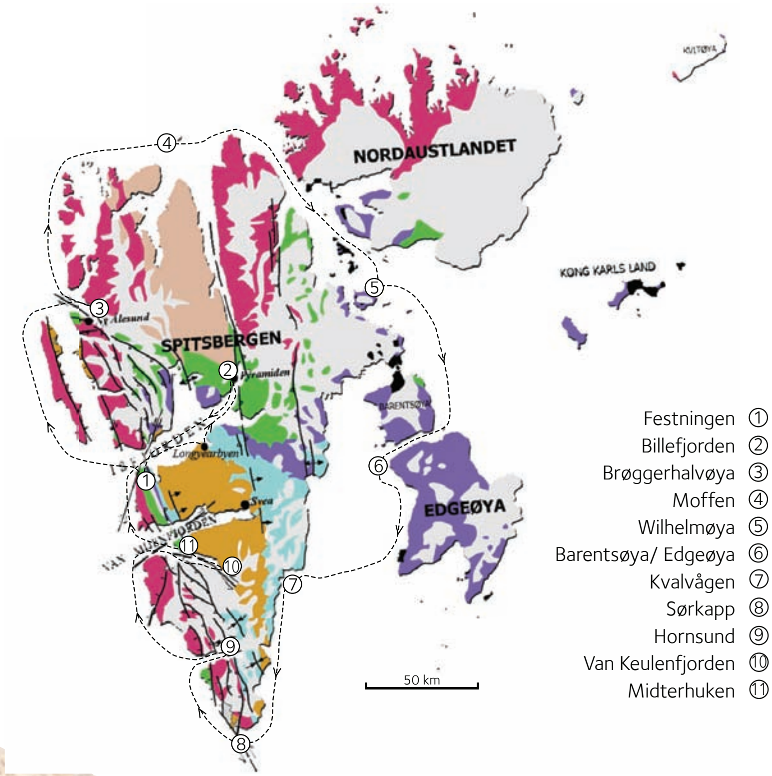
Svalbard (Spitsbergen) round trip

Post Caledonian Tectonostratigraphic and Paleogeographic Development

27. July - 5. August 2008



Field guides: Geir B. Larssen
Erik P. Johannessen
Tormod Henningsen
Bjarne Rafaelsen

IGC Excursions

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Preface

As a part of the International Geological Congress in Oslo 2008 (The 33[rd] IGC) this field excursion is arranged as a pre-conference Spitsbergen round trip. The field trip is partly sponsored by StatoilHydro.

The aim of this trip will give the participants a comprehensive view of the Post Caledonian Tectonostratigraphic and Paleogeographic development around Svalbard. An almost complete stratigraphic overview from Lower Carboniferous to base Tertiary will be given at the Festningen profile. Main focus on the round trip will be Middle Carboniferous (alluvial fans and sabkhas), Upper Carboniferous (shallow marine carbonates), Triassic/Jurassic/Cretaceous (deltaic to shallow marine succession) and Tertiary (a shelf/slope/basin clinoformed succession). Comparison to the rest of the Barents Sea will also be given.

Field guides: Geir B. Larssen, Erik P. Johannessen, Tormod Henningsen og Bjarne Rafaelsen

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Introduction

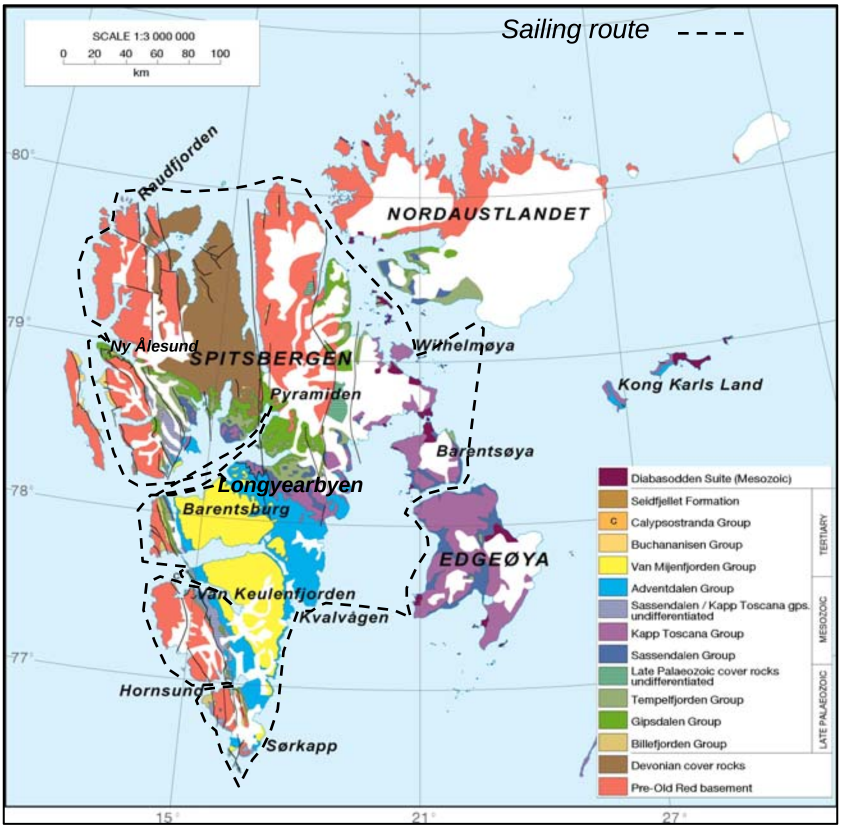
Further than Nansen...

"I bring you with me wherever I go, through fog and ice, across all seas," Fridtjof Nansen once wrote to his wife. Whereas she travelled only in his thoughts, Statoil will give you the opportunity to come all the way…

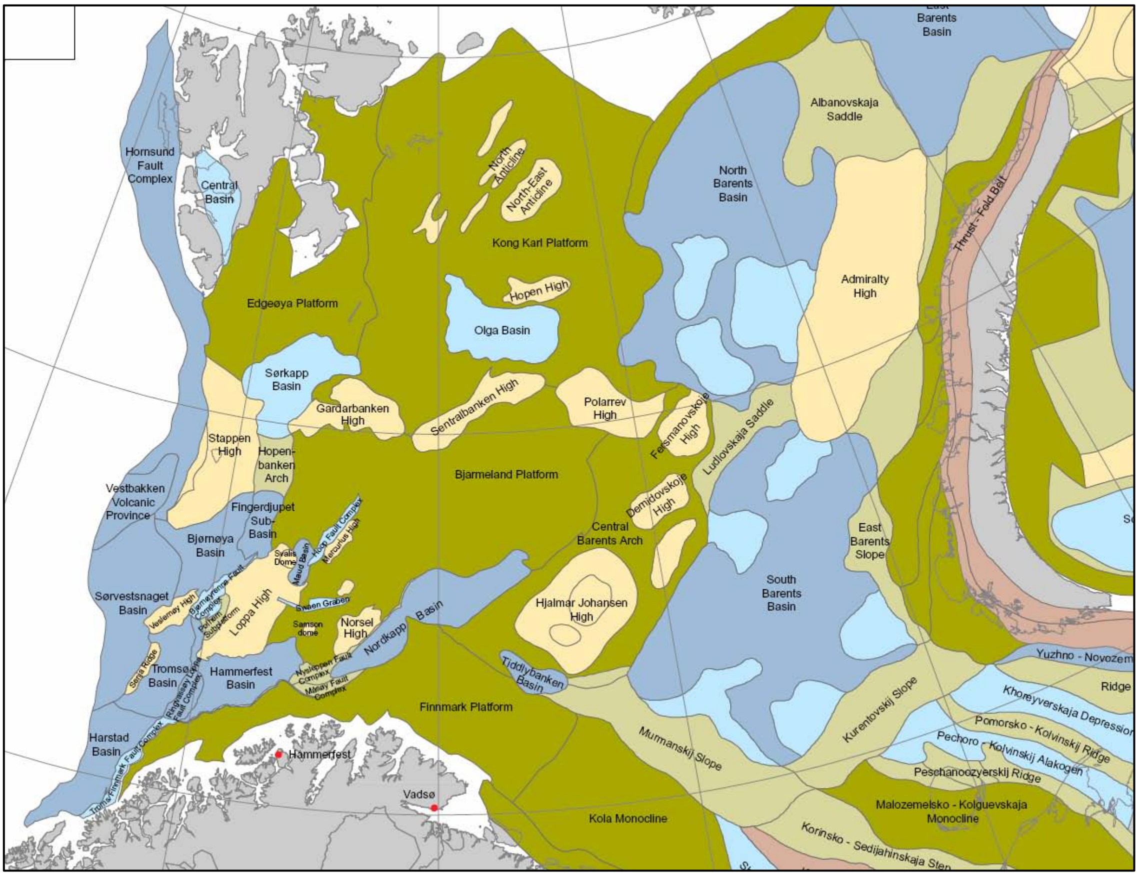
Welcome to Svalbard! During the expedition you will have the opportunity to experience a fantastic diversity of Arctic geology and nature. Sea, mountains, glaciers and valleys and unique plant, bird and animal life. Adjust yourself to the arctic way of living – light 24 hours, little sleep and lots of fresh arctic air. We hope that you will appreciate this excursion both from a geological and a social point of view.

Excursion Guide

This Excursion Guide defines the framework for carrying out the excursion and is meant as a practical aid for quality assurance of the excursion.



Simplified geological map of Svalbard (from Dallmann 1999).
The planned sailing-route of Origo is indicated.



The greater Barents Sea with the main structural elements.

Organisation and responsibilities

Organisation, responsibilities and sailing schedule

StatoilHydro is responsible for the excursion with Erik P. Johannessen as the main expedition leader. He will also be the guide at Pyramiden, Ebbadalen and Storvola localities. Bjarne Rafaelsen and Geir B. Larssen will be the guides at the Raudmosepynten and Fortet localities. Tormod Henningsen is the main structural geologist and will have guide within this topic. Geir B. Larssen will have the main responsibility guiding on the Brøggerhalvøya, Wilhelmøya, Barentsøya, Edgeøya, Kvalvågen, Sørkapp and Hornsund areas. At the introduction profile; Festningen, all four guides will take active part. Geir B. Larssen will in addition have the main responsibility for health, environment and safety. The excursion will be carried out with M/V *Origo* as the excursion vessel.

Localities

The expedition has as a goal to visit and study the localities described in this guide, but sea ice, unfavourable weather conditions or polar bears in the localities may lead to adjustments in the planned programme. A lot of "back up" localities is therefore also described in the guide, and may be visited. We therefore ask the participants to show comprehension for potential deviation in the programme based on arctic elemental forces.

Normal arctic security procedures will be followed during the excursion (see "HSE precautions").

Normal daily routine

07:00-08:00	Breakfast Prepare your own lunch and fill your thermos, bring soft drinks along when we go onshore.
08:30-09:30	Landing personnel (everybody has to use a survival suit!)
09:30-17:00	Geological excursion
12:00-13:00	Lunch in the field
17:00-18:00	Transport back to *Origo*
18:30-19:30	Dinner on *Origo*
20:00-	Summing up the day and preview the following day. "Relevant talks".

Deviation from this schedule ***will*** *happen – in such cases follow the information from the Expedition Leaders*

Communication

StatoilHydro will bring along an iridium telephone. Between MS *Origo* and the group in the field portable VHF-equipment will be used.

Sailing schedule for M/V Origo

Day	Date	Stop	Locality	Location, HSE
			Arrive Longyearnbyen Guiding by Spitsbergen Travel Dinner at Kroa Hotel Funken	
1	28. July	 1 2	Departure Longyearbyen 09:00 Outer Isfjorden Festningen Barentsburg	 Onshore, bring helmet Onshore, bring money
2	29. July	 1 2 3	Billefjorden Pyramiden Ebbadalen Raudmosepynten – Fortet Asvindalen *(optional)*	 Onshore, bring helmet Onshore, bring helmet Onshore, bring helmet Onshore, bring helmet
3	30. July	 1 2 3	Brøggerhalvøya Kulmodden Strypbekken Ny Ålesund *(optional)* Raudfjorden *(optional)* Moffen	 Onshore, bring helme Onshore, bring helmet Onshore, bring money *On boat* *On boat*
4	31. July	 1 2	Wilhelmøya Tumlingodden - Keisarkampen Bråsvellbreen *(optional)*	 Onshore, bring helmet *On boat*
5	1. August	 1 2 3 4	Barentsøya Høgrinden Edgeøya Blanknuten Kvalpynten East Spitsbergen Kvalvågen	 *On boat* Onshore, bring helmet *On boat* *On boat* *On boat*
6	2. August	 1	Sørkapp; South Spitsbergen Kikuttodden – Keilhaugfjellet Mathiasbreen (*optional*) Sørkappøya (*optional*)	 Onshore, bring helmet Onshore, bring helmet
7	3. August	 1	Hornsund; Spitsbergen Adriabukta-Treskelen	 Onshore, bring helmet
8	4. August	 1 2	Van Keulenfjorden, Spitsbergen Storvola Midterhuken Akseløya (*optional*)	 Onshore, bring helmet *On boat* Onshore, bring helmet
9	5. August		Arrive Longyearbyen Guiding in Mine no 7, pick up at boat Eventually shopping Longyearbyen Airport	 *Flight home*

Symbols used in the guidebook:

Wear helmet

Stay on MS Origo

HSE precautions

StatoilHydro has a high standard for Health, Safety, Security and the Environment – the company's goal is zero harm in any activity.

Concerning expeditions and excursions in Svalbard waters it is relevant to have special attention about environmental conservation, polar bear, falling rocks, plant life and vegetation, wildlife in common and common sense.

Goals for environmental conservation

Norway's primary goal for environment conservation in Svalbard is to preserve the unique wildlife in the archipelago. Svalbard should be one of the world's best managed wildlife preserves.

The lofty environmental goals for Svalbard, where the greater part of Norwegian protected areas are situated, have been set by the Government and National Assembly. Most of Svalbard is virtually untouched, and the aim is to keep eco-systems intact to the extent possible, to allow natural ecological processes and biological diversity to take their natural courses, undisturbed by human activity. Representative human artefacts are to be left alone, when possible, as an integral part of the landscape.

Photo: S. Aarvik

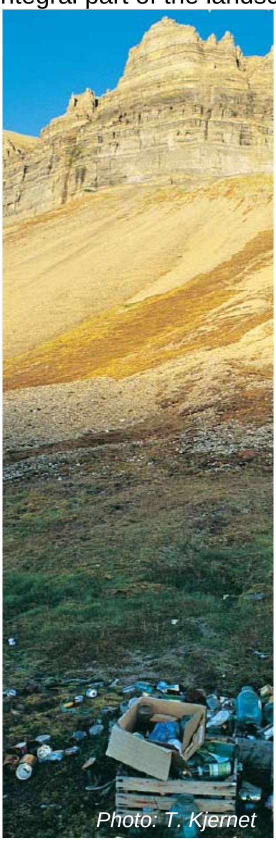


Photo: T. Kjernet

Wildlife areas on the Norwegian mainland have been heavily cut back in the course of a few generations. Svalbard is currently one of Europe's last great wildlife areas, and Norway is responsible for saving it for future generations. Svalbard's unique conditions should nevertheless be enjoyed and people should have the opportunity to take in the magnificent nature. However, traffic can not be allowed to degrade the environment, and in the event of conflicting interests, the balance should always tip in favour of conservation principles.

Objectives
In order to achieve its main goals, the Governor of Svalbard ("*Sysselmannen*") has the following intermediate objectives:

- **Area preservation** in Svalbard should be followed up. Preserving areas is important in view of protecting vulnerable or threatened biotopes. Meanwhile, the wild aspect of Svalbard should be retained, even outside the wildlife preserves.
- **Vulnerable animal species** should be rigorously protected with active population management. Legal hunting of game or fish should not have affect population stability and development.
- •**Traffic** should be restricted so as not to degrade Svalbard's nature and artefacts.
- **Human artefacts and environments** should be protected and a selection of memorials should be conserved.
- **Local pollution** should be kept at a minimum.

The Svalbard Environmental Protection Act

The Svalbard Environmental Protection Act served as an important instrument to reach the lofty environmental goals for Svalbard. On 1 July 2002, the Act came into effect with the purpose of preserving the virtually untouched environment in Svalbard. Within the limits of such a purpose, it allows for environmentally sound settlement, research and commercial activity. The Svalbard Environmental Protection Act embodies updates and therefore replaces previous legislation about Svalbard. Its provisions pertain to the protection of areas, species management (flora and fauna), human artefacts, land use plans, pollution, waste disposal, traffic and cabins.

