Geology of Svalbard

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Tectonic setting

The archipelago of Svalbard forms the emergent northwestern corner of the Barents Sea Shelf, which was uplifted by Late Mesozoic and Cenozoic crustal movements. The area provides a splendid insight into the varied geological structure and geo-historical development of the northwestern Barents Sea since the Palaeoproterozoic. The geological record ranges from possible Archaean to Recent and shows a multi-orogenic development with prominent tectonic events of Grenvillian (Late Mesoproterozoic), Caledonian (Ordovician-Silurian), Ellesmerian or Svalbardian (Late Devonian), Variscan (Middle Carboniferous) and Alpidic (Early Tertiary) age.

North of Svalbard, 50-100 km from the shore, a steep passive continental margin with slopes up to 10° (average 4°) forms the boundary with the Eurasian Basin of the Arctic Ocean. Offshore to the west of Svalbard, a 40-80 km-wide shelf separates the coast of the main island, Spitsbergen, from a structurally complex oceanic area, an active mid-ocean ridge, the Knipovich Ridge. The central part of this ridge is a spreading axis which is segmented by a transform fault system, the Spitsbergen Fracture Zone in the north, and the Molloy Fracture Zone in the south.

The northwestern shelf corner borders the Yermak Plateau, the northern part of which may be all that remains of an Early Tertiary hot spot. Late Cretaceous thermal uplift, Early Tertiary shoulder uplift along the rifted margin of the developing Arctic Ocean, and subsequent transform movements in a periodically transpressive regime along the western margin may all have their share in explaining the uplift of the archipelago and especially of its westernmost and northernmost parts.

Pre-Old Red Sandstone basement

The pre-Old Red succession (key map 11, 10) is exposed in the west and north of the archipelago. U-Pb zircon isotopic age determinations have revealed relict elements of several Precambrian events (1800-1700 Ma, 1400 Ma and two or three older ones), the Grenvillian tectonothermal event (1000-950 Ma) and the Timanian (Baikalian) movements (650-600 Ma). These events are followed by two phases of Caledonian folding and thrusting, including evidence for an oceanic suture zone in the western province (Fig. 1).

Fig. 1. Interlayered eclogite and blueschist in the high-pressure metamorphic, Vestgötabreen Complex, Motalafjella, western Spitsbergen. The formation of the complex was related to subduction along an orogenic suture zone during an Early Caledonian metamorphic event in Ordovician time. Photo: Synnøve Elvevold.

The pre-Old Red is subdivided into three different tectonostratigraphic basement provinces, whose structure, sedimentary record and tectonothermal evolution differ from each other. All of these consist mainly of metamorphosed supracrustals (327, 326), whose lower structural levels were granitised and migmatised during several of the tectonometamorphic events in the two northern provinces (410). Their juxtaposition occurred probably during the Caledonian period, though no consensus about the mechanisms involved yet exists.

Fig. 2. Caledonian angular unconformity between inverted, Early Palaeozoic limestones (Arkfjellet unit: brownish rocks in left foreground) and red and yellowish-brown, Devonian sandstones. A dark-purple weathering horizon is developed directly below the contact. Kneikfjellet, Sørkapp Land, southern Spitsbergen. Photo: Winfried Dallmann.

Fig. 3. Upper Carboniferous platform carbonate rocks of the Wordiekammen Formation (light) intruded by a thick, strongly jointed, Mesozoic dolerite sill. Nannafjellet, Lomfjordhalvøya, northeastern Spitsbergen. Photo: Christian Scheibner.

After the Middle Silurian, however, Svalbard formed part of the 'Old Red Continent'. During the Silurian and earliest Devonian, Caledonian granites (194) and, exceptionally, gabbros (239) intruded the basement rocks. A Caledonian angular unconformity of Late Silurian age is well developed across Svalbard (Fig. 2).

Devonian and younger rocks

Old Red Sandstone (Devonian). During the Devonian period, Svalbard experienced the deposition of a vast thickness of Old Red molasse sediments (177, 175, 170) that are mainly preserved in a downfaulted crustal block in northern Svalbard between Precambrian basement terranes. The main tectonic overprint and tectonic style of this graben system is related to a Late Devonian culmination of tectonism, the 'Svalbardian Phase', which resulted in contractional movements predominantly in northern Svalbard. This phase of deformation is genetically related to the Ellesmerian-North Greenland Fold Belt in the Canadian Arctic and northern Greenland.

Late Palaeozoic. During the Carboniferous period, Svalbard developed from a site of fault-block tectonism with differential sedimentation to a stable shelf that experienced overall subsidence (except for southern Spitsbergen) (147, 140). The main fault-block movements occurred in the Bashkirian and Moscovian, resulting in a new constellation of troughs, mainly half-grabens, with a pre- to syntectonic sedimentary (lower part of 140) record developed along older tectonic lines. With waning tectonic movements in later Carboniferous time, most of Svalbard developed into a carbonate platform (Fig. 3) with episodes of evaporite formation (middle part of 140). These conditions lasted through the Early Permian, while the later part of the Permian experienced renewed clastic influx and a subsequent hiatus at the era boundary (upper part of 140). The latest Permian is represented by a hiatus throughout Svalbard.

