mesozoic and Tertiary until about 40 million years ago, sandstone–shale successions. The strata on Spitsbergen form a huge trough-shaped structure stretching from the Isfjorden area southwards, with the youngest and uppermost beds in the middle as a core and older ones along the margins.

Devonian

Large tracts of red and green-grey Devonian deposits are exposed in Andrée Land in northern Spitsbergen. The deposits, which are called the Old Red Sandstone, consist of silt- and sandstone and conglomerate alternating with small amounts of shale and carbonate rocks. The red colour is due to a high content of iron oxide (hematite)

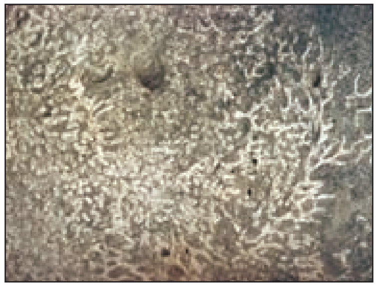


Fossil remains of an armour-plated fish from Devonian sandstones. These fossils have a characteristic bluish-grey colour.
Photo: A. Freiwald

and indicates deposition in periods of dry, desert-like climate. The succession was deposited in fresh or brackish water, lagoons or broad rivers. The Devonian beds were formed from material derived from the eroding Caledonian mountains.

The Devonian is called the Age of Fishes, and many fossils of primitive fish, the first known vertebrates, have been found in Svalbard. The first terrestrial plants evolved at this time as well. Fossils of primitive spore plants that grew on river plains and in shallow lakes are also found in Svalbard.

The gypsum layers in Skansbukta were test-mined twice early in the 20th century. Photo: D. Blomeier



Colonies of fossil corals are common fossils in Carboniferous limestone beds.
Photo: W. Dallmann

Carboniferous and Permian

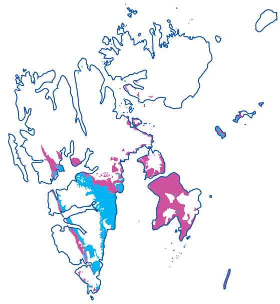
The plateau-shaped mountains in Tempelfjorden and Billefjorden and many other places in north-eastern Spitsbergen consist of Carboniferous and Permian deposits. The lowermost Carboniferous sandstones contain coal seams. The horizontal Carboniferous–Permian strata contain fossiliferous beds of lime- and dolostone with white layers of gypsum and anhydrite. The gypsum and anhydrite beds were formed in a warm and dry climate by evaporation of sulphate-bearing sea water.

Towards the end of the Permian, Svalbard and the Barents Sea became a land surface for some million years, and were still part of a continuous continent which included, among others, northern Europe, Greenland and North America.

The mountain Templet in the innermost part of Isfjorden consists of flat lying Permian sediments.
Photo: W. Dallmann

The Russian settlement Pyramiden mined coal from Lower Carboniferous sediments. The coal mine was abandoned in 1998. Photo: C. Brodersen


Triassic sedimentary rocks, folded, Hornsund. Photo: W. Dallmann


Triassic rocks are shown in red, whereas the blue colour represent areas with Jurassic and Cretaceous rocks.

Triassic, Jurassic and Cretaceous

Deposits from the Mesozoic indicate that the climate was largely temperate and damp. Svalbard was for the most part still covered by the sea, but periods of uplift resulted in alternating marine and terrestrial sedimentation. The rocks from this period are mostly shale, siltstone, sandstone, and seldom limestone. They are exposed in central and southern Spitsbergen and on the eastern islands.

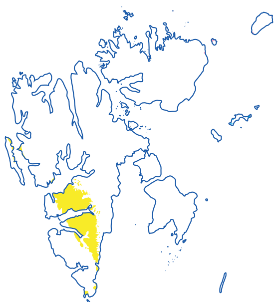
There was a rich animal and plant life during the Mesozoic with reptiles being particularly abundant, and this period is often called the Age of Reptiles. Marin reptiles like the swan-necked reptile lived in the Jurassic seas; whereas the dinosaur lived on land. There are also fossils of ammonites, bivalves and plant remains in the Mesozoic deposits. Triassic and Jurassic strata contain dark shales which are source rocks for oil. However, no economically profitable oil accumulations have been located in Svalbard.

At the beginning of the Cretaceous, the stable conditions in Svalbard were interrupted by a period of disturbance with volcanic activity and faulting. Magma intruded into fractures and bedding surfaces and crystallized in veins and dykes of dolerite. On Kong Karls Land, magma forced its way to the surface and solidified as dark basalt lava.


Dolerite (dark layer) forms a cap on top of the Permian carbonate rocks and protects the underlying sedimentary succession from erosion. Palanderbukta, Nordaustlandet. Photo: W. Dallmann

Cretaceous and Tertiary sandstones make up the bedrock on both sides of Adventfjorden. The sedimentary rocks generally show a horizontal stratification in this area. Photo: S. Elvevold

Tertiary



The plate movement that started at the end of Mesozoic culminated in the Early Tertiary time with formation of a new mountain belt along the west coast of Spitsbergen. The younger belt was much smaller than the older Caledonian mountain belt. Rocks of all ages underwent folding, and large sheets of rocks were thrust eastward («thrust sheets»). Thrust sheets formed at this time can be seen in many mountain sides in Wedel Jarlsberg Land and Oscar II Land. The movements may have been a result of the Greenlandic continental plate pressing towards Svalbard as Svalbard slid past the northern part of Greenland. This happened at the same time as the North Atlantic and Arctic Ocean formed by seafloor spreading.

East of the new mountain range, from the Isfjorden area southwards, the land subsided and formed a huge north–south trending bay. Sandstones and shales were deposited in this area which is called the Central Tertiary Basin. The deposits locally contain abundant plant fossils and host the majority of coal deposits that are worked in Longyearbyen, Sveagruva and Barentsburg.

In the mid-Tertiary, a new volcanic phase took place in the north Atlantic. Lava flows are preserved in Andrée Land, where the basalt lavas form hard protective caps on some of the highest peaks.

Quaternary

The climate became colder towards the end of the Tertiary. The Earth was entering a new Ice Age, and large parts of North America, North Europe, South America and Antarctica were covered by kilometre-thick ice sheets for long periods. Svalbard was also covered by a vast ice sheet. The interven-ing warmer periods lasted between 10 000 and 20 000 years and were characterized by a marginal Arctic climate and vegetation similar to the present type. Twenty to 30 ice ages, with warmer interglacial periods, have probably taken place during the last two to three million years.

There are traces of several glaciations in Svalbard. However, the glacial erosion during the last one removed most deposits and other traces of the former ones. With 60 % of the archipelago covered by glaciers, Svalbard is still in the grips of the Ice Age.