The Act establishes several key principles of environmental law; for instance that a precautionary stance should be taken in cases when knowledge about the effects of intervention on the environment is insufficient. Moreover, it states that any enterprise starting in Svalbard shall be assessed with regard to the sum total of strain imposed on natural environment and memorials of human activity.

Species Management

The purpose of managing naturally occurring plants and animals in Svalbard is to ensure their existence in the future.

The goal of management is that Svalbard's wildlife should remain virtually untouched, meaning that exploitation of species, intervention and disturbances should be restricted, so that a healthy balance between populations can he sustained.

Protection of animals
The main rule in Svalbard is that all animals, as well as eggs, nests and lairs, are protected. Thus, it is illegal to chase, disturb or put down animals. However, hunting and fishing of certain specified species is permitted.

Protection of plants
Moreover, all plants are protected, in the sense that it is prohibited to damage or remove them. An exception has been made for lawful traffic, for authorised activities and the picking of mushrooms, seaweed and kelp for private purposes, as well as for the collection of plants for research or education, assuming that no serious harm comes to the stocks in question.

Responsibilities
Management of species involves various responsibilities, such as those of:

- protecting important habitats in Svalbard from intervention, disturbances and the effects of local activities;
- continued rigorous protection of species and important habitats for selected species;
- continued regulation of hunting and fishing in fresh water so that stocks may develop unhampered by human intervention; at the same time, within reasonable limits, permitting recreational hunting for the local population;
- protecting migrating and border-crossing species and their habitats outside Svalbard, by means of participation in international activities.

Various tasks
In terms of species management, the government has obligations with regard to hunting and fishing: exemption applications need to be processed, and the condition of various stocks needs to be monitored. The polar bear issue is particularly salient: it needs to be followed up with information and measures to pre-empt confrontations between bears and humans. Moreover, bears that get shot in self-defence or for other reasons have to be handled.

Polar bears


Photo: G.B. Larssen

Precautionary principle
Polar bears are impressive creatures. They are the world's largest land carnivores, and are as beautiful – and dangerous – as the arctic wilderness. Occasionally, human encounters with polar bears have a fatal outcome – either for the people involved, the bear(s) or both. By following the precautionary principle (= keep your distance), we can avoid such tragic outcomes.

Polar bears and Humans
Polar bears are potentially dangerous animals, and you should never move around in Svalbard without being well prepared. In Svalbard people have been killed on several occasions, including incidents in resent years. On average, three polar bears have been killed every year during last 10-years period in encounters with humans, i.e. in self-defence. This number can be kept low if people try to avoid critical encounters, and behave in most sensible way when interacting with polar bears. Accidents with fatal outcomes are highly unlikely if we follow a few simple procedures:

<u>Gain knowledge about polar bears:</u> In Svalbard-area exist 2.000-3.000 polar bears, and typical weights vary between 400-600 kg. They are excellent swimmers and feeds almost exclusively on ice-living seals. Moves quickly, reaching a speed of more than 30 km/h over short distances. Polar bears do not normally look upon humans as food, but they are curious of nature and investigate everything searching for something to eat. A really hungry polar bear will eat almost anything! The polar bear may attack very fast and without any warning!!

<u>Avoid confrontations:</u> Pay attention to the surroundings at all times and be prepared to meet polar bears whenever and wherever travelling or camping in Svalbard. Take measures to avoid confrontations and dangerous situations If spotting a polar bear at a distance, avoid an encounter by staying out of its path, and never move towards the bear. It is strictly prohibited throughout Svalbard and surrounding waters to bait, pursue or otherwise seek out polar bears in such a way as to disturb them or expose either bears or humans to danger (jf. Svalbard Environmental Protection Act, § 30). The call of adventure or the desire to take photographs does not justify putting people or the polar bear in danger.

Be armed: Always have sufficiently powerful weapon at hand when travelling in Svalbard outside the settlements. Be prepared to scare away approaching polar bears using scaring device. Polar bears are large and formidable, and a wounded animal is a "worst-case scenario". A high powered big game rifle (calibre .308 win, 30-60 or heavier) is the best weapon and hunting cartridges with expandable lead core bullets are the only recommended ammunition (pump action shotgun with rifled slugs (calibre 12) is the only alternative weapon, if they can take at least four cartridges in the magazine. Be sure that the gun is in good serviceable condition. To avoid accidents, keep the chamber empty, but keep shells ready in a loaded magazine, and put it into the chamber only when the bear is so close that you feel the situation threatening.


Photo: K.M. Kovacs

Encounter with polar bears
Young animals are often the most dangerous; they are inexperienced, have limited hunting skills and may have hard time catching prey. But older weak animals that have trouble catching normal prey can also be dangerous. Females with young cubs are usually quite shy, but if surprised by sudden appearing at a short distance, they are also very dangerous because they will defend their cubs.

Also worth noting is that if there is one polar bear in the area, changes are likely to be another one around too. Most polar bears will run away when confronted by human, or at least attempt to avoid an encounter, even if they are curious. Many situations can be assessed with some common sense and knowledge of polar bear behaviour.

If a polar bear moves directly toward you, make yourself visible early and also make noise. If the bear's interest in you continues, you should be prepared to use a signal pistol with crack cartridge, or shoot warning shot from a rifle, to scare it away. Flare shots are the best equipment when the bear is at some distance; aim such that the flare lands between you and the bear (i.e. not behind the bear!). If an aggressive bear attacks with no sign of being scared away by warning flare or shots, shoot with the aim to kill. This is a last resort. Aim for the chest, below the head, either from the front or the side. Do not attempt a shot in the head because the skull of polar bears is tough and well protected by heavy muscles and the vulnerable area is surprisingly small, even on a big bear. Keep shooting until the bear lies still, and do not approach it until you are sure it is dead. Even then approach the bear from behind. Do not move the bear or remove anything from the scene. Contact the Governor of Svalbard immediately

HSE Reminders

- Always act and attend in a healthy, safe and secure manner

Polar bears
- Gain adequate knowledge about this carnivores
- Pay attention to the surroundings – look around and observe

- Avoid confrontation, keep safe distance.
- Never bait, pursue or disturb the polar bear in any way
- If encounter, try to avoid close contact. If this is impossible: act determined in self-defence. If you have to kill a polar bear notify the Governor.

Disembarkation and behaviour in field

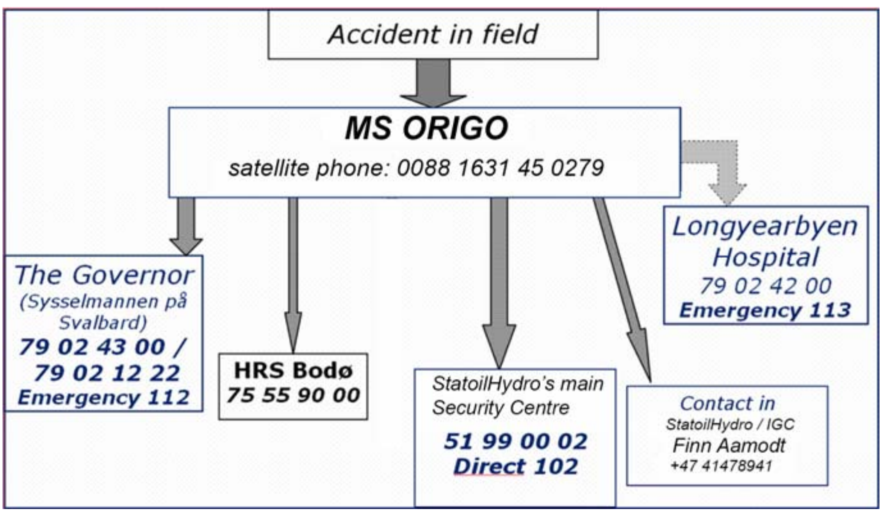
- Lifeboat w/ crew from excursion vessel will disembark/embark field party according to agreement between excursion leader, shipmaster and boatman lifeboat.
- Boatman ensures that all are dressed in approved survival suites before disembarkation/embarkation.
- Boatman is autocratic and gives orders on when and how to embark/ disembark
- Bridge watch on excursion vessel and boatman establish communication during disembarkation/embarkation.
- First person on shore prepares weapon and signal pistol.
- Always have sufficient weapon(s) on hand within every field group.
- Never "wander off" without notifying others of your where-about.
- Use hardhats and eye protection when appropriate – be aware of falling rocks and rockslide when entering steep slopes.
- Take great care when hammering/sampling – use eye protection.
- No one shall be working or passing above other due to risk of rockslide.
- Don't leave garbage behind in field – all refuses shall be collected and brought back to excursion vessel.

Preparedness measures

Reports about the operations will regularly be given to StatoilHydro's main security centre: **tel. <u>51990002.</u>** Family and StatoilHydro leaders who wish to contact any participant about personal issues or the progress of the excursion should also use this phone number. They then leave a message which is given to the right person who then can call directly back using the sat. phone.

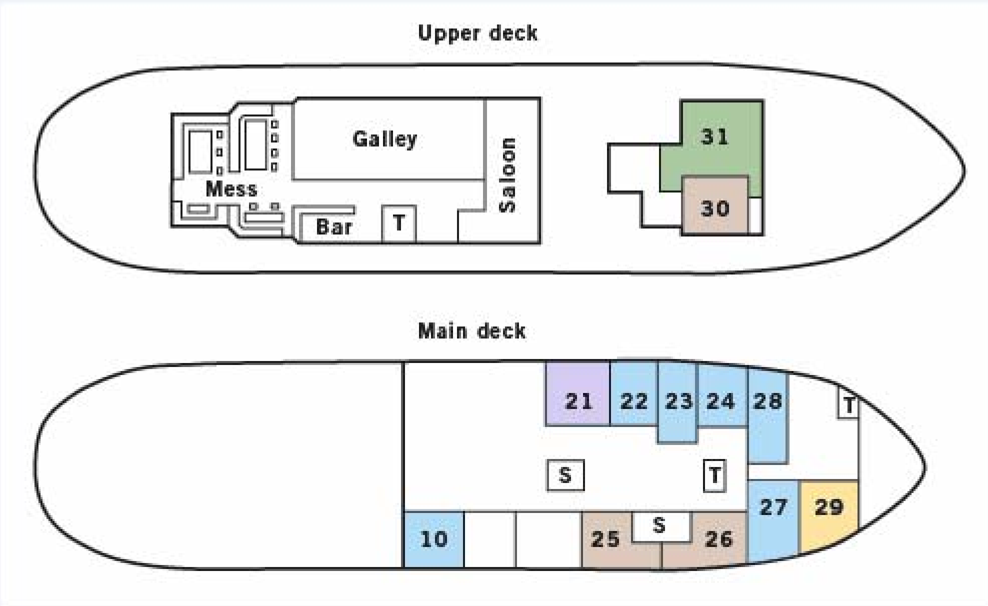
Any incidents will be reported to Statoil's HSE Department

- If accidents need support, notify the Governor through *MS Origo* (the excursion vessel)'s communication equipment.
- The Governor, StatoilHydro and *MS Origo* have names and personal data on the participants, and a general view of the excursion's movement.
- Below is given a notification plan, containing important telephone numbers in the case of notifiable accidents.



M/S Origo

The *M/S Origo* was built in 1955 at Finnboda shipyard in Stockholm for the Swedish National Maritime Administration. In 1991 she started her career as passenger ship and has been cruising in the Arctic waters of Svalbard every summer since. The *Origo* carries a maximum of 24 passengers in outside twin and superior cabins. All cabins except for the superior cabin have upper and lower berths. The superior cabin and two cabins on the main and lower deck have private bath, all other cabins on lower deck have shared facilities.



The plan shows location of the cabins.

Outline of the Geology of Svalbard

Modified from S.O.Johnsen[1], A. Mørk[2], H. Dypvik[3], J.Nagy[3]
1) NTNU, 2) SINTEF Petroleum Research 3) University of Oslo

Introduction

Svalbard is located in the northwestern corner of the Barents Shelf (Figures 1 and 2). The archipelago represents an uplifted part of this otherwise submerged shelf. The uplift was most extensive in the north and west, leaving progressively older rocks in these directions. A pronounced synclinal feature, the Central Spitsbergen Basin, occupies most of central Spitsbergen. The basin is bounded to the west by the West Spitsbergen fold- and thrust belt, which die out towards the eastern part of Spitsbergen. The basin boundaries parallel dominant NNW- SSE structural grain on Spitsbergen comprised through four similarly aligned episodes of tectonic deformation. Regionally Svalbard may be divided into five geological provinces (Figure 2):

1. The Hecla Hoek complex comprising metamorphic rocks of Precambrian to early Silurian age. These rocks crop out along the west coast and on the north-eastern part of Spitsbergen, and on Nordaustlandet (Pre-Old Red basement in Fig. 2)
2. The Devonian Grabens on northern Spitsbergen (Devonian cover rocks in Fig. 2)
3. The central basin in the central parts of Spitsbergen
4. The platform areas on the eastern parts of Spitsbergen and on Barentsøya and Edgeøya
5. The Tertiary fold-belt along the west coast of Spitsbergen

The Caledonian Orogeny including faulting, folding, thrusting, and metamorphism of Precambrian to middle Ordovician sediments and igneous complexes was particularly intense, and formed the Hecla Hoek basement. The total stratigraphic thickness is in the order of 15-20 km and the degree of metamorphism and structural complexity varies considerably, particularly in the older part of the succession.

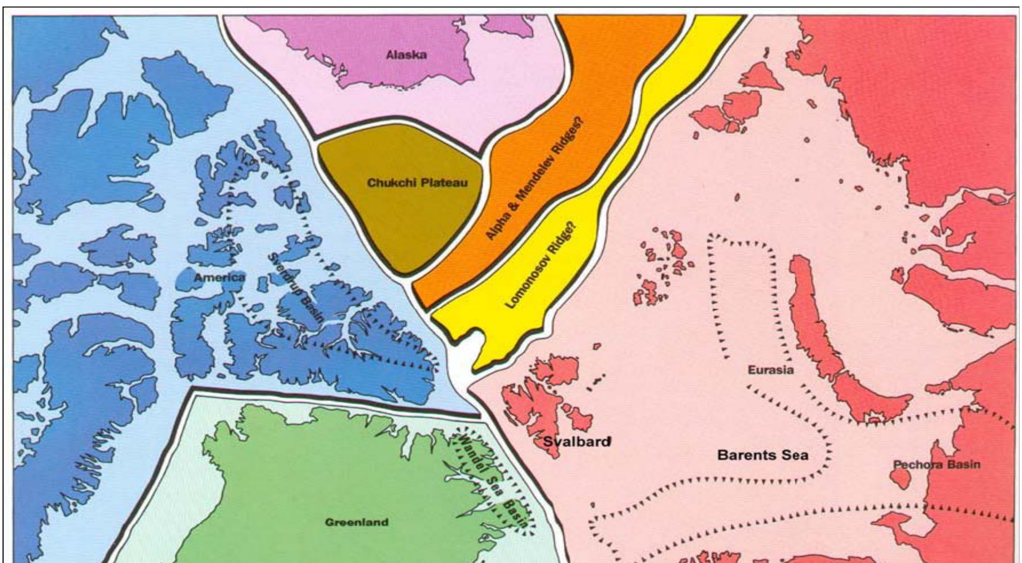


Figure 1 Plate configuration in the Arctic prior to opening of the Atlantic and the Polar Basin (from Worsley 1986).

Following the Caledonian Orogeny, Devonian extensional shearing took place, with rift basin deposition of a thick pile of mostly continental red-beds. A stratigraphic thickness of up to 8 km has been reported in two major, N-S trending grabens in north Spitsbergen. The lower parts are found along the present north-western margins of the grabens and rest directly upon deformed Hecla Hoek. These lower beds consist of coarse clastics, mainly of alluvial fan and fluvial origin. The middle and upper parts comprise a succession of fluvial and possible deltaic sediments**.**

Around the early/middle Devonian boundary there is a change from red to grey facies. It probably reflects a transition from semi-arid climatic regimes (typically of Old Red sedimentation) towards more humid conditions. The fluvial systems are represented by the lower red bed facies of braided streams flowing from the west towards the axial portions of the graben. The basinal axis was characterised by a general northwards tilt and flow of high sinuosity fluvial systems towards a coast to the north. The shift from red to grey sediments is accompanied by a general development towards an upward fining trend. Facies patterns and fossils in the grey sandstones and shales of northernmost Svalbard may suggest deposition in deltaic environments. Channel sands are interbedded with shales representing humid coastal plains and brackish water interdistributary bays. Comparable beds in the main graben further south consist of coarser clastics, coals and ironstones, clearly showing the humid nature of this hinterland area**.**

The so-called Svalbardian tectonic movements in Late Devonian were the result of large scale left-lateral movements along the Billefjorden Fault Zone (Figure 2, marked BFZ)**.** These movements caused folding of the Devonian sediments resulting in an angular unconformity towards the overlying Carboniferous succession (Figure 3).