Late Palaeozoic sedimentation in the Svalbard-Barents Sea area was continuous with that in the Wandel Sea Basin in northeastern Greenland, a site at that time situated not farther than maybe 100 km from what is now the western coast of Svalbard.

Mesozoic. The Mesozoic stratigraphic record consists of repeated clastic sedimentary successions, mainly Triassic-Early Jurassic, delta-related coastal and shallow-marine, shelf sediments (105, part of 103) and Mid Jurassic to earliest Cretaceous deeper shelf sediments (88, part of 103), and again Early Cretaceous shallow shelf/delta deposits (86). The source area of the sediments was mainly situated to the west, and later also to the north, while the basin opened towards the present Barents Sea. This view is consistent with the less complete Mesozoic sections in the Wandel Sea Basin of NE Greenland (not seen on the map). Early Jurassic block faulting and development of sedimentary basins during the Cretaceous in the Wandel Sea Basin are explained by the Mesozoic onset of transform faulting between Greenland and the Barents Sea. In Svalbard, no such tectonics are seen, and the entire Upper Cretaceous is lacking due to an overall uplift, with highest uplift rates in the northwest.

The first sign of break-up between Greenland and Europe and the opening of the Arctic and North Atlantic oceans recorded in Svalbard is the intrusion of dolerites (102) from the latest Jurassic through the Early Cretaceous. They occur most commonly as sills in Carboniferous through to Jurassic strata (progressively younger to the east) (Fig. 3). On Kong Karls Land, in eastern Svalbard, basaltic lavas (within 88) were extruded during the later part of the Early Cretaceous. They belong to a larger volcanic province (81) that also includes large parts of the Barents Sea and Franz Joseph Land (Zemlja Frantsa Iosifa).

Tertiary. The opening of the Arctic and North Atlantic oceans caused a tectonic overprint in western Svalbard during the Palaeocene and Eocene. Tectonism was related to a transform fault system between the Greenland and Barents shelves, the Spitsbergen Fracture Zone, offshore to the west of Svalbard. Despite this dextral transform plate setting, the developing Tertiary fold-thrust belt consists mainly of convergent structures. This led to a decoupling model, meaning that strike-slip and convergent movements may be localised in different deformation zones. An alternative – and mechanically more easily understandable – model makes plate motions between Greenland and Ellesmere Island responsible for the convergent deformation, which would thus be unrelated to the Arctic-North Atlantic transform displacement.

The western part of the fold-thrust belt was uplifted and eroded down to Precambrian strata, which were thrust ENE-ward onto the simultaneously developing, depositional foreland basin (Central Tertiary Basin). Thrust movements were transferred to the east ahead of the fold belt along high-level detachments within the cover sediments and interfered with basement-involved fault zones farther east (Billefjorden and Lomfjorden fault zones). The stratigraphical record of Tertiary basins is entirely clastic, with intervals of coal-bearing successions (72, 68) that have been worked for almost a century (Fig. 4).

During the later stages of fold belt development (Eocene-Oligocene), minor sedimentary basins, especially the Forlandsundet Basin with a clastic sedimentary fill (54), developed in the west of Svalbard. Their structural record contains components of strike-slip. The latest tectonic overprint involved faulting associated with a post-Eocene, E-W extensional regime throughout western Svalbard, in connection with the development of a passive continental margin to the west.

Tertiary and Quaternary volcanic activity. Volcanic activity of both Tertiary and Quaternary age occurred in NW Spitsbergen. Plateau basalts of Miocene to Pliocene age (transitional olivine basalts, 53) overlie Devonian and Precambrian rocks. Quaternary volcanic centres of off-ridge alkali basalts (B) are situated on old fracture zones; their age is probably between 700,000 and 100,000 years. Thermal springs in several places in northwestern and southern Spitsbergen indicate continuously high geothermal gradients along the Tertiary fold-and-thrust belt.

Selected literature for further reading

Aga, O. J. & Worsley, D. 1986: *The geological history of Svalbard. Evolution of an Arctic archipelago.* Den norske stats oljeselskap a.s, Stavanger, 121 pp.

Dallmann, W. K. (ed). 1999: *Lithostratigraphic lexicon of Svalbard. Upper Palaeozoic to Quaternary bedrock. Review and recommendations for nomenclature use.* Committee on the Stratigraphy of Svalbard. Norsk Polarinstitutt, 320 pp.

Harland, W. B. 1997: *The geology of Svalbard.* Geological Society of London Memoir 17, 521 pp.

Hjelle A. 1993: Svalbards geologi (Norwegian language edition). *Polarhåndbok No.6*, Norsk Polarinstitutt, Oslo, 163 pp.

Hjelle, A. 1993: Geology of Svalbard (English language edition). *Polarhåndbok No. 7*, Norsk Polarinstitutt, Oslo, 163 pp.

Fig. 4. Basal part of the Tertiary succession of the Central Tertiary Basin, Spitsbergen. The sandstone unit in the upper part of the photo is the Endalen Member of the Firkanten Formation. The underlying Todalen Member is largely covered by scree. The coal seams of the Todalen Member are still worked in Longyearbyen, Sveagruva and Barentsburg. Here, however, in Sverdrupbyen, Longyeardalen, central Spitsbergen, we see the abandoned coal mine 'Nye Gruve 1', which was worked during the period 1939–1958. Photo: Winfried Dallmann.