Plate tectonics

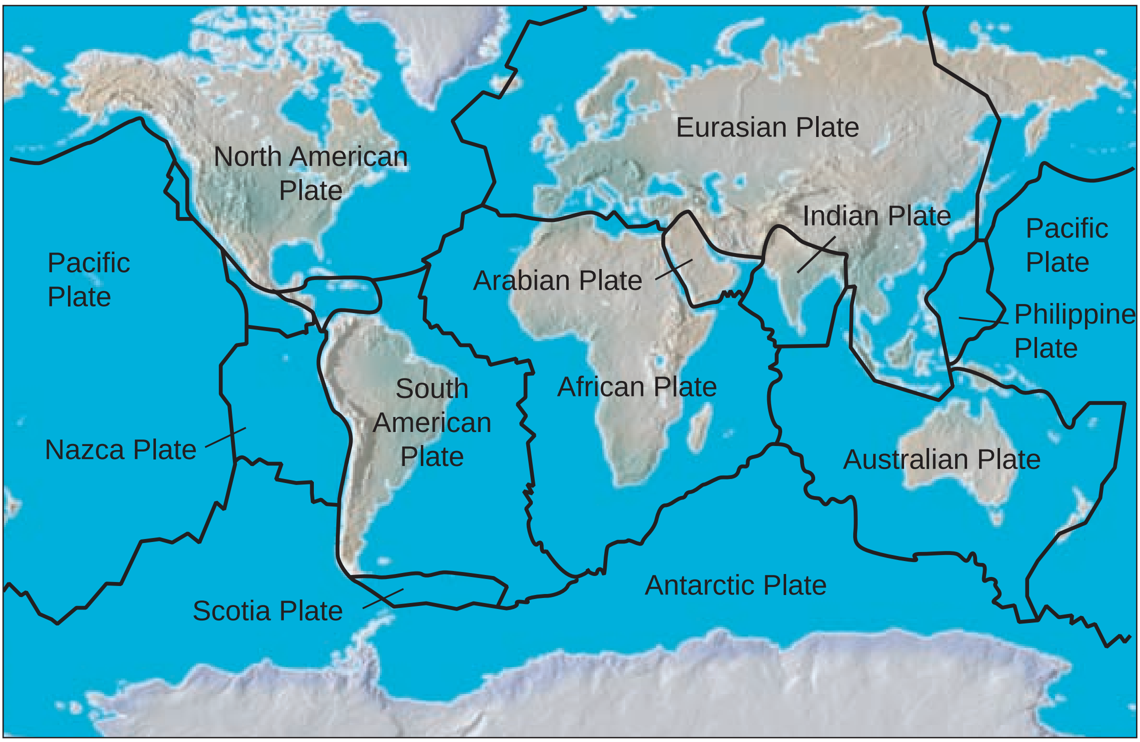
Continental drift

The Earth's crust is not a fixed rigid shell surrounding the interior. Rather, the crust and a little mantle form the lithosphere which is divided into seven larger and numerous smaller plates that move relative to each other. The plates, with both continents and ocean floors, are floating on a pliant, partially molten layer in the upper part of the mantle. The driving force for the plate motion is convective flow in the mantle. The theory describing the plate motion is called plate tectonics.

Modern plate tectonics started with the theory of continental drift that was suggested by the German meteorologist Alfred Wegener in 1915. Basing his idea on the near-parallel coastlines of Africa and South America on opposite sides of the South Atlantic, Wegener suggested that these now separate landmasses once were joined, and later drifted to their present position. Wegener had, however, no satisfactory explanation for the driving forces and the dynamics behind the plate motion. The hypothesis was therefore rejected and ridiculed by the vast majority of the scientific community at the time.

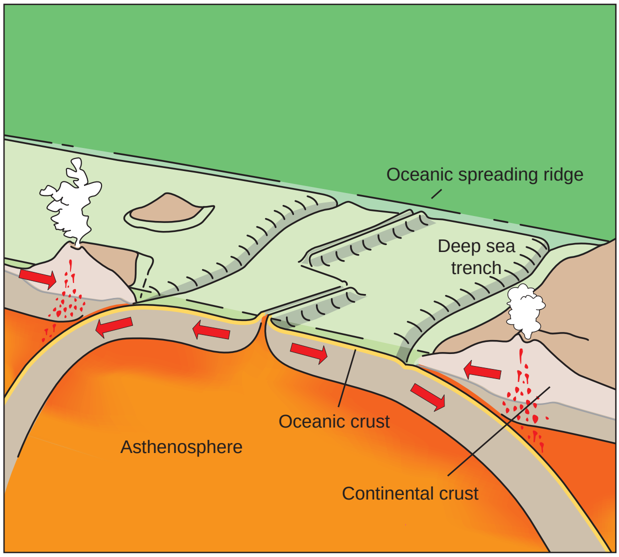
Mountain belts are formed and demolished

It was not until the 1960s that a good explanation for Wegener's observations began to emerge. Oceanographic exploration led to the discovery of a global oceanic ridge system. It was also recognized that new oceanic lithosphere is generated along the mid-ocean ridges. As the plates move away from the ridge axis, the deep fractures that are formed are filled with molten material that wells up from the hot mantle below. Gradually this magma cools to produce new slivers of seafloor. This process is called seafloor spreading. The Mid-Atlantic Ridge is a submerged structure positioned in the middle of the Atlantic. In the north Atlantic, the ridge separates the Eurasian plate from the North American plate at a spreading rate of 3-5 cm per year. Frequent, but relatively weak, earthquakes and volcanic activity occur along the mid-ocean ridges.



The crust is divided into several larger and smaller plates. Geological phenomena such as earthquakes and volcanism predominantly occur along the plate boundaries. Fig.: A. Igesund

New oceanic crust is constantly being produced at the mid-ocean ridges. Because the volume and the total surface area of the planet remains constant, older portions of lithosphere is destroyed along plate boundaries. Whenever an oceanic plate converges with a continental plate, the buoyant continental block remains floating, while the denser oceanic slab sinks into the mantle. This type of plate boundary is characterized by frequent and strong earthquakes. Volcanic activity is also typical of these areas due to melting of the descending oceanic plate. The volcanic activity along the margins of the Pacific Ocean is known as the "Ring of Fire". Convergence can also result in the collision of two continental plates. These plate boundaries are characterized by strong earthquakes. During collision, the crust is strongly buckled, folded and metamorphosed and large mountain ranges are produced. A modern example is the ongoing collision of India and Asia, which has formed the spectacular Himalayas.



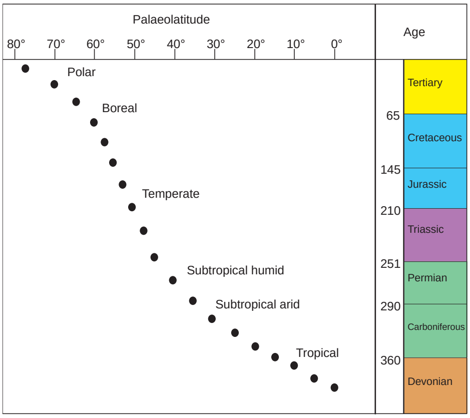
The outer crustal layer with spreading ridges and subduction zones.
Fig.: A. Igesund

Folding and faulting has produced the complex pattern seen in this mountainside at Midterhuken. Photo: W. Dallmann

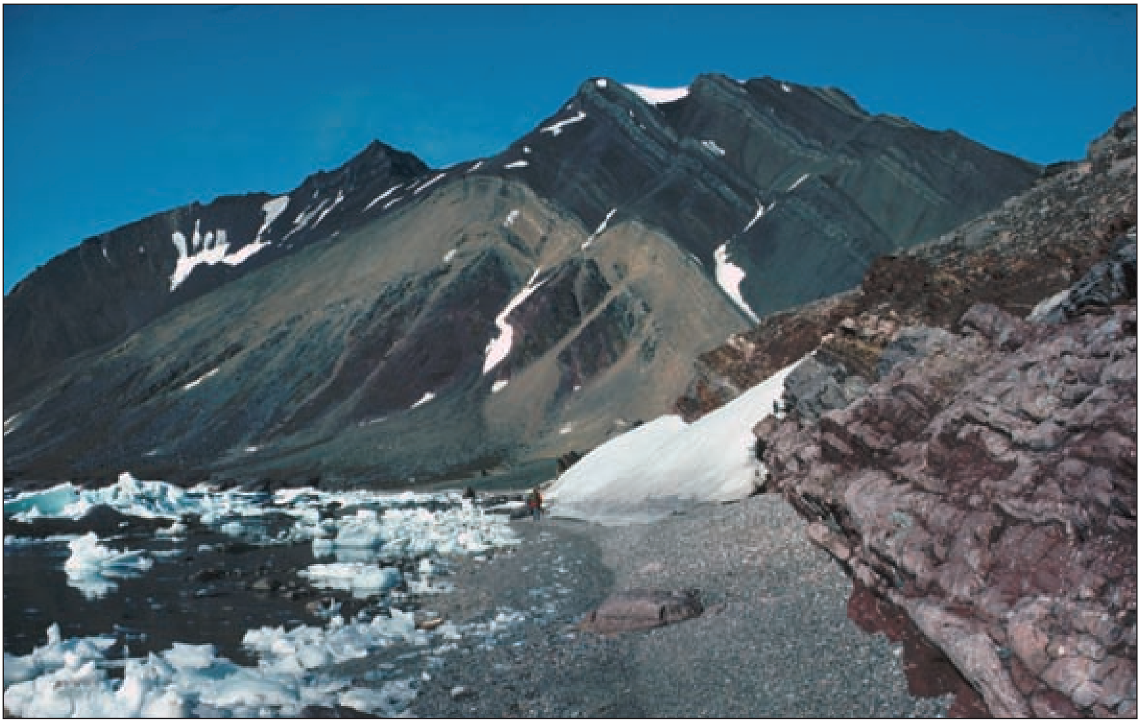
Mountain belts in Svalbard

Svalbard is located in the north-western corner of the Eurasian plate. The deep ocean is situated west of the archipelago, and the North Atlantic mid-ocean ridge separates Svalbard from Greenland.