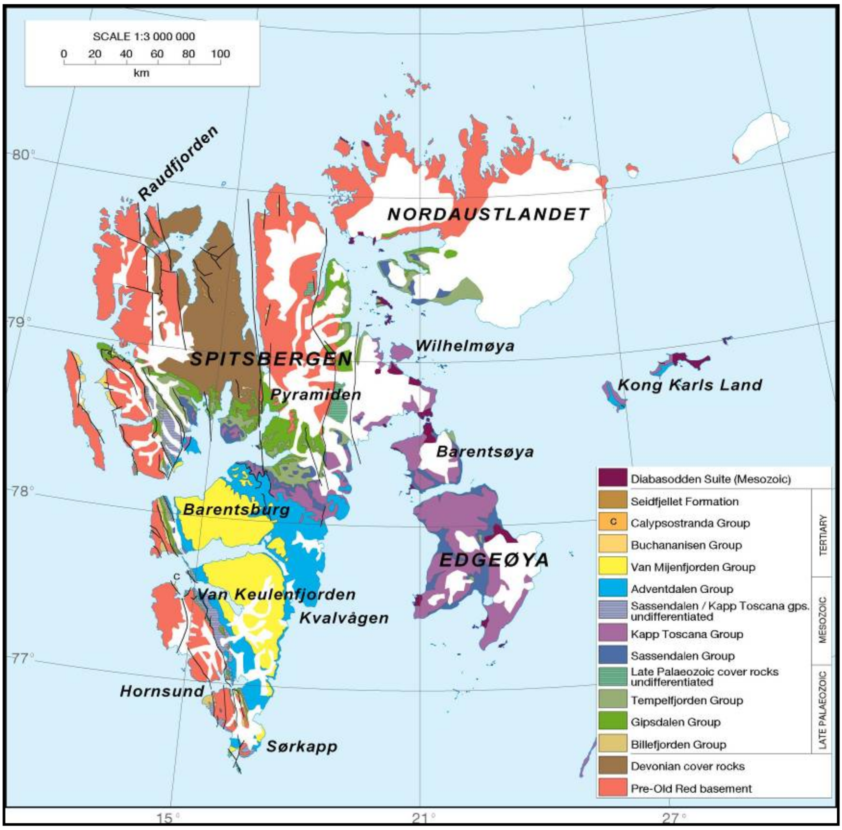


Figure 2 Simplified geological map of Svalbard (from Dallmann 1999).

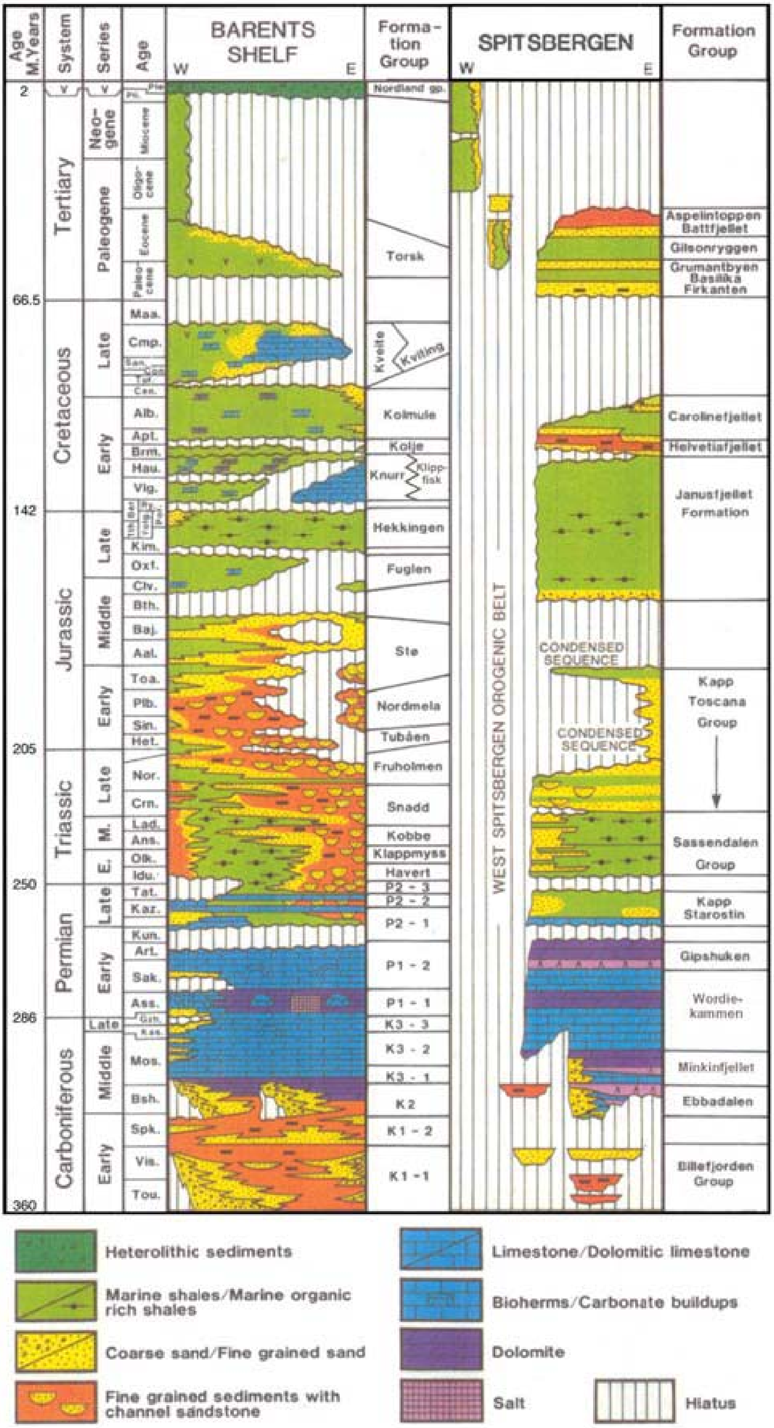


Figure 3 The Carboniferous to recent stratigraphy of Svalbard and the Barents Sea. (The stratigraphic nomenclature of this area was revised in 1999, resulting in changes of names and rank for a few units, see Figure 10) (Modified from Nøttvedt et al.,1993).

The early to middle Carboniferous comprise a period of extension, with a small component of left-lateral shear in the middle Carboniferous. The middle Carboniferous extension concentrated along a few major lineaments like the Billefjorden Fault Zone, which caused the formation of the Billefjorden Graben east of it (Figures 2 and 4). Areas of major faulting and pronounced graben formation shifted across Spitsbergen during this period with non-marine to marginal marine infill of up to 2 kilometre in thickness.

The Billefjorden Group (Figures 2 and 3) consists of conglomerates, sandstones, and coals. The group represent palaeoenvironments dominated by large humid alluvial fans which built out from active fault scarps into adjacent swamps lakes and fluvial plains (Figure 4)

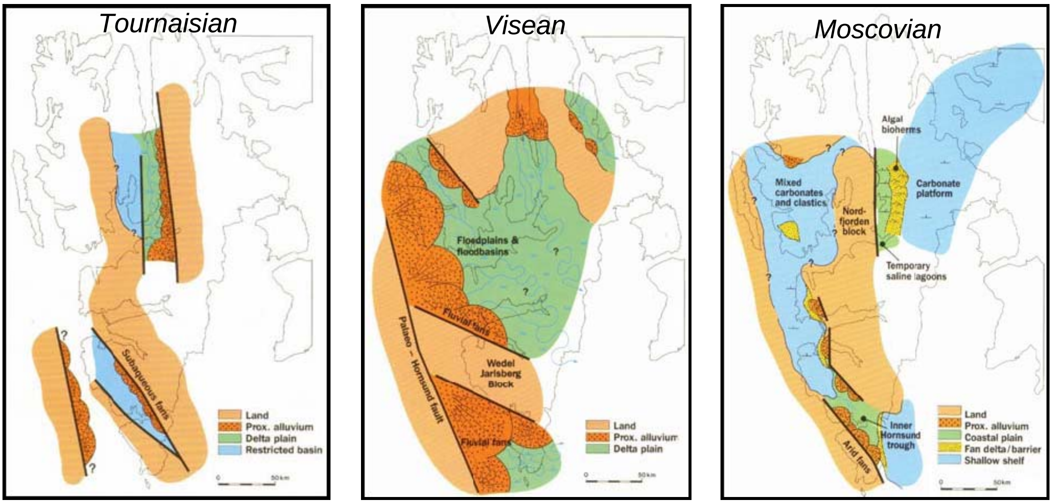


Figure 4 Carboniferous palaeogeography (from Worsley 1986)

The uppermost parts of the Billefjorden Group show decreasing subsidence rates and retreating fan systems being replaced by fine-grained marsh and floodplain deposits. These include the youngest coal-bearing Carboniferous strata, which were mined by Russians at Pyramiden in the innermost part of Billefjorden up to 1997 (See the excursion map in Figure10). This early Carboniferous succession is followed by up to 1 km of alluvial redbeds, marine carbonates and evaporites of the Gipsdalen Group continuing into the middle Carboniferous.

During the late Carboniferous, Permian and Mesozoic, a stable platform evolved, comprising Svalbard and large parts of the Barents Shelf. The lower Carboniferous-Permian succession consists of limestones, dolomites and evaporites grading upwards into cherty limestones and silicified shales/siltstones belonging to the Tempelfjorden Group (Figure 5).

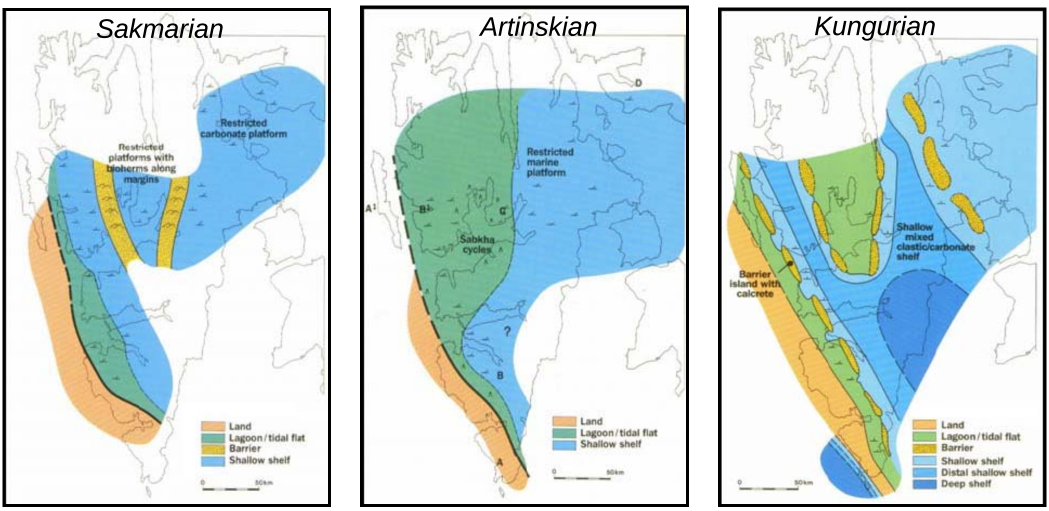


Figure 5a, b, c Permian palaeogeography (from Worsley 1986)

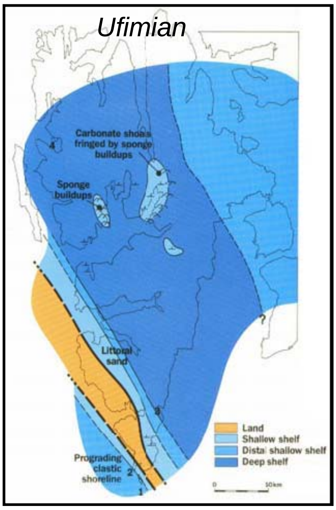


Figure 5 d Late Permian palaeogeography (from Worsley 1986)

The Permian - Triassic boundary is widely exposed on Svalbard and can also be traced throughout the Barents Sea Shelf as a pronounced reflector. During the late Permian and early Triassic the depositional centre was situated in the outer Isfjorden area. In this area continued sedimentation took place. Today cherty black shales are overlain by soft dark grey shale without any visible break. Further east on central Spitsbergen the upper Permian succession consists of well-cemented sandy carbonates, often glauconitic, which at the top has an erosional surface. Reworked Permian sediments often occur in the basal Triassic beds, which consist of sandstones grading to greenish grey shales. The break in sedimentation increases from the depocenter and both south- and eastwards, being most extensive at Edgeøya were the entire lower Lower Triassic is missing.

The Mesozoic succession consists of repeated cycles of siliciclastic coastal and deltaic progradations into a wide shelf basin. The passage from lower Permian carbonates and evaporites to upper Permian and Triassic clastics took place while the plate drifted towards higher palaeolatitudes. Numerous well developed upwards coarsening sequences from shales and siltstones to variable sandstones in the Triassic and early Jurassic (Sassendalen and Kapp Toscana groups, Figures 3 and 6), pass into more homogeneous shales in the late Jurassic early Cretaceous (Janusfjellet Subgroup).

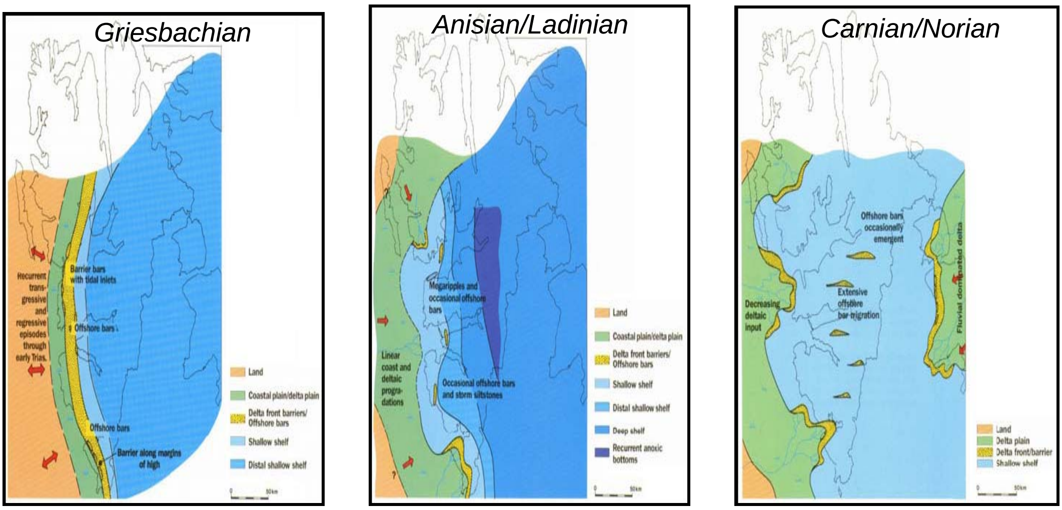


Figure 6 Triassic palaeogeography (From Worsley 1986)

The Lower and Middle Triassic Sassendalen Group is exposed along the Tertiary fold belt, in central and eastern Spitsbergen and on Barentsøya and Edgeøya. It represents series of stacked transgressive – regressive sequences, each being initiated by a significant transgression. In western Spitsbergen the group comprises deltaic to shallow shelf deposits grading eastwards and southwards into shelf mudstones. The upper part is highly organic and phosphatic and consists of fine-grained sandstones, siltstones and shales, representing shallow shelf deposition in an epicontinental sea (Figure 6).

The Upper Triassic to middle Jurassic Kapp Toscana Group is exposed in the same areas as the Sassendalen Group. The lower parts is made up of grey shales upwards grading into immature sandstones. This sandy interval contains a number of coarsening-upward units showing increasing proportions of sandstone towards the south-west, north-east and east. The uppermost part forms a condensed clastic sedimentary succession containing some thin phosphatic nodule layers. The Kapp Toscana Group was on Svalbard deposited in a generally nearshore, deltaic environment and is characterised by shallow marine and coastal reworking of deltaic sediments (Figure 6).

Overlying the Kapp Toscana Group, the Brentskardhaugen Bed is a 1 to 2 m thick, phosphatic conglomerate. It was deposited during the extensive Bathonian transgression initiating the deposition of the Adventdalen Group. On top of this bed the oolithic Marhøgda Bed is developed in several localities**.**

The Middle Jurassic to Early Cretaceous Adventdalen Group is widely exposed along the margins of the Central Basin, as well as in eastern Spitsbergen. The group is dominated by dark, marine mudstones, but also includes deltaic and shelf sandstones as well as thin, condensed carbonate beds (Figure 7).

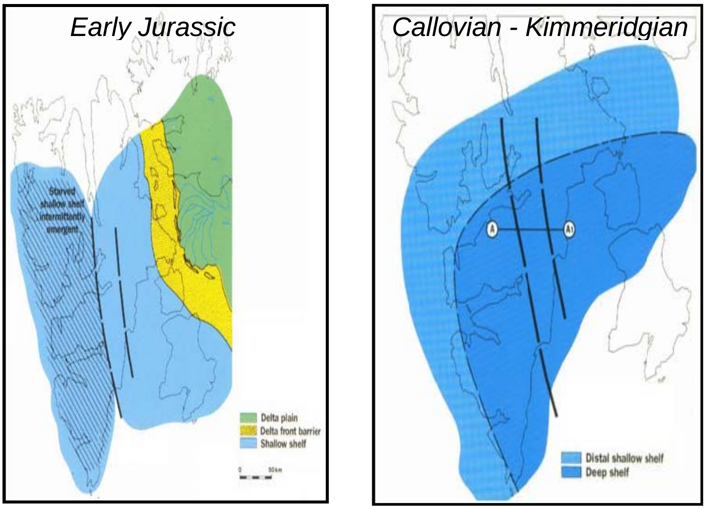
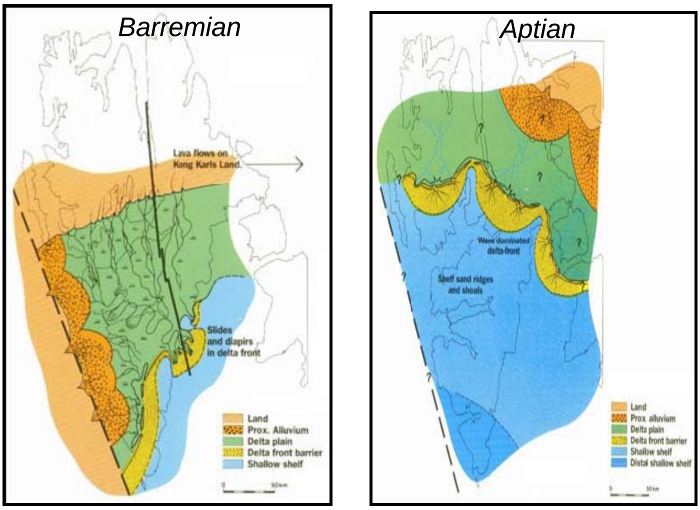


Figure 7 Jurassic palaeogeography (from Worsley 1986)

A hiatus occurs near the Jurassic – Cretaceous boundary. This hiatus is found a few meters below the Myklegardfjellet Bed, which consists of reddish-yellow to green plastic clays. It is an easily weathering marine deposit, rich in glauconite at some horizons.

In Early Cretaceous clays were deposited in a deeper shelf setting than before. These shales grade upwards into prodelta-deltafront siltstones and sandstones (Figure 8). These are overlain by a pronounced, prograding deltaic sandstone unit in the Barremian (Helvetiafjellet Fm.) which is succeeded by a series of transgressive, stacked shelf sandstones and siltstones (the Albian–Aptian Carolinefjellet Fm., Figure 8).



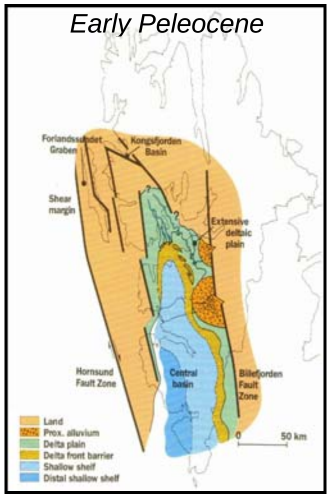


Figure 8 Early Cretaceous palaeogeography (Worsley 1986) *Fig 9 Paleocene paleogeogr.*

The Late Cretaceous opening of the Arctic Basin caused a northerly uplift and progressive soutwards development of the basal Tertiary unconformity. In central Spitsbergen, Aptian – Albian strata are succeeded by the Tertiary section, with an intervening angular unconformity.

The Tertiary deformation of Svalbard was the result of right-lateral transtension in the Paleocene followed by right-lateral transpression in the Eocene as Greenland slid by Svalbard during the initial opening of the North Atlantic - Arctic basins. The Tertiary Central Spitsbergen Basin may be regarded as a regional foreland depression with cyclic infill of mixed continental to marine clastics (Figure 9).

An overall transgressive package, from coal bearing deltaic deposits to marine sandstones and shales, characterises the transtensional phase. A large-scale regressive package, from marine shales to fluviodeltaic sandstones and shales is typical for the shift towards transpressional conditions. The change in tectonic regime is evidenced also by a mutual shift from easterly to westerly sediment input, reflecting the growing compression of the West Spitsbergen fold and thrust belt.

Plate Tectonic Constraints on The Formation of the Spitsbergen fold and thrust Belt *(modified from S. Bergh)*

The formation of the Spitsbergen fold and thrust belt was related to the break-up of the North-America, Greenland and Eurasian plates at the Yermark triple junction, and the subsequent 550Km of dextral strike-slip movement along the Hornsund Transform in the Eocene. It is generally accepted that the fold and thrust belt resulted from transpression (Harland 1969, Lowell 1972). Models for the tectonic movements between Greenland and Eurasia show convergence (Reknes & Vågnes 1985). The dating of the orogeny now seems well constrained, with the onset in the latest Paleocene. This is indicated by the shift from an easterly to a westerly siliciclastic source area in the Central Basin of Spitsbergen (Steel et al. 1985). The orogeny must have continued at least until deposition of the syn-orgenic Eocene formation. The latest Paleocene onset of the orogeny may predate the onset of sea-floor spreading in the Norwegian-Greenland Sea in the earliest Eocene, but the discrepancy is near the limit of resolution of the biostratigraphical dating available, and may thus be an artefact. On the other hand, part of the orogeny may have been a response to movements pre-dating the break-up of the continents. Late Cretaceous to early Paleocene dextral strike-slip movements are reported from the Trolle Land fault zone in the Wandel Sea Basin (Håkonsen & Pedersen 1982). Major Late Cretaceous subsidence and deposition is observed in the basins of central Norway. This is in striking contrast to the south-western Barents Sea where little coeval deposition is observed. In reconstructed position, the Trolle Land fault zone and the Senja fracture zone are aligned. We suggest that the Late Cretaceous extension to the south was taken up as dextral strike-slip movement along the Trolle Land Fault – Senja Fracture zones, thus shielding the south-western Barents Sea from Late Cretaceous extension. These movements caused deformation of Spitsbergen.

A latest Paleocene/earliest Eocene rifting episode formed a major Tertiary basin along the Senja margin in the south-western Barents Sea. The onset of the Spitsbergen Orogeny was a part of the same tectonic episode, a result of pre-drift movement between Greenland and Eurasia. Along the Harderfjord fault zone, 20 km of Tertiary dextral strike-slip has been reported (Higgins 1985). Furthermore, when Eurasia and Greenland are reconstructed to their late Paleocene positions, the trend of the Harderfjord fault zone intersects the Svalbard margin at the southern termination of the Spitsbergen fold and thrust belt. The Harderfjord fault zone also had a more westerly azimuth than the post-break-up direction of movement between Greenland and Eurasia. These observations are consistent with a model in which a wedge of crust, limited to the south by the Harderfjord fault zone, became squeezed northward. This resulted in transpression along the Harderfjord fault zone. At this time the Spitsbergen Orogeny may be seen as the south-easternmost part of the Eurekan Orogeny. (Fig.10A). Increasing movement forced a break between Greenland and Eurasia, initiating large scale strike-slip movements between Eurasia and Greenland and producing the post-break-up part of the orogeny. The geometry of the initial plate boundary was probably a compromise between the direction of plate motion and the Harderfjord fault zone trend. The larger the impact of the Harderfjord fault zone trend on the initial plate boundary, the more transpression on Spitsbergen. An average of 30 km of shortening along the fold and thrust belt may easily be accommodated in such a model (Fig 10B). The fold and thrust belt does not cover the full length of the palaeo-transform. A trend-shift in the plate boundary of Kongsfjorden, north-western Spitsbergen, would explain its northward termination. Evidence for such a northward shift in the azimuth of the present ocean-continent boundary has been reported (Eiken & Austgård 1988). Major orogenic activity ended in the late Eocene (40 Ma). When Greenland had slid past Svalbard a distance equal to the plate boundary the direction of movements had become parallel to EW-lines along the whole Spitsbergen fold and thrust belt. The pre-Oligocene trend is thus a product of transpression. (Fig.10D).

In earliest Oligocene, the Greenland plate became part of the North-American plate. The Yermark Triple Junction became extinct and extension became dominant between Spitsbergen and Northeast Greenland, probably overprinting some of the compressive structures. The present lineaments along the Hornsund trend and the Forlandsundet Graben are likely a result of post-orogenic movements, which may have commenced in the late Eocene. Important information regarding the orogeny, particularly the position of main transform fault, was probably erased by this event.

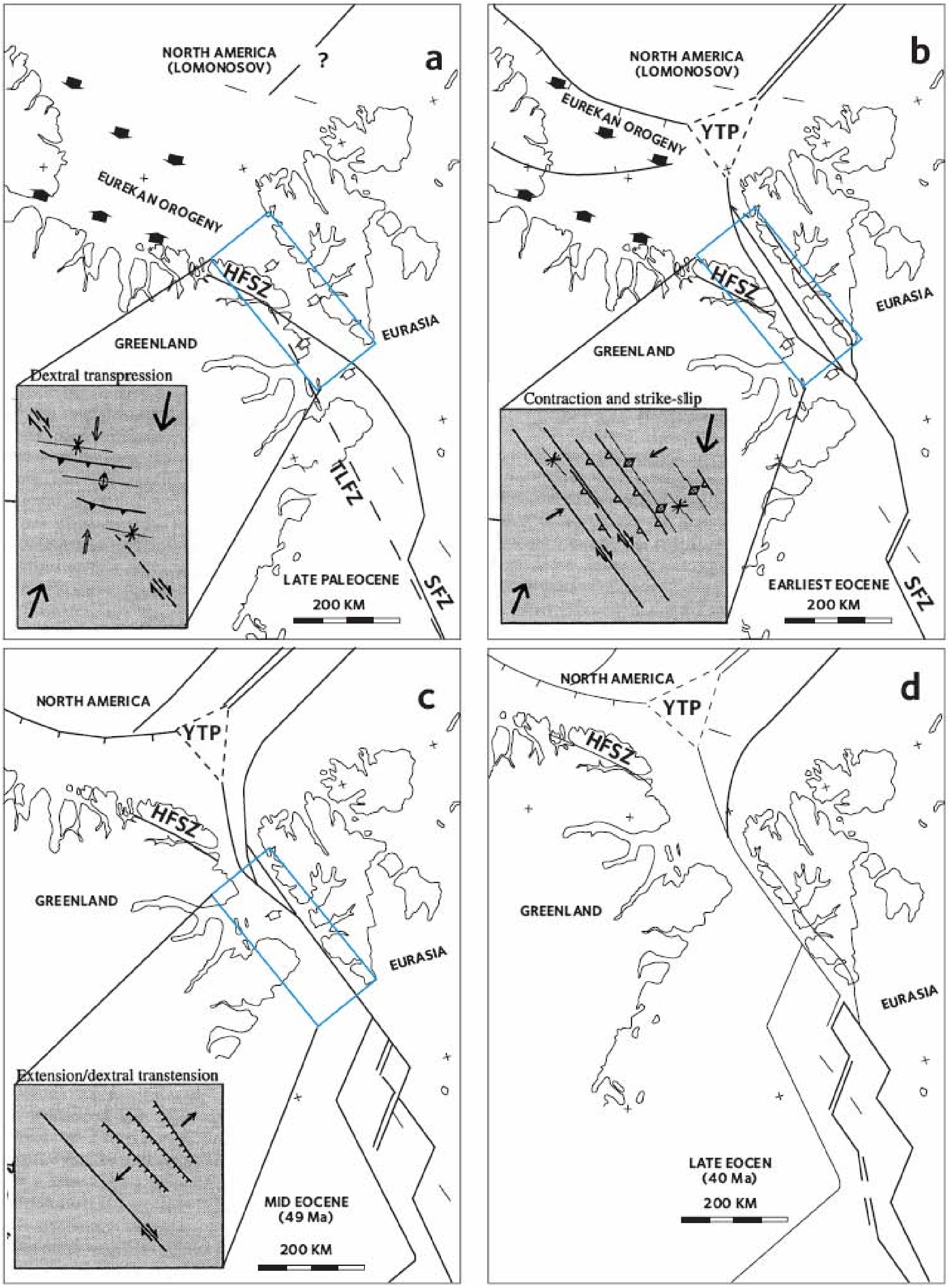


Fig 10 a, b, c & d: Schematic illustration of the interaction between plate movement and the plate boundary during Tertiary orogenesis on Spitsbergen. (YTP=Yermak Triple Junction, HFFZ=Harder Fjord Fault, TLFZ=Trolla Land Fault Zone, SFZ=Senja Fracture Zone). Modified from Vågnes (1985) and Berg (1995).

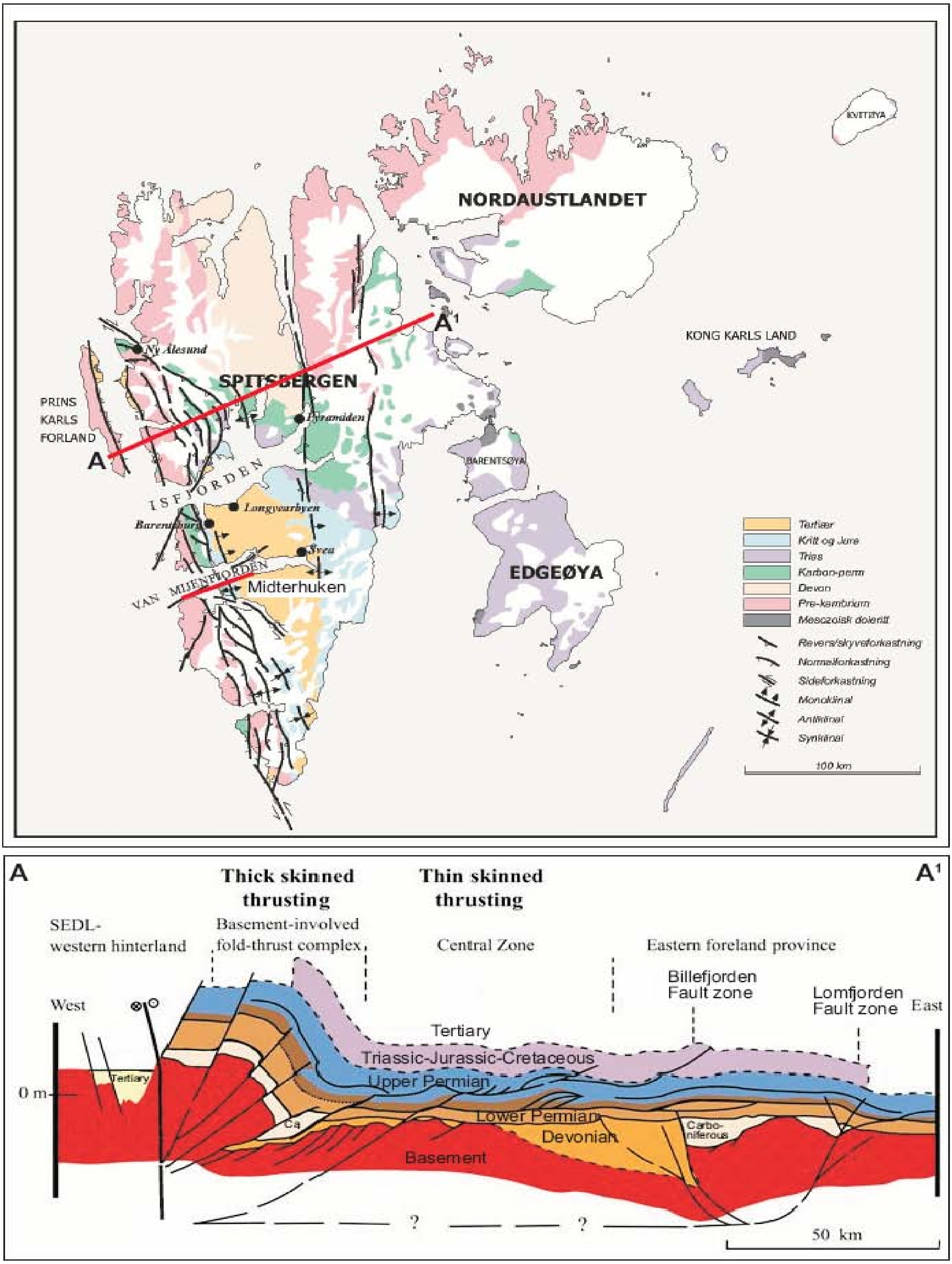


Fig 11 Schematic cross-section illustrating theTertiary deformation in Central Spitsbergen. (From Bergh et al., 1988a).