For a long time (from the Devonian to the Cretaceous), Svalbard was part of the large Old Red continent which included North America, Greenland and Eurasia. North-east Greenland was situated some hundred kilometres off Svalbard, and for long periods Svalbard and north-east Greenland were submerged beneath a shallow ocean. At the transition between the Cretaceous and the Tertiary, the North American and the Eurasian plate started to drift apart. During the first rift phase, while Svalbard and the Barents Shelf slid past one another, the Greenland continental plate was pressed obliquely against Svalbard. These movements resulted in intense folding and thrusting, and the sharp, jagged peaks along the west



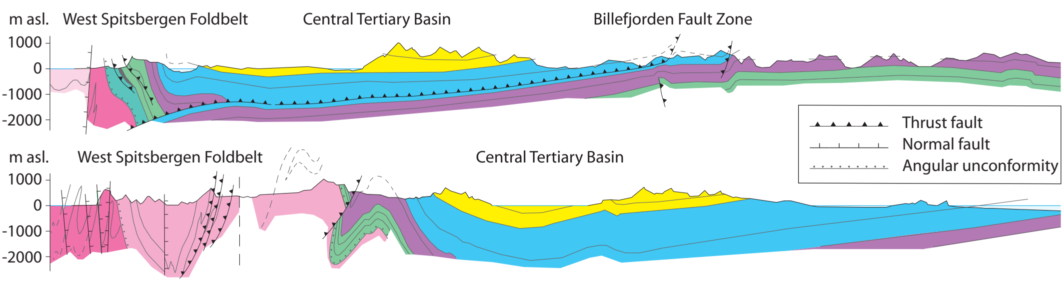
The Devonian to Tertiary succession in Svalbard reflects a voyage through all climatic zones. The conditions around the Devonian/Carboniferous boundary (about 360 million years ago) were tropical. Deposits of late Carboniferous/Permian age indicate a subtropical arid climate, whereas there must have been moderate climatic conditions in the Mesozoic. These climatic changes are due to the movement of Svalbard, which is located in the north-western corner of the Eurasian plate, from the Southern Hemisphere through the equatorial zone further northwards to its present arctic position. Fig.: S. Elvevold



Folded sedimentary rocks in Hornsund. The Carboniferous to Triassic layers were folded during the Tertiary deformation event. Photo: W. Dallmann coast of Spitsbergen were formed. This mountain range, the so-called Tertiary fold-and-thrust belt, is the youngest mountain range in Svalbard.

The older Caledonian mountain range formed 470-400 million years ago, when the North American plate (Laurentia) collided with the North European plate (Baltica). During collision, continental crust on both sides of the collision zone was compressed and folded, and large sheets of rocks were thrust on top of each other. The continental crust was thickened in the collision zone, and some rocks were buried to great depths where they were metamorphosed (altered) at high pressures and temperatures. Remnants of the Caledonian mountain range are present in Svalbard, mainland Norway, Scotland and East Greenland.

Folding of Triassic sandstones and shales within the Tertiary West Spitsbergen fold belt, Midter-huken. Photo: J.R. Eide



Schematic west–east cross sections through Spitsbergen: The upper profile shows a geologic cross section immediately south of Isfjorden. The lower profile shows a section from Dunderbukta to Kvalvågen. The colours correspond to the stratigraphy of the geological map on page 34. The profiles demonstrate that the west coast of Spitsbergen consists of basement rocks and Carboniferous, Permian, Triassic, Jurassic and Cretaceous strata that are folded and thrust into sheets on top of each other. The rocks dip steeply within the fold belt. Horizontal Tertiary strata in the Central Basin lie east of the fold belt. Fig.: W. Dallmann

Fossils

Impressions of leaves. Beautiful fossil leaves from deciduous trees are commonly found in Tertiary sandstones around Isfjorden. Tertiary plants resemble present-day plants rather than Cretaceous or older plants. D. Blomeier

Tropical plant fossils, 300-400 million years old, occur in Svalbard. Through the study of fossils, scientists have been able to partly reconstruct the evolution of life on Earth through the last three billion years. The greater part of the fossils are from the Cambrian and later eras, i.e. younger than 542 million years.

Fossils provide evidence for changes in climate and habitats. Fossils are also important time indicators. For example, we know that dinosaurs were plentiful on Earth in the Mesozoic, i.e. the Triassic, the Jurassic and the Cretaceous. When the remains of a dinosaur are found in a rock, the rock must be of Mesozoic age. Other fossils are characteristic of other eras. Fossils that are widespread geographically and are limited to a short span of geologic time are called index fossils.

Fossils from all periods from the Cambrian to the present are found in Svalbard, and in the sediments submerged in the North Sea, the Norwegian Sea and the Barents Sea.

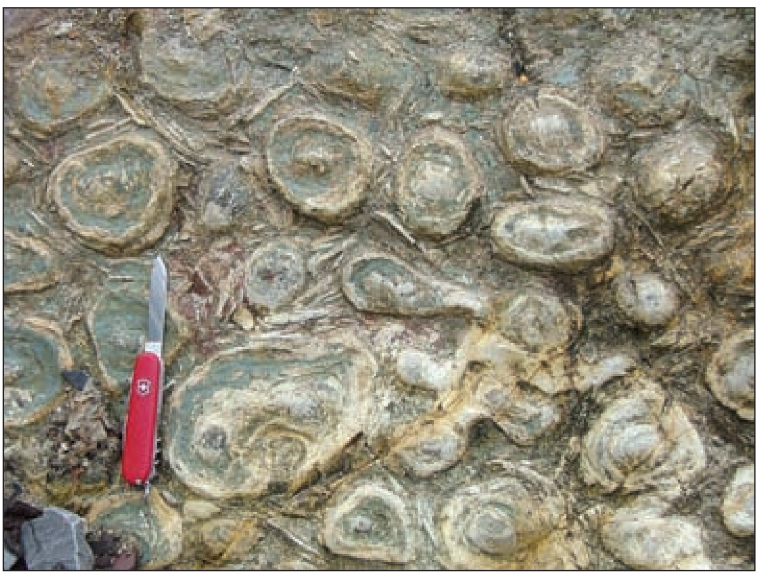
The oldest fossils in Svalbard are stromatolites, which are fossil colonies of algae. Stromatolites are found in dolostone from the Precambrian.

Trilobites (*Trilobita*) were particularly numerous in Cambrian and Ordovician times. They are articulated animals that lived on the seafloor. Many species are good index fossils including graptolites (*Graptoloidea*) which were colonial animals living in the sea and now found in Cambrian and Ordovician rocks.

The Devonian is often referred to as the Age of Fishes and fossils of two principal groups of primeval fish have been found in Svalbard. The jawless fishes (*Agnatha*) declined at the end of the Devonian, whereas the jawed fishes (*Gnathostomata*) continued as the precursor to vertebrates. The latter group comprises the cartilaginous fishes, which today are represented by sharks and rays, armoured fishes (*Placodermata*), and bony fishes. Bony fishes were the precursor to the majority of modern fishes as well as the lobe-finned fishes which may be the ancestor of land vertebrates. Fish bones and teeth are found in beds from other eras such as the Triassic.

Plants evolved rapidly in the Carboniferous and the Devonian. Primitive plants are found in Devonian deposits. Forests of tall spore plants (the precursor to ferns, club moss and horsetails) were present in Svalbard, which at that time was part of a continent that also included Europe and North America. These forests gave rise to some of the coal deposits in Svalbard. Typical fossils are trunks of *Sigillaria*, a tall, tree-like plant.

Lamp-shells (*Brachiopoda*) are two-shelled marine animals with an external morphology like that of bivalves. Brachiopods are common fossils throughout the Palaeozoic; particularly good examples are present in the Carboniferous and Permian rocks in Svalbard. Upper Permian beds contain well preserved siliceous sponges (*Silicispongiae*) and moss animals (*Bryozoa*).



The oldest fossils in Svalbard are stromatolites. Fossil stromatolite is composed of carbonate deposited by algae. Photo: W. Dallmann

Facts

What are fossils?
Fossils are remains, tracks or impressions of prehistoric organisms that are preserved in sedimentary rocks or in unconsolidated deposits. Fossils include shells, bones, plant remains, impressions or traces of activities such as footprints, wormholes and excrement. Plants are rarely preserved in their entirety, although impressions and carbonized remains of leaves and stems can be found.

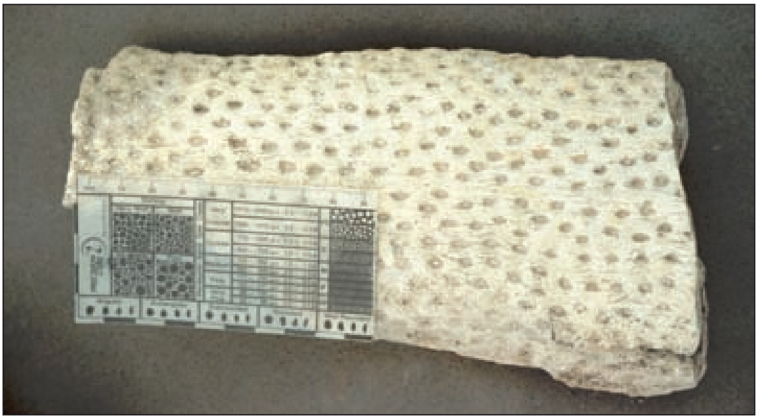
Facts

Lamp-shells (*Brachiopoda*). Photo: B. Frantzen

The Mesozoic is the age of molluscs (*Mollusca*). Ammonites (*Ammonoidea*) were particularly numerous in Jurassic and Cretaceous times. They are excellent index fossils and it is often possible to link the rock layer in which they are found to specific geological time periods. The fossil shells usually take the form of flat spirals.

The Mesozoic was also the age of the dinosaurs. Some of these reptiles had awesome dimensions. For the most part, the dinosaurs were land animals, but some reptiles took to the skies and others lived in the sea. In Svalbard, skeletons of the swan-necked reptile (*Plesiosaurus*) and fish reptiles (*Ichtyosaurus*) are found, in addition to footprints of other species. Fossil dinosaur footprints were found in Grønfjorden in the Isfjorden area in 1960. The three-toed foot imprints found were ca. 75 cm long and the tracks were made by a closely related, unknown relative to the dinosaur Iguanodon.

Finally, bivalves (*Bivalvia* or *Lamellibranchia*) form an important group of fossils that occurs throughout the more recent geological history. Clams from the Ice Age and the following period are of special scientific interest because they can be used as climatic indicators.



Fossil *Sigillaria* tree-trunk found in Carboniferous strata from the eastern part of Spitsbergen. Photo: D. Blomeier

Recently found in Triassic sediments on the northern side of Isfjorden, fossil remains of a marine reptile that was probably 10 m long in life. Photo: J. Ziegler

Volcanoes and hot springs

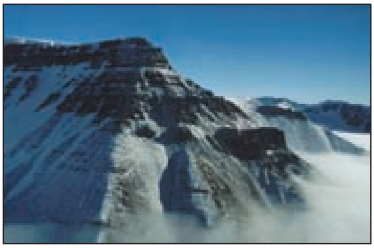
Halvdanpiggen is a remnant of a volcanic pipe. The volcanic rocks are surrounded by red, Devonian sandstones. Photo: W. Dallmann

Throughout the history of Svalbard, there have been several phases of volcanic activity. Metamorphosed lava and other volcanic rocks are present in the Precambrian basement. Deformed remnants after volcanic complexes occur between Hornsund and Torellbreen (west Spitsbergen) and on Botniahalvøya (Nordaustlandet). It takes experience to identify the older metamorphosed, deformed and eroded volcanic rocks. There are, however, younger volcanic rocks in Svalbard that are easier to recognize.

Dark massive dolorite sills

When moving through the sedimentary package of Svalbard, particularly in the inner part of Isfjorden, around Storfjorden and Hinlopenstretet, one can often see dark, massive beds between the sedimentary layers. The dark layers vary from a few dm up to several tens of metres in thickness. For the most part they occur parallel to the sedimentary beds, but in places they cut vertically through the layering and they may also ramify. These rocks are dolerites. The difference between basalt lava and dolerite is that lava flows solidify at the surface, whereas dolerite forms from magma that penetrates into fissures in the host rock and solidifies at relatively shallow depths.

The dark, horizontal-trending bands are sills of dolerite that intruded parallel to the horizontal layers of whitish limestone, Lomfjorden. Photo: D. Blomeier



Tertiary lava flows within the upper part of the mountain overlying Devonian sedimentary rocks, Woodfjorden. Photo: W. Dallmann

Columnar jointing in basalt, Kong Karls Land. Photo: G. B. Larsen

In Kong Karls Land magma forced its way to the surface and solidified as dark basaltic lava. The lava occurs at mountain tops and often displays distinct hexagonal columnar jointing. Columnar joints are common in basalt and form as magma cools and develop shrinkage fractures.

The rocks described above formed in the Jurassic–Cretaceous when Svalbard was stretched as the rift that led to the opening of the Atlantic was formed (see chapter on "plate tectonics").

Volcanism in Andrée Land

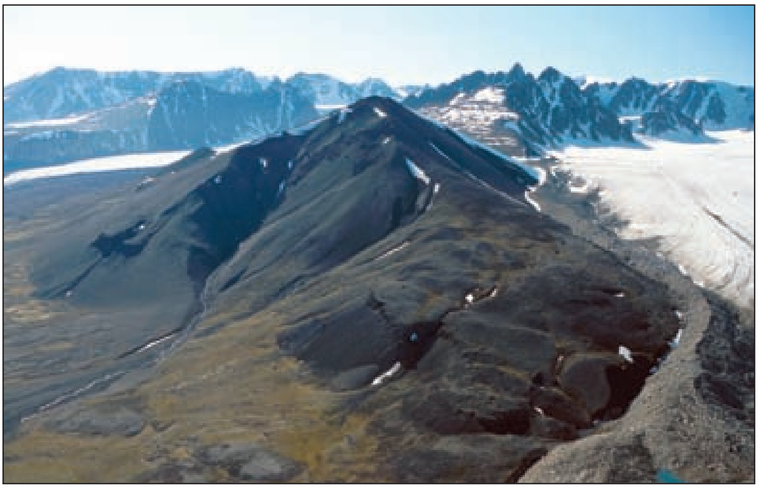
Large areas of reddish brown sandstones occur in the area between Dicksonfjorden, Woodfjorden and Wijdefjorden in northern Spitsbergen. Several peaks in this distinctive landscape are covered by lavas that are up to 400 m thick. The lava flowed out across a large area, filling existing valleys and low-lying areas 25-10 millions years ago. The land later rose, became tilted, and new valleys were formed. The remnants of the basalt form hard protective caps on some of the highest peaks. Up to 20 lava flows are recorded and some lavas display columnar jointing.

Volcanic ruins in Bockfjorden

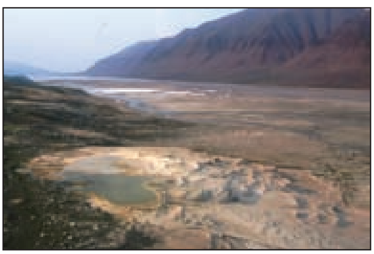
The last volcanic activity took place during the glacial periods, probably between a million and 100 000 years ago. The volcanic activity developed in north-western Spitsbergen in the area around Bockfjorden. This Quaternary activity and the Tertiary volcanism are related to a so-called "hot spot" lying north of north-west Spitsbergen.

Remnants of Quaternary volcanoes are present at Sverrefjellet (506 m), south of Bockfjorden. The cone shape of Sverrefjellet resembles that of a present-day volcano, although the volcano underwent glacial erosion during the Ice Age. Lava, volcanic ash and remnants of volcanic pipes can be recognized. Several thermal springs recording temperatures up to 24°C occur near Sverrefjellet. Trollkjeldene south of Bockfjorden show well-developed sinter terraces of carbonate.

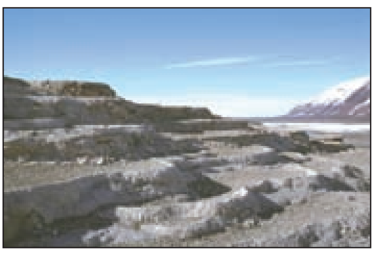
Halvdanpiggen, situated between Bockfjorden and Woodfjorden, is a ruin of a volcanic pipe. The peak gives shelter to a sea bird colony.