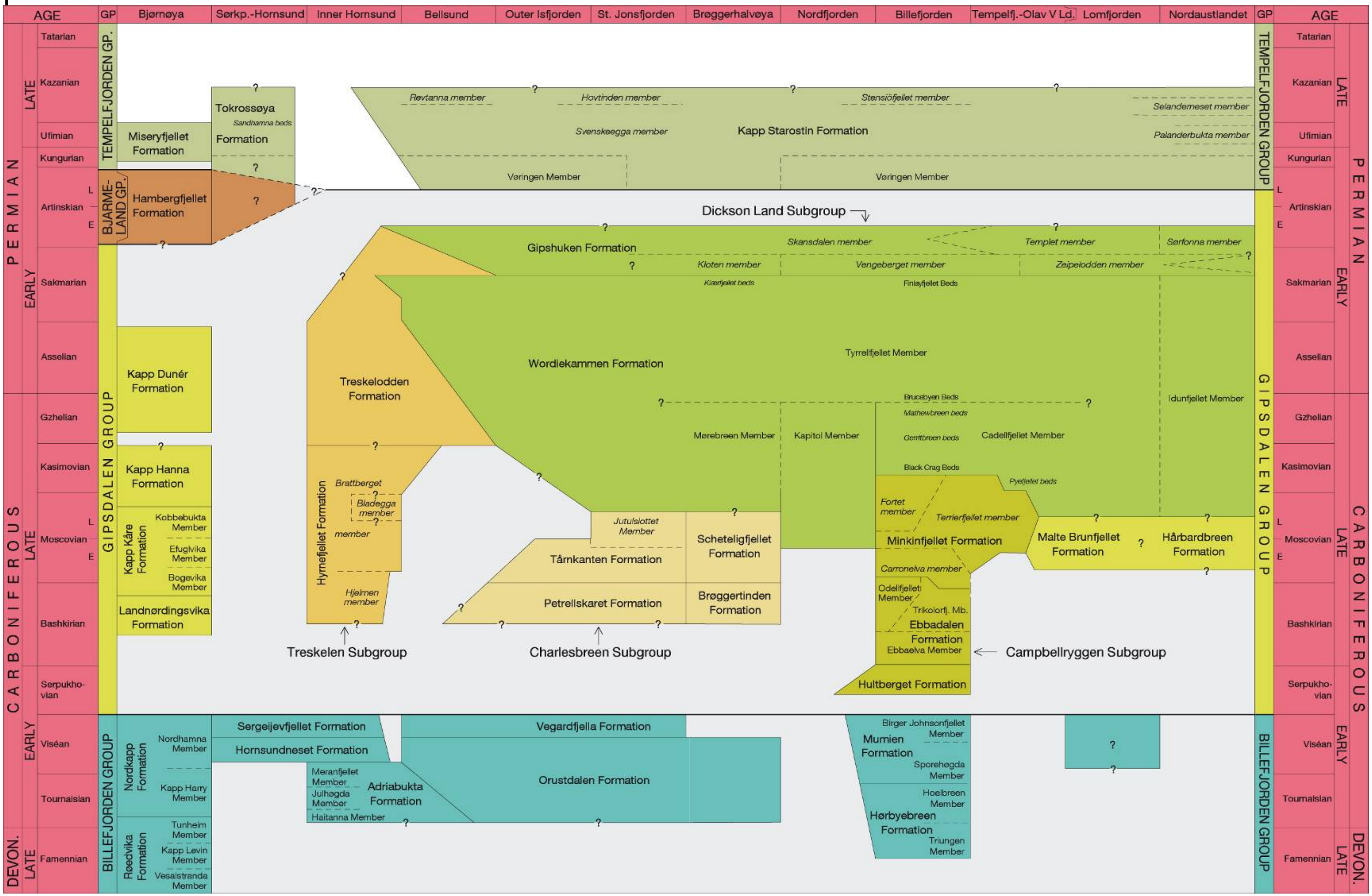

AGE
GP
Bjørnøya
Sørkp.-Hornsund
Inner Hornsund
Bellsund
Outer Isfjorden
St. Jonsfjorden
Brøggerhalvøya
Nordfjorden
Billefjorden
Tempelfj.-Olav V Ld.
Lomfjorden
Nordaustlandet
PERMIAN
CARBONIFEROUS
DEVON.
LATE
EARLY
Tatarian
Kazanian
Ufimian
Kungurian
Artinskian
Sakmarian
Asselian
Gzhelian
Kasimovian
Moscovian
Bashkirian
Serpukhovian
Viséan
Tournaisian
Famennian
TEMPELFJORDEN GP.
TEMPELFJORDEN GROUP
BJARME-LAND GP.
GIPSDALEN GROUP
BILLEFJORDEN GROUP
Miseryfjellet Formation
Tokrossøya Formation
Sandhamna beds
Hambergfjellet Formation
Kapp Starostin Formation
Røvtanna member
Hovtinden member
Stensiöfjellet member
Selanderneset member
Svenskeegga member
Palanderbukta member
Vøringen Member
Dickson Land Subgroup
Gipshuken Formation
Skansdalen member
Templet member
Sørfonna member
Kloten member
Vengeberget member
Zeipelodden member
Kiærfjellet beds
Finlayfjellet Beds
Wordiekammen Formation
Tyrrellfjellet Member
Treskelodden Formation
Kapp Dunér Formation
Kapp Hanna Formation
Brucebyen Beds
Mathewbreen beds
Gerritbreen beds
Black Crag Beds
Idunfjellet Member
Mørebreen Member
Kapitol Member
Cadellfjellet Member
Pyefjellet beds
Fortet member
Terrierfjellet member
Minkinfjellet Formation
Malte Brunfjellet Formation
Hårbardbreen Formation
Carronelva member
Odellfjellet Member
Trikolorfj. Mb.
Ebbadalen Formation
Ebbaelva Member
Hultberget Formation
Campbellryggen Subgroup
Kapp Kåre Formation
Kobbebukta Member
Efuglvika Member
Bogevika Member
Landnørdingsvika Formation
Hyrnefjellet Formation
Brattberget member
Bladegga member
Hjelmen member
Treskelen Subgroup
Jutulslottet Member
Tårnkanten Formation
Scheteligfjellet Formation
Petrellskaret Formation
Brøggertinden Formation
Charlesbreen Subgroup
Sergeijevfjellet Formation
Hornsundneset Formation
Vegardfjella Formation
Orustdalen Formation
Meranfjellet Member
Julhøgda Member
Haitanna Member
Adriabukta Formation
Nordkapp Formation
Nordhamna Member
Kapp Harry Member
Røedvika Formation
Tunheim Member
Kapp Levin Member
Vesalstranda Member
Mumien Formation
Birger Johnsonfjellet Member
Sporehøgda Member
Hørbyebreen Formation
Hoelbreen Member
Triungen Member

Fig.12A

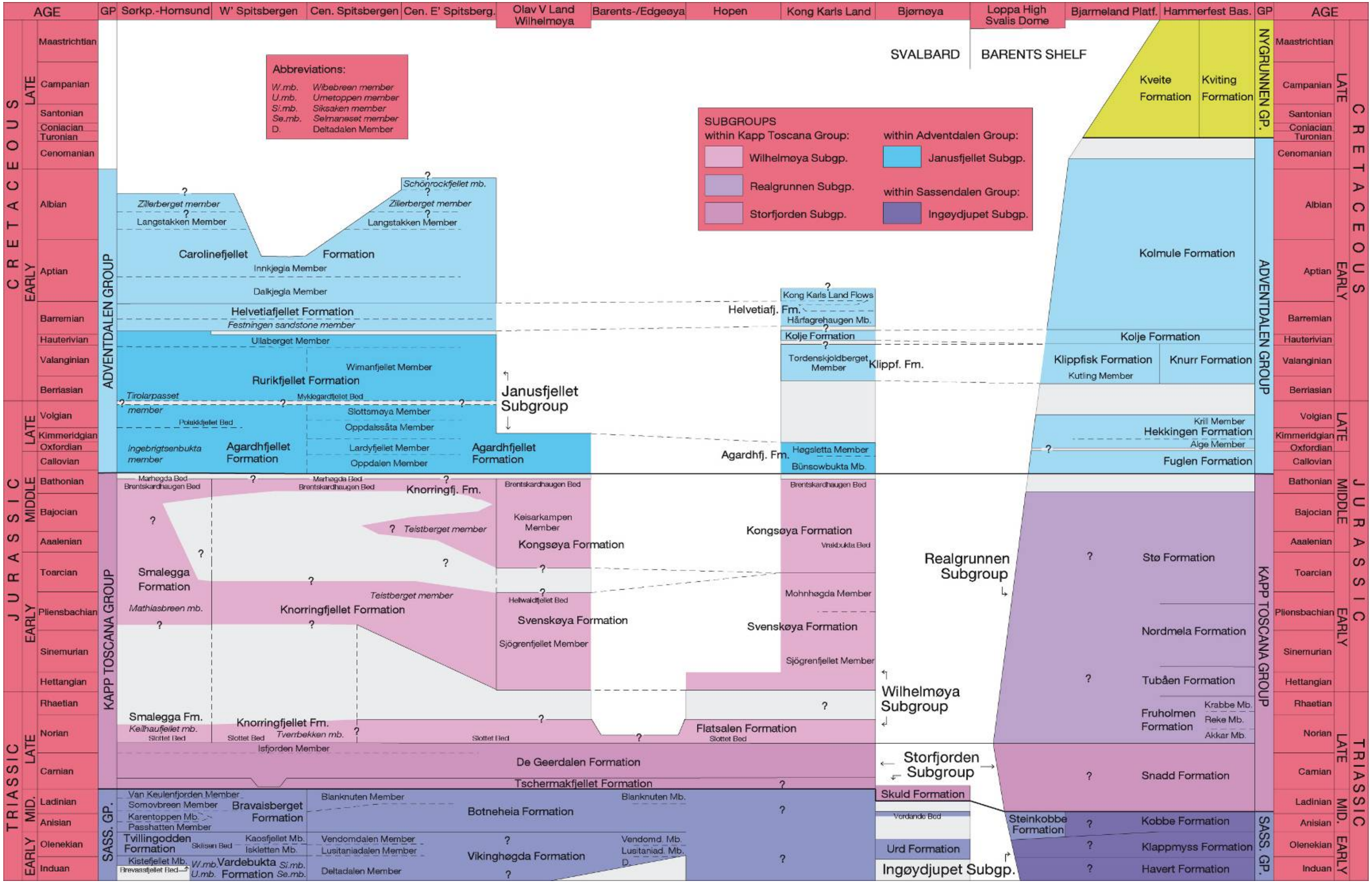

AGE
GP
Sørkp.-Hornsund
W' Spitsbergen
Cen. Spitsbergen
Cen. E' Spitsberg.
Olav V Land Wilhelmøya
Barents-/Edgeøya
Hopen
Kong Karls Land
Bjørnøya
Loppa High Svalis Dome
Bjarmeland Platf.
Hammerfest Bas.
SVALBARD
BARENTS SHELF
CRETACEOUS
JURASSIC
TRIASSIC
LATE
EARLY
MIDDLE
MID.
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Volgian
Kimmeridgian
Oxfordian
Callovian
Bathonian
Bajocian
Aalenian
Toarcian
Pliensbachian
Sinemurian
Hettangian
Rhaetian
Norian
Carnian
Ladinian
Anisian
Olenekian
Induan
Abbreviations:
W.mb. Wibebreen member
U.mb. Urnetoppen member
Si.mb. Siksaken member
Se.mb. Selmaneset member
D. Deltadalen Member
SUBGROUPS
within Kapp Toscana Group:
Wilhelmøya Subgp.
Realgrunnen Subgp.
Storfjorden Subgp.
within Adventdalen Group:
Janusfjellet Subgp.
within Sassendalen Group:
Ingøydjupet Subgp.
ADVENTDALEN GROUP
KAPP TOSCANA GROUP
SASS. GP.
NYGRUNNEN GP.
Kveite Formation
Kviting Formation
Schønrockfjellet mb.
Zillerberget member
Langstakken Member
Carolinefjellet Formation
Innkjegla Member
Dalkjegla Member
Helvetiafjellet Formation
Festningen sandstone member
Ullaberget Member
Wimanfjellet Member
Rurikfjellet Formation
Tirolarpasset member
Myklegardfjellet Bed
Slottsmøya Member
Oppdalssåta Member
Lardyfjellet Member
Oppdalen Member
Polakkfjellet Bed
Ingebrigtsenbukta member
Agardhfjellet Formation
Janusfjellet Subgroup
Kong Karls Land Flows
Helvetiafj. Fm.
Hårfagrehaugen Mb.
Kolje Formation
Tordenskjoldberget Member
Klippf. Fm.
Høgsletta Member
Agardhfj. Fm.
Bünsowbukta Mb.
Kolmule Formation
Klippfisk Formation
Kutling Member
Knurr Formation
Krill Member
Hekkingen Formation
Alge Member
Fuglen Formation
Marhøgda Bed
Brentskardhaugen Bed
Knorringfj. Fm.
Keisarkampen Member
Kongsøya Formation
Teistberget member
Smalegga Formation
Mathiasbreen mb.
Knorringfjellet Formation
Hellwaldfjellet Bed
Svenskøya Formation
Sjögrenfjellet Member
Vraldbukta Bed
Mohnhøgda Member
Realgrunnen Subgroup
Stø Formation
Nordmela Formation
Tubåen Formation
Wilhelmøya Subgroup
Fruholmen Formation
Krabbe Mb.
Reke Mb.
Akkar Mb.
Smalegga Fm.
Keilhaufjellet mb.
Slottet Bed
Knorringfjellet Fm.
Tverrbekken mb.
Flatsalen Formation
Isfjorden Member
De Geerdalen Formation
Tschermakfjellet Formation
Storfjorden Subgroup
Snadd Formation
Van Keulenfjorden Member
Somovbreen Member
Karentoppen Mb.
Passhatten Member
Bravaisberget Formation
Blanknuten Member
Botneheia Formation
Blanknuten Mb.
Skuld Formation
Verdande Bed
Steinkobbe Formation
Kobbe Formation
Tvillingodden Formation
Skilisen Bed
Kaosfjellet Mb.
Iskletten Mb.
Vendomdalen Member
Lusitaniadalen Member
Vikinghøgda Formation
Vendomd. Mb.
Lusitaniad. Mb.
Urd Formation
Klappmyss Formation
Kistefjellet Mb.
Brevassfjellet Bed
Vardebukta Formation
Deltadalen Member
Ingøydjupet Subgp.
Havert Formation

Fig.12B

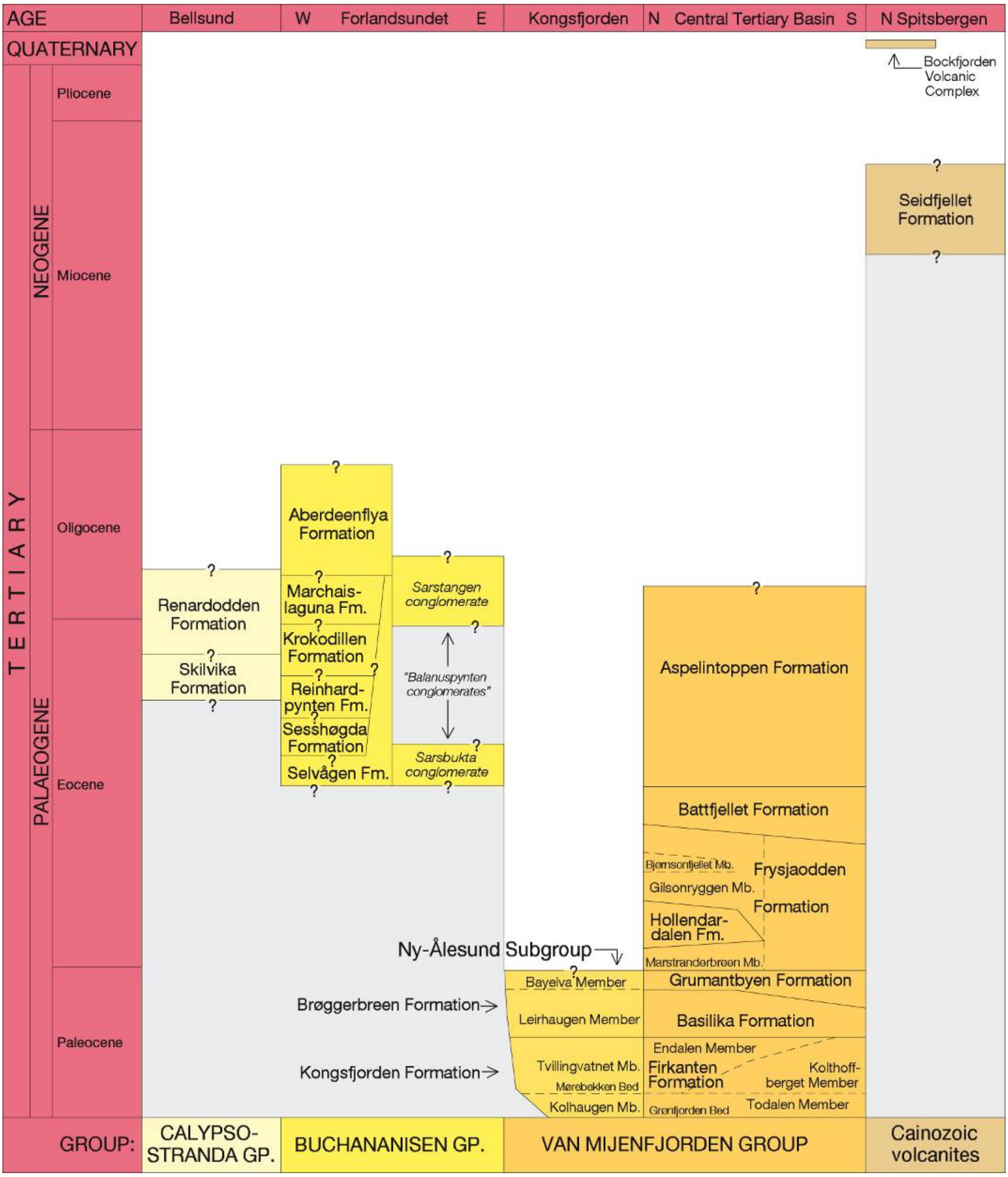


Fig 12C

Fig. 12 Proposed lithostratigraphic scheme for the Upper Palaeozoic (A), Mesozoic (B) and Tertiary (C) of Svalbard. The diagram contains all names recommended by SKS at group, subgroup, formation, member and bed levels. Member and bed names in italics represent informal units. The ages and age boundaries of the units are indicated in accordance with existing data, but are admittedly schematic. Possible diachronous boundaries are drawn straight unless reliable data can document the diachronism. The indicated major hiati are also drawn schematically and do not claim any precision concerning their age range. Minor hiati are omitted. Vertical lines between formations may represent interfingering relationships. (From Dallmann, 1999).

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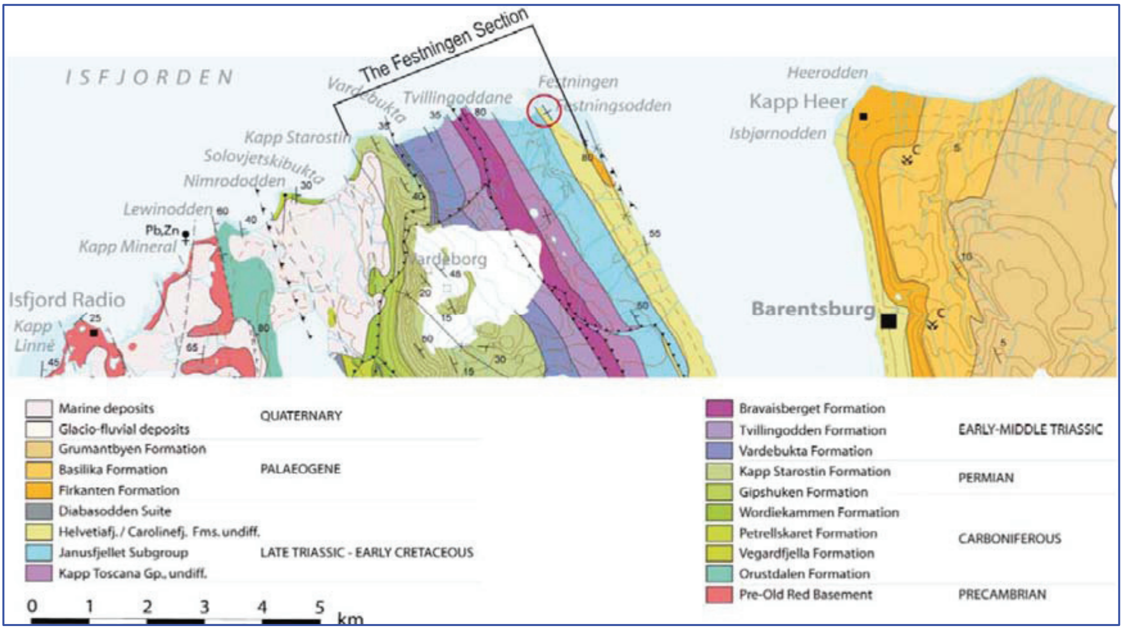
Excursion localities

Day 1, Stop 1: *FESTNINGEN*

(modified from Mørk & Worsley, 2006)



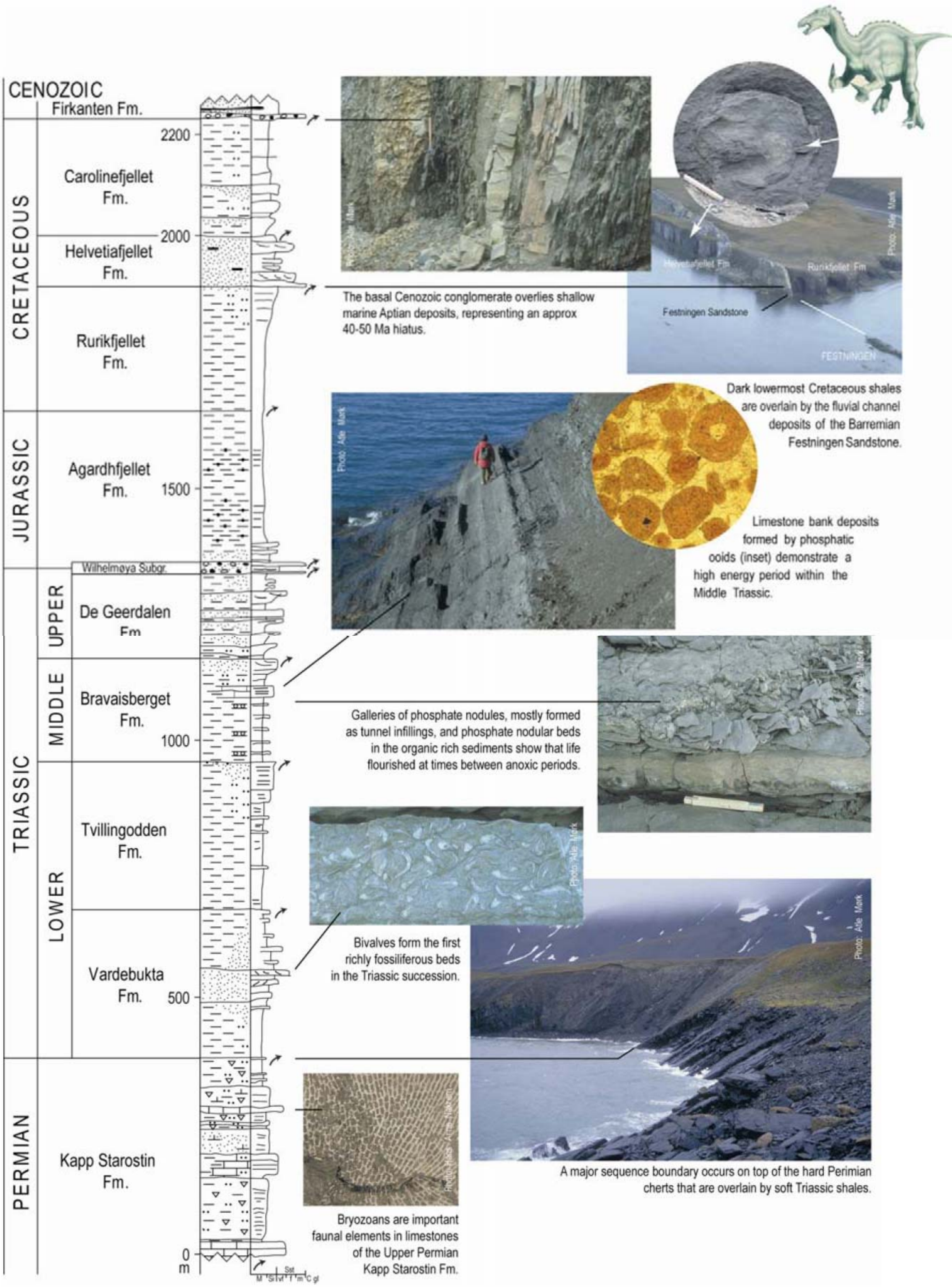
Geological map of the Festningen Section enlarged in the lower part .

The section is named after Festningen ("The Fortress"), a small islet with a lighthouse marking the western approaches to Grønfjorden. Only scattered exposures of carbonates and some remains of collapse breccias representing Upper Carboniferous to lowermost Permian evaporites and carbonates can be seen under well-exposed Upper Permian limestones and cherts. The 400 m thick Kungurian to Upper Permian Kapp Starostin Formation has bioclastic limestone banks with brachiopods and bryozoans at its base (Vøringen Member). These limestones grade up into siliceous shales with deeper and colder water faunas, including prolific siliceous sponges and bryozoans; spectacular zoophycoid burrows are also common. These spiculites alternate with sandy silicified limestones in a series of three transgressive regressive sequences in this type section.

The Triassic succession of the Festningen section is represented by five formations, each starting with a major sequence boundary. The 290 m thick basal (Induan) Vardebukta Formation consists of deep shelf shales with occasional storm siltstones low in the formation grade upwards into massive sandstones and fossiliferous (*Myalina* bivalves) beds with conspicuous *Skolithos* in the shallowest coastal bar. Above this bar complex deepening again occurs, with more shales and siltstones in the upper part of the formation. The aftermath of the late Permian mass extinction can be seen as fossils are sparse in the uppermost Permian spiculitic shales and virtually absent in the lower 100 metres of the soft Vardebukta Fm claystones. Even trace fossils are quite sparse here.

The 220 m thick Olenekian Tvillingodden Formation also represents a major coarsening upward succession. Parallel-laminated beds with sparse fossils and little bioturbation grade up into shallow shelf interlaminated shales and siltstones. Occasional lenticular carbonate concretions may contain well preserved ammonoids. Interesting assemblages of *Rhizocorallium jenense* in the upper part of the unit indicate improved living conditions. A topmost bed contains mixed Spathian and Anisian brachiopods and bivalves and represents the basal Anisian transgression.

The ca 200m thick Bravaisberget Formation (Anisian-Ladinian) here consists of dark shales at its base with thick calcareous siltstone beds. Poorly preserved ammonoids are abundant. Phosphatic



Schematic interpretative section through the sediments from the Late Permian to the base Cenozoic. Thickness values are approximate as strong compression may have taken place in the shaly units.

nodules, occurring as *Thalassinoides* tunnel fillings and as nodular horizons occur repeatedly through the lower part of the formation. Towards the top of the formation thinly laminated beds with abundant phosphatic oolites and microcoquinal shell fragments form a few metre thick unit. The microcoquina beds are thought to represent the remains of mass-deaths of juvenile bivalves. The interplay of highly burrowed siltstone beds, galleries of *Thalassinoides* tunnels, organic rich mudstone and these microcoquinas indicate fluctuating oxygen levels during deposition. The upper part of the formation consists of silt- and sandstones deposited above wave base.

The organic rich and soft Middle Triassic shales (Bravaisberget Fm) have been strongly folded making stratigraphic studies complicated.

A major transgression led to changing sedimentational regimes at the advent of the late Triassic. Over most of Svalbard a prodeltaic shale unit, the Tschermakfjellet Formation, consisting of grey (organic-lean) shales with red weathering siderite nodules, marks the base of the Kapp Toscana Group – here about 300 m thick. The Tschermakfjellet Fm is only represented by a few metres of shale below the De Geerdalen Formation, which has repeatedly small coarsening upwards rhythms from shales to thin sandstone beds interpreted as sand banks and shoals deposited in a moderately deep to shallow shelf. The uppermost 70 m (early Norian) of the formation show greenish and red mudstones indicate restricted (?lagoonal) depositional environments.

A thin polymict conglomerate containing pebbles of quartz and phosphate forms the transgressive Slottet Bed of the Wilhelmøya Subgroup. This subgroup, here represented by the 18 m thick highly condensed beds of the Knorringfjellet Formation and the Triassic – Jurassic boundary occurs within this unit. It is abruptly overlain by a widespread polymict phosphate nodule containing bed, the Brentskardhaugen Bed or “Lias conglomerate”, with remanié fossils of Toarcian to ? Bajocian age.

Callovian marine sandstones overlie the conglomerate and initiate a highly tectonised approximately 400 m thick black shale unit, the Janusfjellet Subgroup. Its Jurassic part, the Agardhfjellet Formation, contains abundant organic rich paper shales, which are elsewhere an excellent source rock for hydrocarbons. Separated by an unconformity the lowermost Cretaceous Rurikfjellet Formation is also organic-rich, but without oil-prone kerogen. This forms a coarsening upward and shallowing succession, in its upper part loaded with characteristic cannon-ball concretions.

Fluvial sandstones of the Festningen sandstone itself follow with a marked erosional contact. Here three thick distributary channels are preserved as near-vertical beds, the lowermost of which has revealed dinosaur footprints of an ornithopod herbivore, previously referred to *Iguanadon*. These beds belong to the 75 m thick fluviodeltaic Barremian Helvetiafjellet Fm, whose upper parts show a gradual transgression to the shallow marine sandstones lowermost in the Aptian to Albian Caroline-fjellet Fm. This 320 m thick unit shows increasing clay content and deeper storm-generated silt- and sandstones upwards. The occurrence of Glendolites indicates significantly cooling water conditions.

Day 1, Stop 2: *BARENTSBURG*

Heroic Soviet-style mural on the sports centre building, Barentsburg

Barentsburg is the second largest settlement on Svalbard, with about 850 inhabitants, almost entirely Russians and Ukrainians. The main economic activity is coal mining by the Arktikugol company, although tourism is beginning to be developed. The distance from Longyearbyen to Barentsburg is about 55 km, however there are no roads connecting the two settlements.