Sverrefjellet in Bockfjorden is made up of remnants of a volcano that formed in the Quaternary. Photo: W. Dallmann



Thermal springs, Trollkjeldene. Photo: S. Elvevold



The sinter terraces at Trollkjeldene consist of carbonate deposited from the thermal springs. Photo: W. Dallmann

The Ice Age

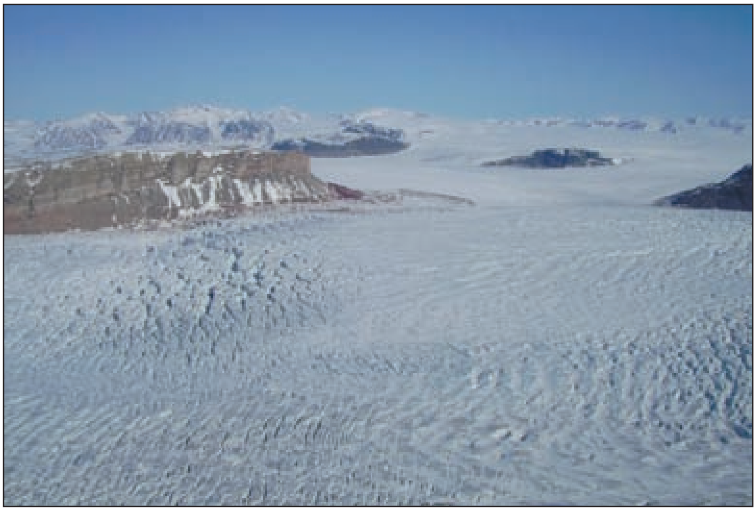
The landscape in Svalbard, as we see it today, was largely formed during the Quaternary, the period that includes the present. When the Quaternary began, Svalbard and the floor of the Barents Sea were several hundred metres higher than now. The landmass stretched from Svalbard to Norway and northern Russia. Svalbard was located in the polar region throughout the Quaternary, and the area was covered by inland ice several times. Unconsolidated deposits formed during and after the last Ice Age are moraines, fluvial deposits, beach deposits, talus and block fields.

Emerging from the sea – shoreline features

Svalbard was covered except for a few mountain peaks, by a vast ice sheet at least once during the Quaternary. The ice sheet was thickest near Kong Karls Land in eastern Svalbard. As on the Scandinavian Peninsula, the land was pressed down by the ice load, with the greatest depression where the ice was thickest. When the climate became milder, the ice melted and the land rose up again. Kong Karls Land for instance, has risen approximately 130 m relative to sea level after the ice sheet disappeared approximately 10,000 years ago. A series of raised beaches with shorelines formed during this period. Shorelines are formed when the sea level remains stable and marine erosion is allowed to shape the coast over some period of time. The two most common features formed in the tidal zone are beach terraces and beach ridges. A few beach terraces in Svalbard contain shells such as common mussels which required warmer water than is found today. Studies of pollen demonstrate that the climate during some periods after the last Ice Age was milder than today.

Permafrost

Except from the sea shore, the ground is permanently frozen in the ice-free areas of Svalbard. The thickness of the permafrost varies from absent close to the sea, up to 500 m in higher areas. In most places, the uppermost soil layers only thaw down to between 1 and 1.5 m in the summer. The permafrost has a significant influence on the surface processes. Because of poor drainage, melt water will accumulate in the thin surface layer that thaws in summer, thus favouring mudflows and rock slides.



Kronebreen. Photo: O. Brandt

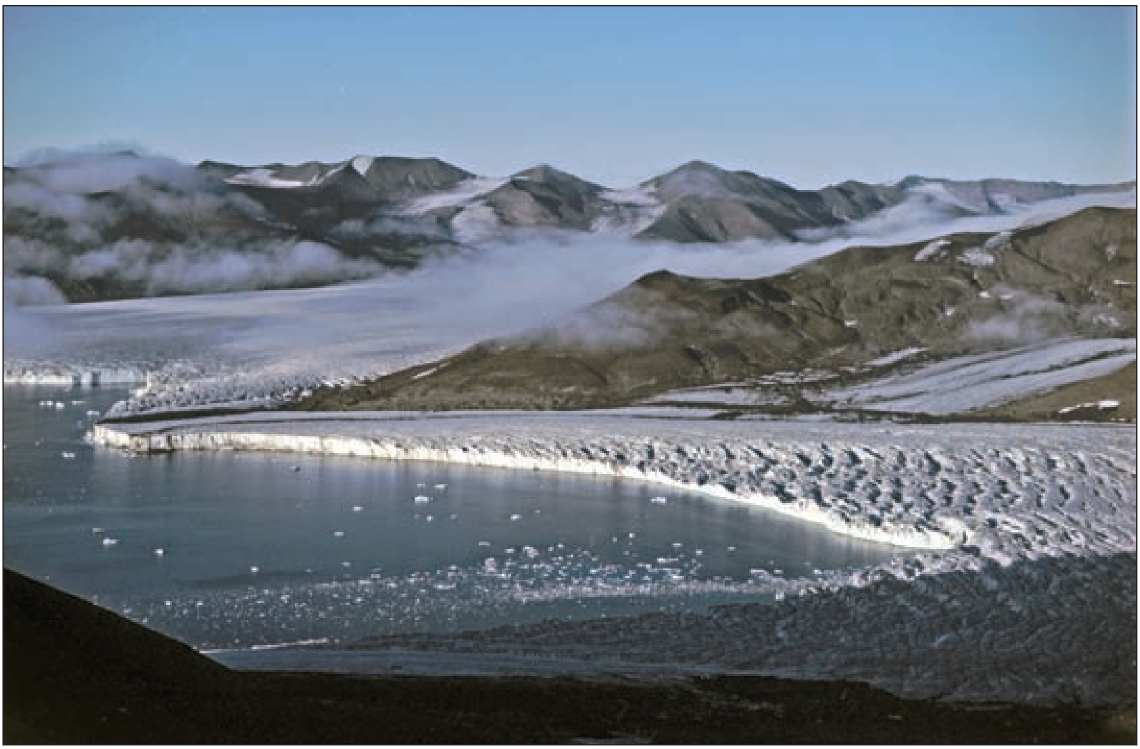
Air photo of Gipsvika, Sassenfjorden, shows raised shorelines. The colours are filtered such that areas with vegetation appear as orange.

Glaciers

About 60 % of the land area of Svalbard is covered by glaciers. These are particularly extensive in the north-east, Austfonna on Nordaustlandet being the largest. There are areas that are almost ice-free in the west where warm waters of the final branch of the Gulf Stream make their presence felt and mild air currents from the south meet land.

Most glaciers in Svalbard have retreated during the last hundred years. Many glaciers in Svalbard show a spectacular pattern of movement in which the ice movement suddenly can increase several hundred times its normal speed. Consequently, the glacier front may advance several kilometres in 1-3 years. This type of rapid advance is called a surge. Several surge-type glaciers have been documented in Svalbard.

Photo: D. Blomeier



Svalbard is still in the Ice Age. Sixty percent of the land is still covered by ice. Brepollen, inner part of Hornsund, is surrounded by several wide glaciers that terminate in the sea and have active calving cliff faces. Photo: W. Dallmann

Landforms

Photo: S. Elvevold.

Svalbard has beautiful mountains and spectacular landscapes. The west and north-west coasts of Spitsbergen are characterized by alpine landforms with steep, sharp peaks, whereas the mountains in the central parts of Spitsbergen are commonly plateau-shaped. The landforms depend mainly on the composition and the structural framework of the bedrock. Alpine landscapes are formed in basement areas that are composed of resistant, hard rock types such as gneisses and granites. Mountains built of horizontal beds are often flat-topped, for instance Templet in Isfjorden. If erosion proceeds far enough, pyramidal peaks may form, such as Tre Kroner east of Ny-Ålesund. Poorly consolidated rocks result in gently-sloping scree slopes, whereas steep cliffs form in hard rocks. The plateau-shaped mountains are often separated from each other by broad and flat valleys formed by glacial erosion. Smaller valleys are V-shaped and are formed by fast-moving water.

Landforms associated with glaciers

Glaciers have been very active in shaping the land surface in Svalbard. The work of the ice can be seen everywhere. Erratics are boulders transported by glaciers. When the glacier melts, the boulders may end up a great distance from their place of origin. When the ice at the bottom of the glacier contains fragments of rocks, long scratches and grooves called striations may be gouged into the bedrock. The debris that is picked up and transported by a glacier is deposited in moraines. There are different types of moraines, e.g. terminal moraine, lateral moraine, push moraine and medial moraine. Debris like mud, sand and gravel may be deposited from glacial streams below, within or on top of the glacier. Sandur (from Icelandic) consists of glacial debris deposited on a plain in front of the glacier. Where glacial melt water flow into water or the sea, sediments are deposited in a delta.

Landforms associated with permafrost

Pingos are rounded or conical mounds, up to about 50 m high, of mineral soil containing a core of ice. They form when groundwater under pressure forces its way along zones of weakness in frozen layers of earth. About 80 pingos have been registered in Svalbard, many of them are found in the large valleys of central Spitsbergen (Adventdalen, Reindalen and Kjellströmdalen).

Patterned ground is a pattern on the surface of soil, sand or gravel in the form of more or less continuous rows or rings of stones or ice-filled cracks. The rings are generally irregular but circular in shape. However, distinct hexagons are sometimes seen. Patterned ground is found in nearly all ice-free areas in Svalbard.

Tre Kroner viewed from Ny-Ålesund. The gentle slopes consist of red, Devonian sandstones, whereas the light pyramidal peaks consist of Carboniferous limestone. Photo: W. Dallmann

Medial moraine forms when two glaciers coalesce to form a single ice stream. Photo: W. Dallmann

Glacial deposits, Motalafjella. Photo: S. Elvevold

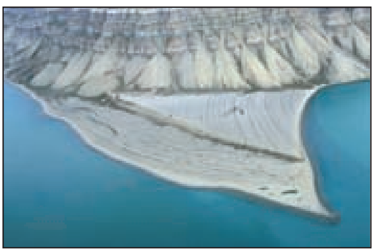
The mountains in Svalbard are intensively frost-eroded and often have extensive scree slopes or talus cones. Block fields are formed on gentle slopes and mountain plateaus where stones loosened by frost do not slide downhill. Hard rock types produce large, sharp-edged stones, whereas soft shales, for instance, disintegrate to produce mineral soil.

Rock glaciers are common in areas of permafrost and usually form because stones in talus slopes slide downwards through the influence of their own weight and repeated freezing and thawing of the water in the scree.

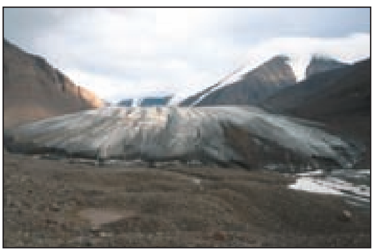
Pingo in Reindalen. Photo: W. Dallmann

Erratic block is a piece of rock that has been carried by ice some distance from the rock outcrop from which it came. Photo: W. Dallmann

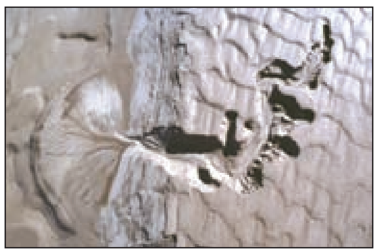
Patterned ground made up of rings of stones. Photo: O. Salvigsen



Shoreline terraces, Tempelfjorden. Photo: D. Blomeier



Moraine formed at the terminus of a glacier. Photo: W. Dallmann



Small-scale sedimentary processes can produce structures that resemble large landforms. The picture, which is 25 cm across, shows how erosion has formed a little canyon (to the right) and the eroded material is deposited in a delta below (to the left). Photo: D. Blomeier

Coal

The cable-car was used for the transport of the coal from the mines to Longyearbyen and to the harbour.
Photo: Norwegian Polar Institute

In 1899, Søren Zachariassen, the skipper of a sealing vessel, returned to the mainland with about 6 m3 of good quality coal from the Isfjorden district. In the following years, people became aware that large coal deposits were to be found in Svalbard and serious interest for coal and mineral deposits in Svalbard was aroused. Since 1906, Longyearbyen has had many working mines. The first mining companies were American owned but Store Norske Spitsbergen Kulkompani has operated the mines since 1916.

The Sveagruva mine is located in the inner part of Van Mijenfjorden. Photo: S. Gerland

Coal from fern forests

During the transition from the Devonian to the Carboniferous, about 360 million years ago, the crust that later became Svalbard and the Barents Sea was situated in the tropical zone north of the equator. In the beginning of the Carboniferous, the land sank and the sea began flooding the land.

The flooded land formed areas of shallow water, extensive tidal flats, and river plains with braided streams. Gradually, luxuriant swamp vegetation formed on the plains. In the Carboniferous there were mostly spore plants, which are the ancestors to ferns, and club moss and horsetails found today. The Carboniferous plants were much larger with heights of 10-30 m not unusual.

The swamps were periodically flooded, like the mangrove swamps today, and large areas were submerged under the sea. Plant remains from the swamps were buried below large quantities of mud and sand and the layers of organic material were gradually converted to coal seams.

Profitable coal from the Carboniferous is found in the northern part of Billefjorden. The Scottish Edinburgh expedition made an attempt to mine the coal at Brucebyen in the early 1900s. However, only the Russian mine in Pyramiden has been productive over a longer period of time, even though the mine is situated in a structurally very difficult position. The mine that was abandoned in 1998 produced around 9 million tonnes of coal since the end of the Second World War.

Modern coal mining in the Sveagruva mine.
Photo: A. Taurisano

Coal from deciduous forests

In the beginning of the Tertiary, about 65 million years ago, the conditions were quite different from those in the Carboniferous. Svalbard was situated around 60 degrees north but the Earth's climate was generally warmer. Deciduous trees dominated the woods, making forests similar to those of Central Europe today.

As described above (see chapter on "The sedimentary successions") the Central Tertiary Basin formed in Early Tertiary. It appeared as low-lying flatlands with forests, bogs and rivers that were periodically flooded.

Decayed organic material from the swamped vegetation was buried below large quantities of debris that was transported by rivers from the highland to the north and east. This material lead to formation of the coal seams that are, or have been, worked in Longyearbyen, Grumantbyen, Barentsburg, Sveagruva and Ny-Ålesund.

Today coal is being worked in the Russian settlement of Barentsburg and the Norwegian mines in Longyearbyen and Sveagruva. Founded in 1932, Barentsburg has produced up to 250 000 tonnes per year. The profitability of the operation has decreased in recent years. Since 1906, several mines have been worked around Longyearbyen. The total production of the mines in this area is ca. 22 million tonnes. Only Mine 7 is being operated today (2007). The mines run parallel to the coal seams, which dip 1-2 degrees. The Svea Nord mine lies in the Central Field, the largest coal deposit in Svalbard. Store Norske calculates that 32 millions tonnes are commercially viable in Svea Nord, whereas the entire field is estimated to contain 72.5 million tonnes of coal. The coal seams in the Central Field range from 3 to 5.5 m thick, which means extremely effective coal production.

Facts

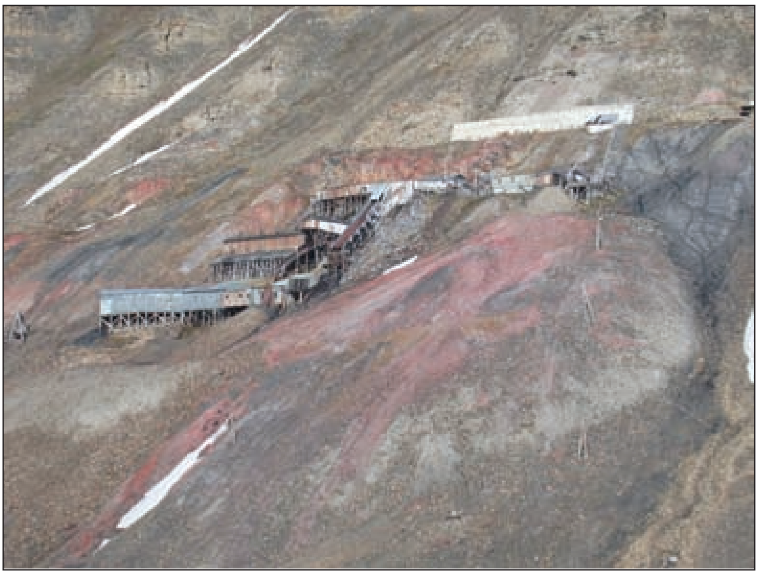
Facts about coal

Coal is a combustible, carbon-rich rock formed from peat and other plant remains. Coal is subdivided into brown coal, bituminous coal and anthracite. Coal should contain at least 55 wt % carbon. The coal in Svalbard is classified as bituminous coal and contains 75-90% carbon.

Natural coal occurs as lenses, pockets or layers in sedimentary rocks. The layers, also called coal seams, can be several metres thick. For coal seams to be profitable, they need to have a certain lateral extent, thickness and location that make mining and quarrying profitable in relation to infrastructure and the price of coal.