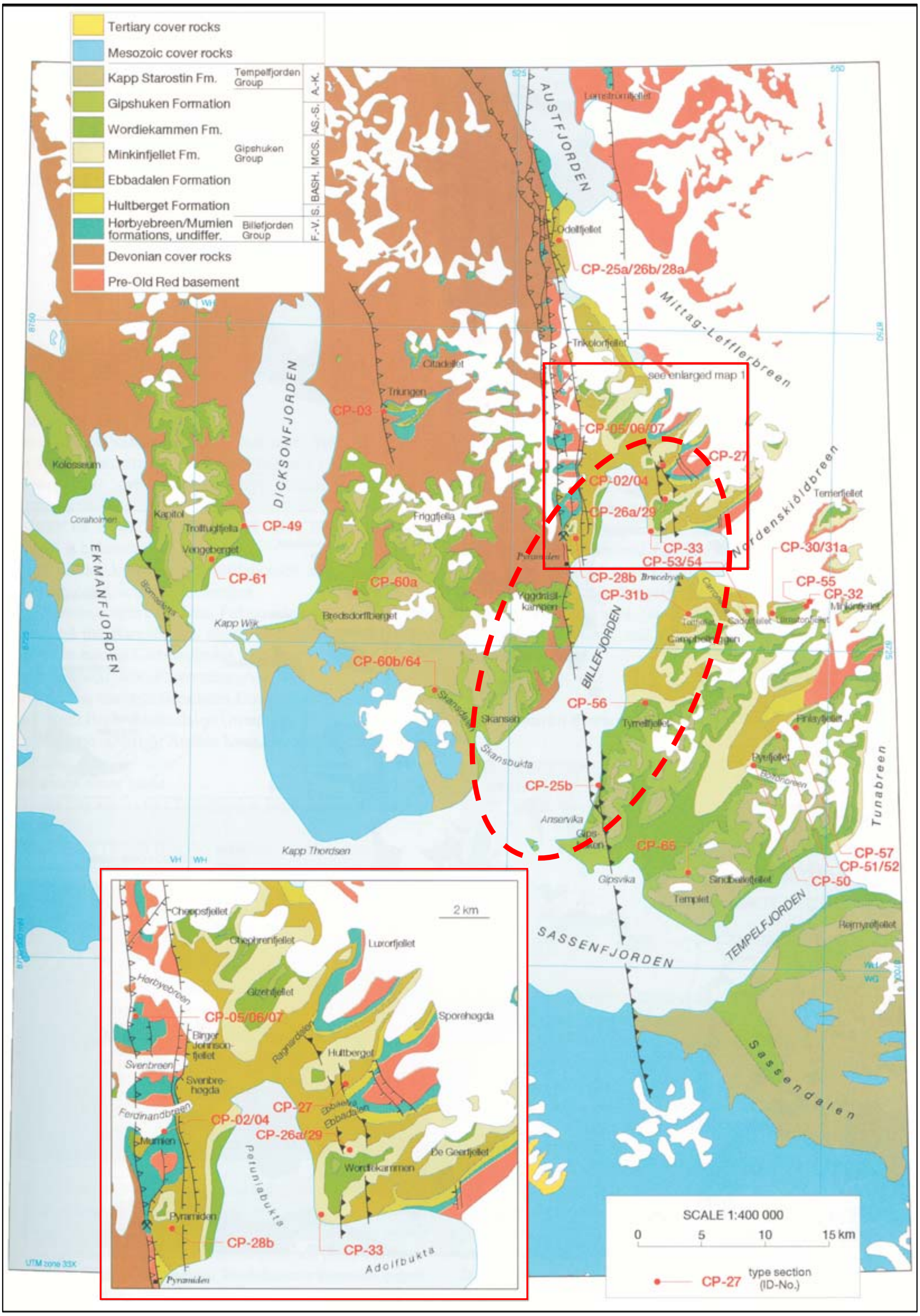
Although coal is still mined in Barentsburg, it is no longer exported, and the town relies entirely on mainland Russia for food and coinage. There have been instances when not enough food is sent, and aid packages are sent from Longyearbyen. Also, the coal company has been known not to pay employees until they finish their three year contract, and have returned to Russia.

Tourism, although budding, is still not generating enough income to revive the town.

During the Soviet era, Barentsburg was used as a posterchild for Communism in the arctic, and as such was well maintained and populated. However, after the end of the USSR, the town fell into decay, and today is a mere shadow of its former self.

Day 2, BILLEFJORDEN AREA

From Grønfjorden we continue to Billefjorden where we will focus on the Upper Carboniferous geology. This area offers superb exposures of seismic-scale outcrops, analogues to subsurface Barents Sea geology.



Tectonic and stratigraphic framework

The bedrock map of the Billefjorden area shows that the upper Palaeozoic rests unconformably on Caledonian metamorphic rocks or deformed Devonian predominately siliciclastics rocks.

The most important structural feature in the Dickson-Bünsow Land area is the Billefjorden Fault Zone, a long-lived tectonic element that runs approximately north-south from north-eastern Dickson Land, across Billefjorden and into south-western Bünsow Land (Gipshuken). The fault is an old structural element with evidence of movements since late Precambrian. However it also appears to have been active in Late Devonian, Carboniferous and Tertiary times (e.g. Harland et al. 1974, Mc Cann & Dallmann 1996). Differential subsidence along the Billefjorden Fault Zone during the Carboniferous created a major half graben, which is generally referred to as the Billefjorden Trough which represents the western margin of the Ny Friesland Block (Harland et al. 1974). The footwall area west of the Billefjorden Fault is the Nordfjorden Block.

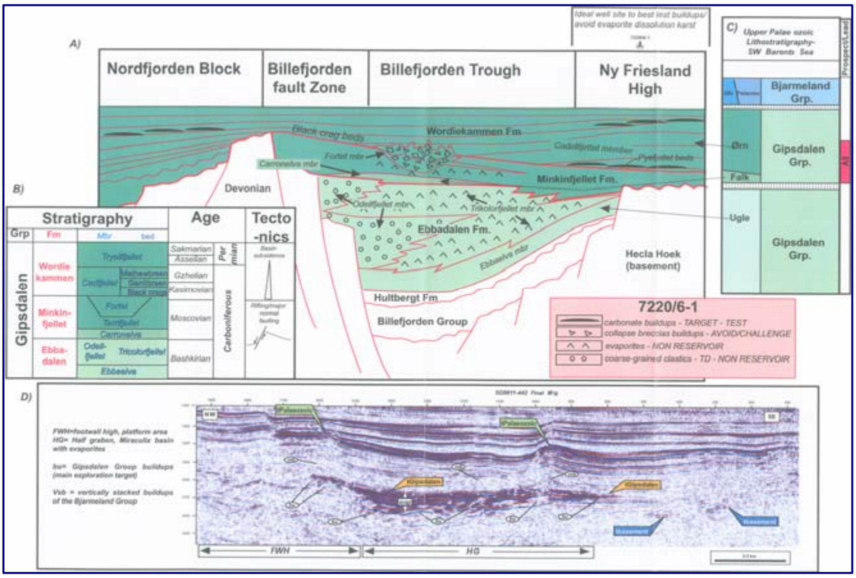


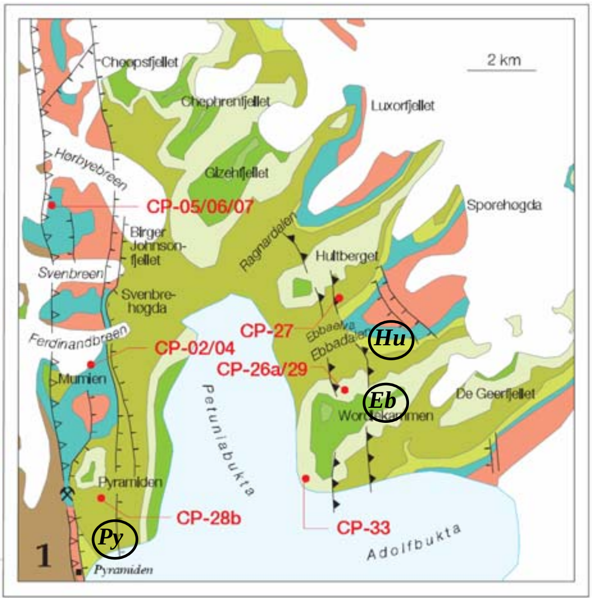
Diagram attempting to show comparasion between the outcrops on Svalbard and the Loppa High. A) Schematic cross section across the Billefjorden Trough. The Billefjorden Gp, Hultberget, Ebbadalen and Minkinfjellet formations represent synrift deposits, while Wordiekammen Fm represents post-rift deposits (From Eliassen and Talbot, 2003). B) Outcrop stratigraphic nomenclature and C) comparasion to the lithostratigraphic scheme used in the S. Barents Sea (Larssen et al., 2005).

D) Comparison to seismic line through the Loppa High showing a similar fault control on facies distribution in a location downdip and basinward of the 7220/6-1 drill site. It is thought that the outcrop in the Billefjorden area thus represent more basinal environments than iis to be expected at the Obelix 7220/6-1 drill site.

The development of the Tertiary West Spitsbergen Fold Belt in the Paleocene-Eocene involved compressive reactivation of the basement–sealed Billefjorden Fault Zone. In the Billefjorden-Wijdefjorden area this produced a large monoclinal fold across the fault zone, which was later cross-cut by extensional structures to produce the present day Billefjorden syncline. The Billefjorden Trough is a good analogue to Carboniferous graben structures in the Barents Sea.

Carboniferous and Permian strata form the bulk of the rock succession exposed in Dickson Land and Bünsow Land. Pre-mid-Moscovian sediments of the Billefjorden Group and Ebbadalen Formation of the Gipsdalen Group were confined to the Billefjorden Trough. In mid-Moscovian the Nordfjorden Block was gradually transgressed with carbonate platform while more basinal deposits including significant evaporite deposits accumulated in the Billefjorden Trough. By the end Carboniferous the Billefjorden Trough were filled and carbonate platforms developed across the entire area until the mid-Sakmarian time when the restricted marine deposits of the Gipshuken Formation were deposited. There is a major unconformity associated with extensive karst development separating the Gipshuken Formation from the Upper Permian cherts of the Kapp Starostin Formation, Tempelfjorden Group. Triassic rocks are only exposed on the southern part of Dickson Land.

Day 2, Stop 1: *PYRAMIDEN*



Geological map of the Billefjorden area showing the location of Pyramiden.

Py – Pyramiden. Marginal clastic sequences
Hu. Hultberget. Shallow basinal sequences
Eb. Ebbadalen South. Shallow basinal sequences

The Pyramiden town with the mountain Pyramiden to the north. Reddish brown rocks to the left are Devonian. The black rocks are the Lower Carboniferous coaly Billefjorden Group overlaid by alluvial red-bed dominated succession and with Upper Carboniferous greyish carbonates of the Minkinfjellet and Wordiekammen formations. (Photo by Asle Strøm).

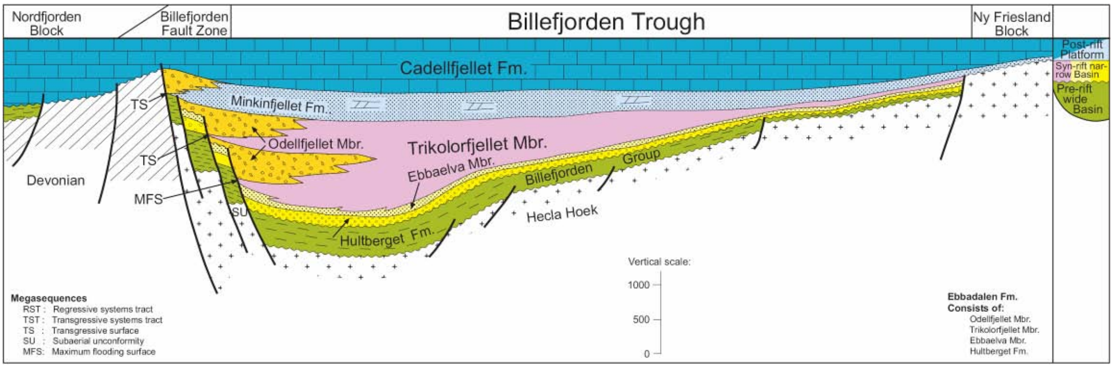
The Pyramiden is a former Russian mining town which produced coal from the Lower Carboniferous Billefjorden Group. It is located on the west side of the Billefjorden. In the mountain Pyramiden to the North of the town, syn-rift sediments of Upper Carboniferous age build eastward from the Billefjorden Fault and are beautifully exposed there

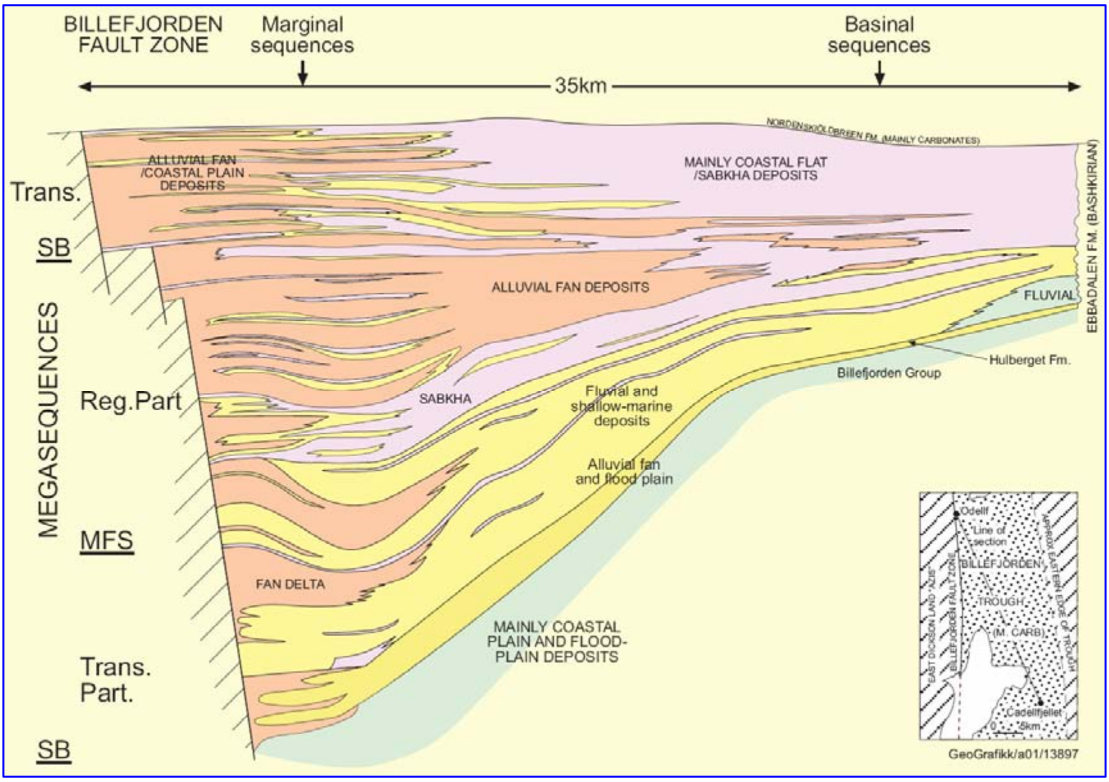
Bashkirian, from heralded the transition humid times to semi-arid terrestrial climates and a general rise in sea level. A main rifting phase, influencing large part of the Arctic, including the Billefjorden Fault, started in the Bashkirian. It was associated with rapid subsidence and faulting along the main fault and is illustrated in Figure 3. The Billefjorden Trough developed as a half graben with the Billefjorden Fault to the west.

The varied development of the <800m thick Ebbadalen Formation represents alluvial fans and fan deltas which build eastward from the Billefjorden Fault Zone into restricted marine and sabkha environments**.** Rhythmic intercalations of these, often into thin upwards coarsening units, reveal an intricate interplay of local lineament activity and regional transgression. The Billefjorden Trough thus developed as a marine embayment opening to normal marine environments to the north.

Johannessen & Steel (1992) subdivided the Ebbadalen Formation into four members. The lower unit, the Hultberget Member has been upgraded to a formation (Hultberget Formation) by Dallmann et al. 1999 and consists of a basin-wide infill of alluvial red beds. The overlying Ebbaelva Member is also of basin wide occurrence and consists of grey/green shales interbedded with grey and yellow sandstones and represent a basin-wide flooding of the Billefjorden Trough.

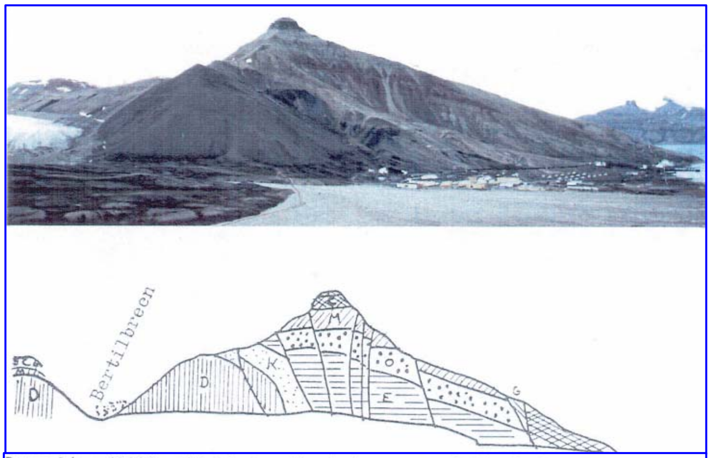
Odellfjellet Member is basin margin-attached and consists of red, grey and yellow conglomerates and sandstones, red shales (sometimes with gypsum nodules) and yellow dolomites.