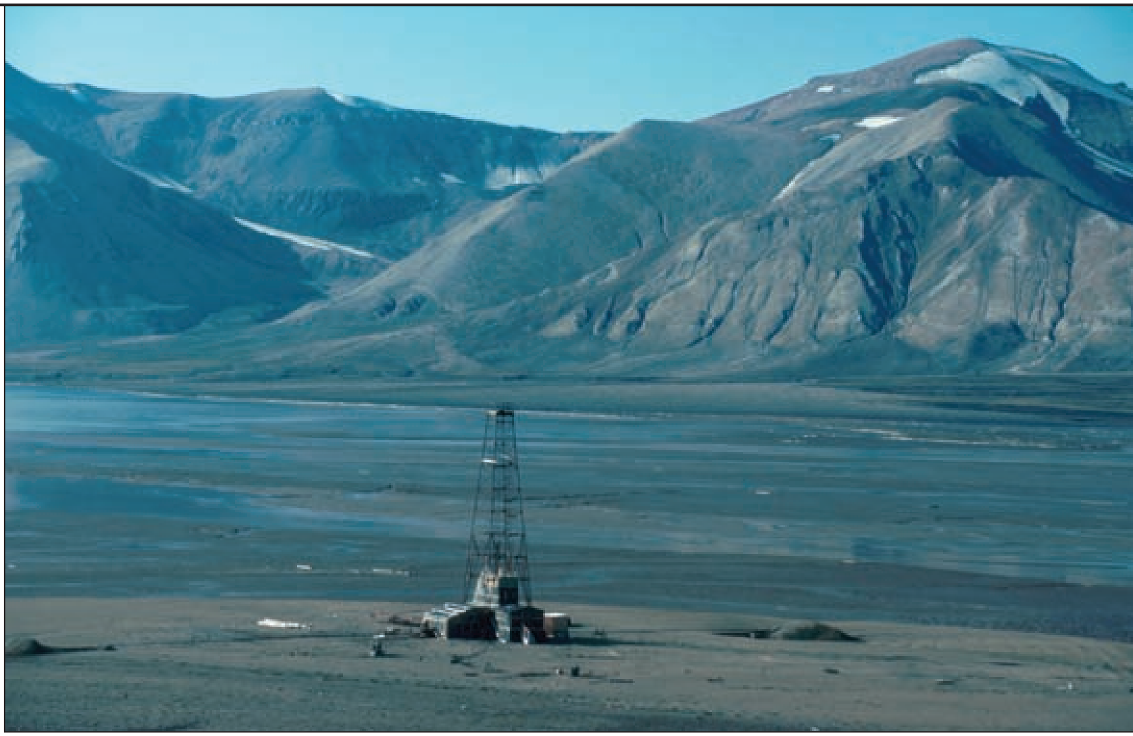
Coal is formed from peat or other partly altered plant material. The gradual process of "coalification" takes place over millions of years during burial, compaction, and weak heating in the absence of oxygen.

Facts



Abandoned mine (Mine 2) in Longyearbyen. Photo: D. Blomeier

Oil and natural gas



Russian rig in Billefjorden. Coal drilling in 1991 resulted in gas blow-outs and small amounts of oil came up to the surface. Photo: W. Dallmann

Oil and natural gas are biological products derived from the remains of plants and animals. Mudstone and shale may contain large quantities of organic matter. The most important source rocks on the Norwegian continental shelf are Jurassic shales rich in organic material. Certain beds in Permian and Mesozoic rocks in Svalbard are rich in organic matter and are potential source rocks for hydrocarbons. The structural framework of Svalbard has resulted in many possible oil traps. However, no economically profitable oil or gas accumulations have yet been located.

Petroleum and gas prospecting in Svalbard started in the early 1960s. The first bore hole, which was 972 m deep, was drilled by Norsk Polar Navigasjon AS in the Grønfjorden area. The company later carried out exploratory drilling in Berzeliusdalen by Van Mijenfjorden. Many companies, including Caltex Group, Fina Group, Nordisk Polarinvest, the Russian mining company Trust Arktikugol, Store Norske Grubekompani and Norsk Hydro, have since been conducting investigations. In total, 16 holes have been drilled. Most of them were drilled in Nordenskiöld Land (central Spitsbergen), but several were placed at Forlandsundet, on Edgeøya and on Hopen. Seismic surveys have been undertaken along the fiords and glaciers. The deepest drill hole at Ishøgda in Van Mijenfjorden reached about 3300 m depth. The last bore hole was drilled at Kapp Laila in Colesbukta in 1994.

Drilling results have repeatedly shown that the potential source rocks have too high of an organic grade of maturation and that the porosity of potential reservoir rocks is too low. Any mobile oil is restricted to relatively insignificant fracture systems.

In 1991, Trust Arktikugol hit a petroleum bearing bed at 630 metres depth when drilling for coal in Petuniabukta, Billefjorden. There were gas blow-outs in two bore holes, and a small amount of oil came up to the surface. As of 2007, plans for systematic petroleum exploration have not been realized.

Geology and environmental protection

Environmental protection is an important issue in Svalbard. As early as 1973, a network of national parks, nature reserves and bird sanctuaries was established covering large parts of Svalbard outside central Spitsbergen. Additional protected areas were established in 2002-2005. Today approximately 65 % of Svalbard's land area has some sort of protected status. However, non-motorized traffic and outdoor activities are permitted in most places – except for Kong Karls Land, where access is generally prohibited because the islands are a unique denning area for polar bears. Access is also prohibited to bird sanctuaries and the island of Moffen (because of its walruses) during certain parts of the year.

The Festningen Geotope Protection Area was established on the south side of Isfjorden in 2003 to preserve an area with valuable geological features of special scientific interest. The area provides a complete and well-investigated geological reference section – the Festningen Section, unique permafrost features and fossil dinosaur footprints. Many other protected areas also include valuable geological localities.

In 2002 the Svalbard Environmental Law came into force. All sorts of large impacts on the landscape in the entire Svalbard area are restricted by this law. It is permitted to collect rocks and minerals, either as souvenirs or scientific samples. It is not allowed to collect fossils within the protected areas of 1973 and in the Hopen and Bjørnøya nature reserves. Visitors must inform the Governor or the Norwegian Polar Institute about findings of special scientific value.

Some important regulations

All travel in Svalbard must be conducted in a way that does not damage, pollute or in any other way degrade the natural or cultural environment or lead to unnecessary disturbance of humans or animals.

Individual travellers who are not residents but wish to travel on their own in Svalbard are obliged to submit a report when leaving management area 10 (the area from Van Mijenfjorden to Isfjorden in central Spitsbergen). For trips on land outside a 20 km range from Ny-Ålesund or boat trips out of Kongsfjorden, tourists and other travellers are also obliged to submit a report.

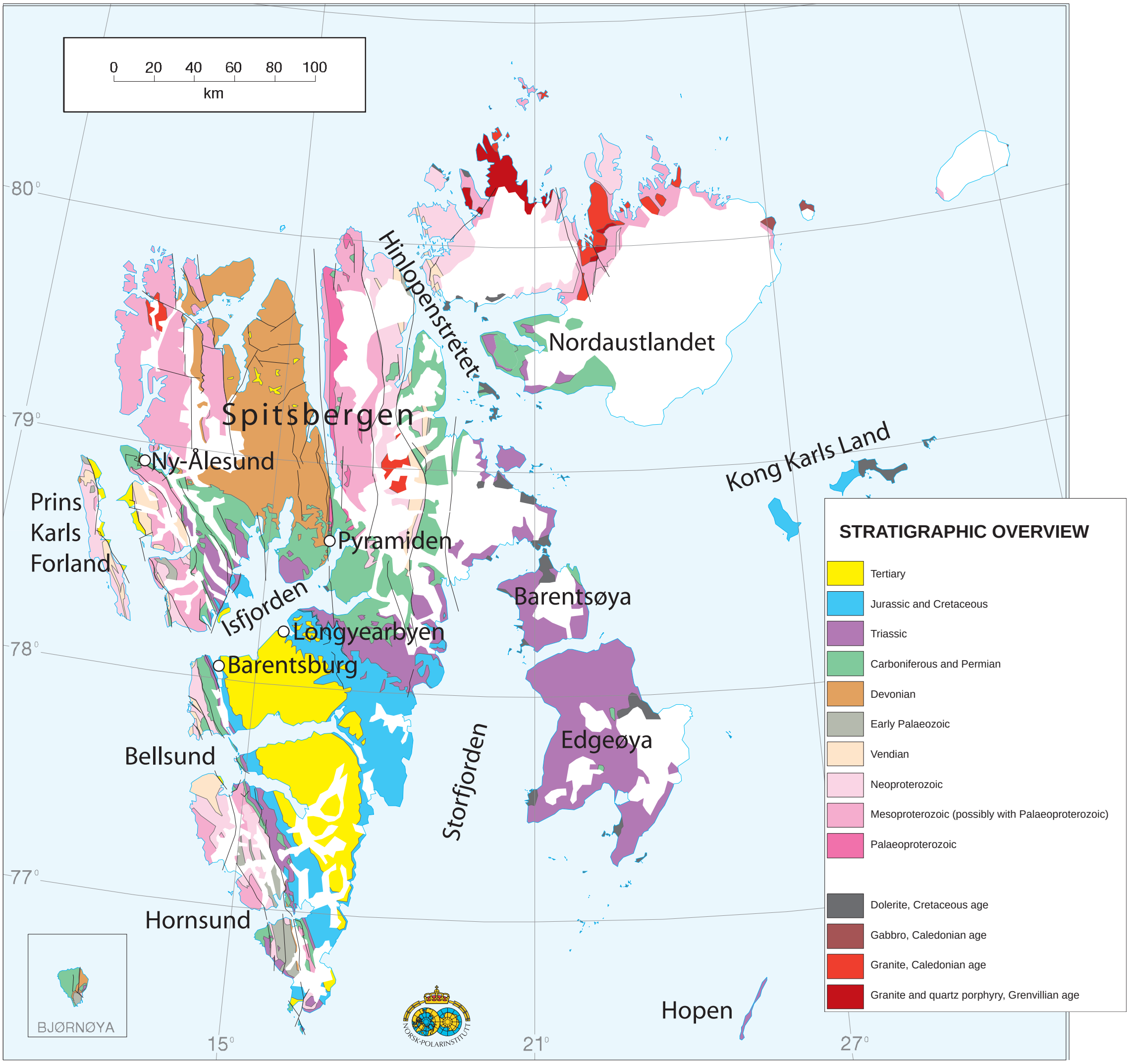
Travellers must make sure that their activity is conducted in accordance with the requirements and provisions of the current legislation for the areas they visit. This applies also to hunting and fishing regulations. Visits to protected areas presume that the traveller is familiar with the relevant environmental regulations.

All motor traffic on land, except for snowmobile traffic regulated by the Motor Traffic Regulation, needs an exemption permit. This applies also to landing with helicopters outside of approved landing sites. Exemption permits are mainly given in connection with research. Be aware of differing regulations for Svalbard's residents and visitors.

When leaving the settlements, all travellers need to carry a weapon suitable for defending themselves against polar bears. Never approach or pursue polar bears! Polar bears are totally protected and may only be shot in self-defense, when killing is the only alternative. Information about polar bears and safety can be obtained from the Governor or from the Norwegian Polar Institute.

All remains of human activity from 1945 or before are automatically protected cultural heritage objects. This applies to both firm and loose objects. Installations of more recent age may also be protected by special notice. It is not allowed to establish a camp or to store equipment closer than 100 m from any protected, firm cultural heritage site. Planned permanent camps of one week or more must be reported to the Governor in advance.

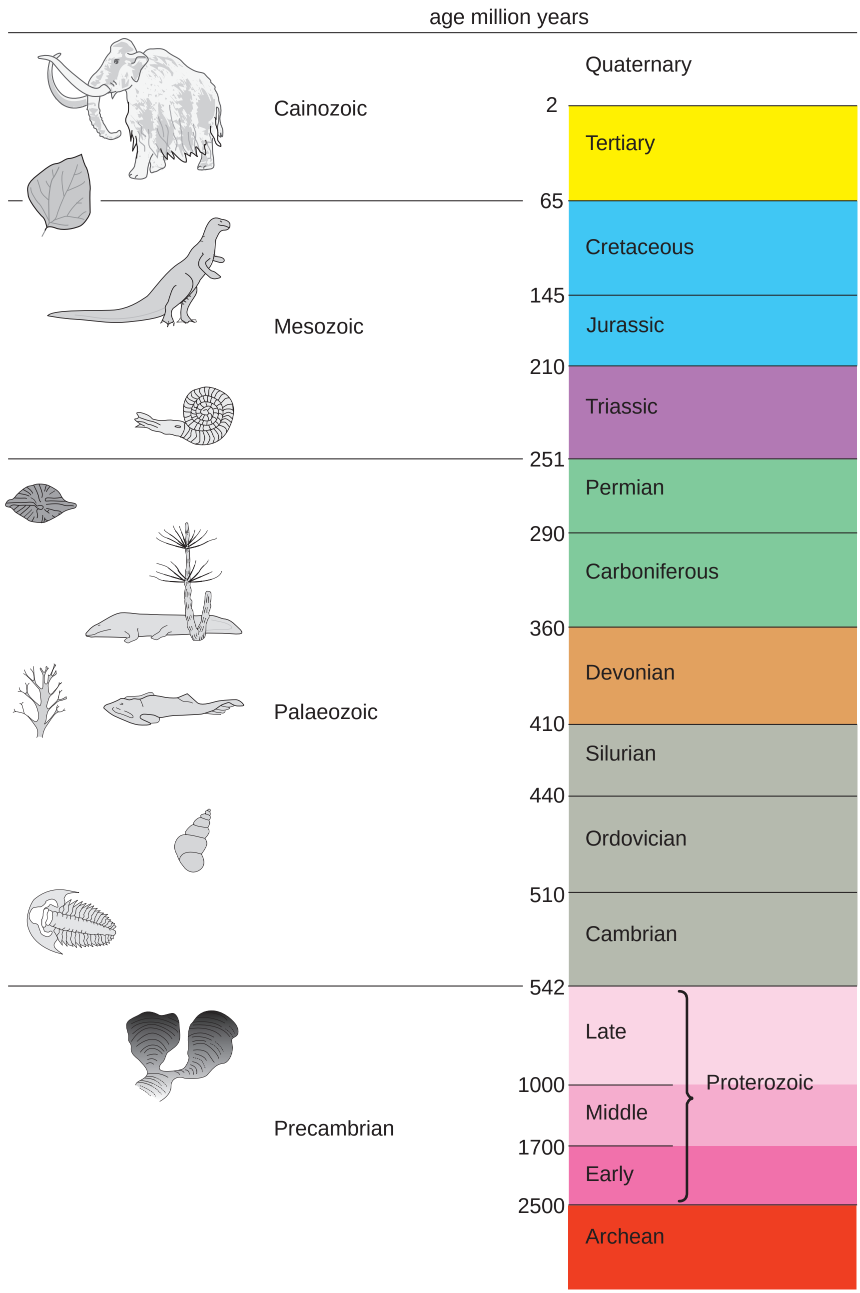
Photo: D. Blomeier



The time scale – the framework of geology

The geological time scale is subdivided into several periods, principally on the basis of the observed presence or absence of particular life-forms that characterized each of them. The names of the geological time scale constitute the standard time nomenclature used by geologists all over the world. The oldest time unit is the Precambrian, which covers the entire era from the beginning of the Earth's history until 542 million years ago. The era between 542 and 251 million years ago is named the Palaeozoic, which was followed by the Mesozoic that endured until 65 million years ago. The Cenozoic is the era that started 65 million years ago and still goes on. The latest two million years in the Earth's history is named the Quaternary.

GEOLOGICAL TIME SCALE



Fascinating geology

For more than a hundred years, Svalbard has fascinated people. Many who have visited Svalbard have been taken with the stark wilderness of the archipelago and its beautiful mountains. The diverse geology of Svalbard has resulted in a wide range of differing landscapes. Hornsund for example, is surrounded by jagged mountain ridges; the east coast of southern Spitsbergen is characterized by plateau-shaped nunataks, whereas the landscape around Woodfjorden is distinguished by gentler slopes with peculiar, reddish colours. No other place in northern Europe displays such diversity in geological formations and no other place has so many geological eras exposed in outcrops. Since many areas lack significant amounts of soil and vegetation, the bedrock exposures can be studied unimpeded over large distances. All of these factors make Svalbard a unique place for studying geological processes – or for being captivated by the beauty of the land.