Schematic E-W cross sections across the Billefjorden Trough illustrating the infill of the half-graben during the Carboniferous. Alluvial fan and fan deltas prograded out from the Nordfjorden Block to the west and interfingered with shallow marine sediments to the east.

The Trikolorfjellet Member represents the axial or basinal facies and consists of gypsum/-anhydrite in alternation with black and yellow limestones/dolomites and black shales**.** Red sandstones and mudstones, related to the interfingering of the Odellfjellet Member, are found in the western and central developments. The deposits are organized into shallowing upward sequences.



Pyramiden (1000 m high) is situated on one of the fault blocks in the Billefjorden fault zone (?). The drawing is modified from Livshitz (1966). D = Devonian, K = Billefjorden Group (from where the Soviet community is mining coal), E = Ebbaelven Member and O = Odellfjellet Member (red beds and our main stop) in Ebbadalen Formation and M = Minkinfjellet Member and C = Cadellfjellet Member (shallow marine carbonates) in Nordenskjøldbreen Formation.

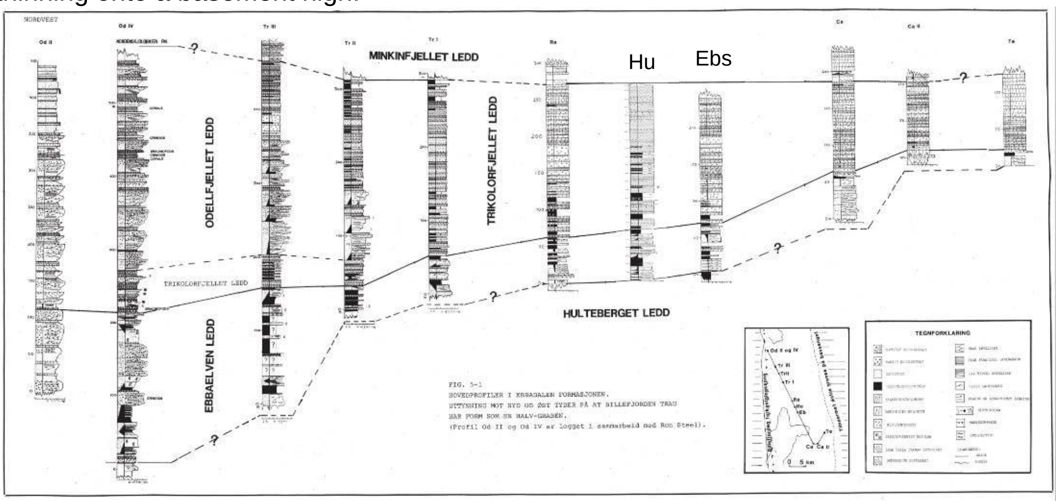
A traverse across the Billefjorden Trough shows that more than 500m of red beds are deposited along the Billefjorden Fault Zone. Small radius (2-3km), arid alluvial fans and fan deltas built out from this western margin of the rift basin, interfingering with evaporites, carbonates and shallow marine sandstones. On a basin fill scale (>500m) the succession shows an overall fining to coarsening to fining upward trend.

The Ebbadalen Formation exhibits a cyclisity in both its marginal (fan) and distal (sabkha) facies. Marginally the bulk of any sequence is composed of the upward coarsening alluvial plain/-fanglomerates regressive component. Basinally evaporites make up the bulk of any (shallowing upward) sequences. The cyclisity clearly reflects repeated rapid submergence (beach spit sandstones and carbonates) and more gradually emergence (fan and sabkha progradation) of the basin floor. Each tectonic down faulting is a lowering of the basin floor which gives a marine incursion on the alluvial fans with deposition of lagoons and beach spits. Marine carbonates dominate during time of maximum marine flooding. As the new hinterland manages to establish its new drainage, a new alluvial fan system starts to prograde as a delayed response to the tectonic activity. In proximal areas these alluvial fan sequences are stacked upon each other, because the marine incursion does not reach that far. But distally or in this case higher in the sequence it is more likely to find interfingering marine beds (upper part of Pyramiden profile).

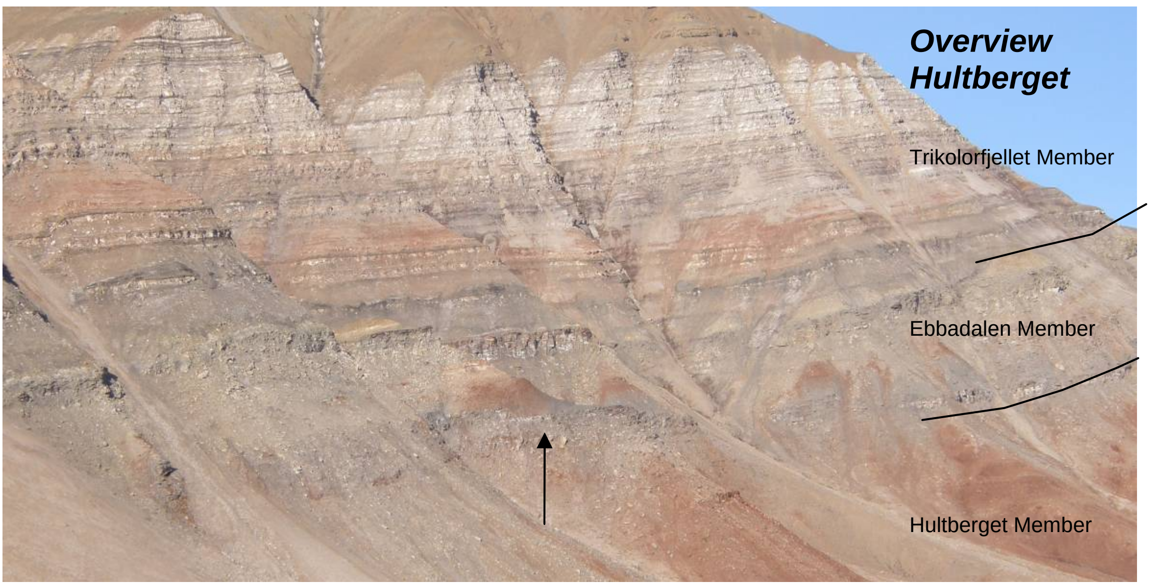
Alluvial red beds overlaid by grey shallow marine sandstones and grey marine limestone rich in brachiopod fragments

Day 2, Stop 2: *EBBADALEN*

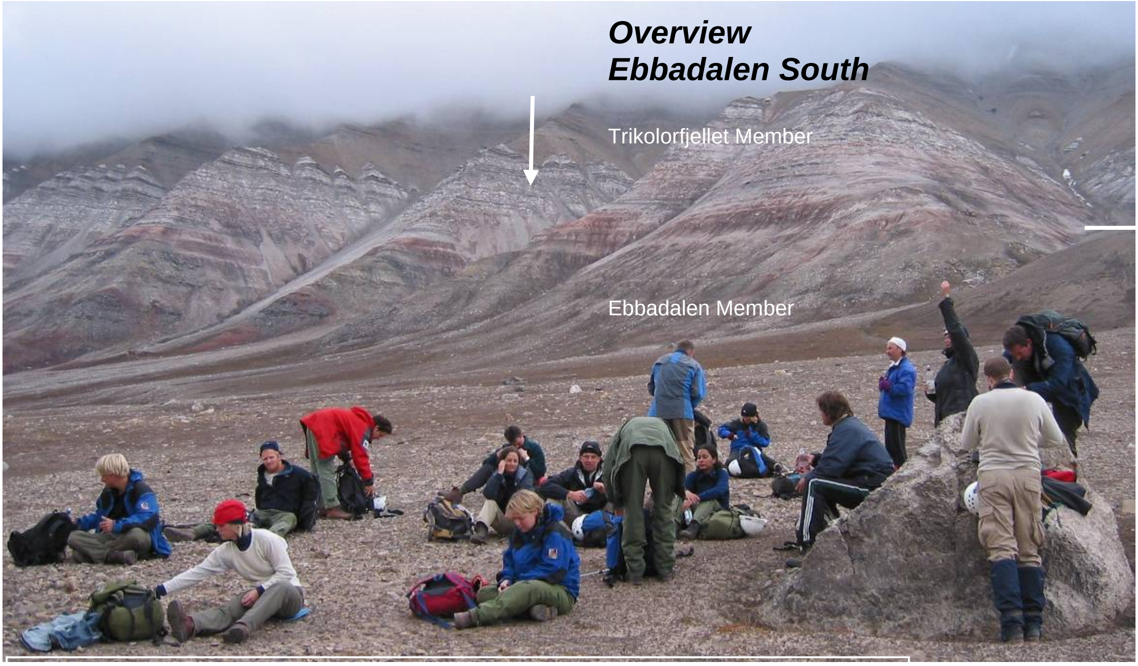
Hultberget or Ebbadalen South (time dependent which locality to visit):
In Ebbadalen we will have an overview of the Eastern part of Billefjorden Trough and it's thinning onto a basement high.



At Hultberget (Hu) or Ebbadalen South (Ebs) (see correlation) we will examin the easterly derived fan delta/barrier/lagoonal section of Ebbaelva Member and the overlying sabkha cycles and interbedded distal alluvial fan red beds of Trikolorfjellet Member. This section will be compared and contrasted back to Pyramiden section.



Hultberget. Arrow suggest position of where to walk a profile



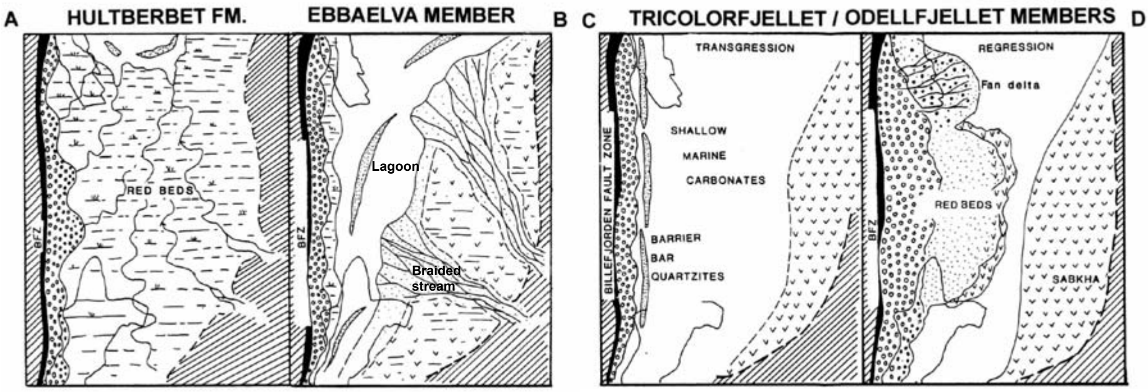
Ebbadalen South. Arrow suggest position of where to walk a profile

The southernmost exposures of Ebbaelva Member consist of large scale cross-stratified Sandstone, deposited from braided streams flowing towards Northeast. These streams entered standing water northward, and in the Ebbadalen area mouth bars, 2-7 m thick are developed. Ripple lamination is the dominating structures in these deposits. The laterally associated black green shales with some thinly stratified, bioturbated sandstones and dark carbonates, suggest deposition in shallow seas or lagoons.

Large scale x-bed (7m thick). 1m thick sets dominated by ripple laminations. Interpreted as a mouth bar.

Lateral facies variations in Ebbaelva Member. Fluvial / Mouth bar sandstone are laterally pinching out into finegrained lakes (red) or lagoons (greenish).

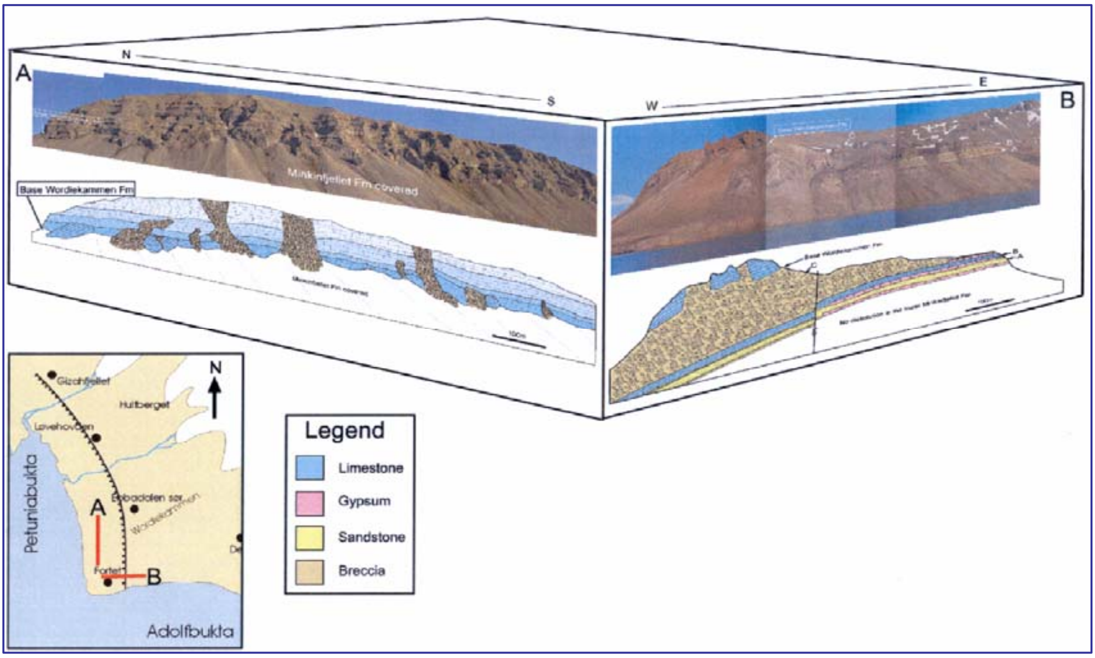
The sediments described above are arranged into two (40 m thick) fining upward sequence (braided stream to mouth bar to lagoon. Complicating the fining upward pattern are assosoated evaporates, fine grained red beds (interpreted as playa and playa lake) and well laminated yellow sandstone (beach deposit). The two fining upward sequences are believed to be the lower transgressive component of the Ebbadalen megasequence.



Paleogeographic reconstruction of the Billefjorden trough Bashkirian time.

Day 2, Stop 3: *RAUDMOSEPYNTEN - FORTET*

The carbonate breccias of the Minkinfjellet and Wordiekammen formations have been studied in detail by Eliassen & Talbot (2002) at Fortet. They differentiated between breccias that are essential: 1) strata-bounded and 2) cross-cut stratal boundaries.



Photos and geological models of the western and southern flank of the Fortet site illustrating thick breccias and sinkholes (dolinas). From Eliassen & Talbot 2002

The different breccia types have distinct geographic extent. The strata bounded breccias have the widest geographic distribution and are interbedded with undeformed carbonates and siliciclastic strata. These breccias range from 0,3m to 10's of m thick and will not be shown during this excursion. In contrast, the crosscutting breccias are up to 200m thick and restricted to the basin centre and are associated with distinct pipes and v-shaped structures (figure above). The crosscutting breccias extend up through the middle and upper part of the Minkinfjellet Formation and into the lowermost part of the Wordiekammen Formation and will be discussed at the Fortet site.

The thick breccia bodies have a chaotic appearance.The clasts are predominately angular, although sub angular and sub rounded are not uncommon, varied from a few millimetre to tens of meter, but most are between 1-10cm in diameter. Limestone is the dominant clast type, but clasts of chert, sandstone, shale, dolomite and rare anhydrite are also present. The breccias are matrix-poor and clast supported and have a intraclastic porosity of up to 30% (Lønøy, 1995). Although the breccias appear chaotic, subtle bedding or zonation of various breccia types are locally present (figure next page).

Fortet site with the lighthouse at Raudmosepynten

Cut-and-fill structures in the upper part of the Fortet Member braccias is indicative of fluvial deposits. Yellowish brown vadose dolomite-silt is common and represents periods of very slow depositional rate within the palaeo caverns. The base of the thick breccia body is well-exposed in at Fortet section along the beach at Raudmose-pynten. Here the base cut into the middle part of the Minkinfjellet Fm. consisting of shallow marine sandstones and dark grey limestones/-dolomite rich in silica nodules.

Sharp, basal contact between dark carbonates of the underlying Minkinfjellet Fm and the Fortet Breccia. The breccias are massive and poorly sorted.

Black, bitumen in pores of the Fortet, breccia, Raudmosepynten

Sinkhole (dolina) c. 100m wide crosscutting Upper Carboniferous carbonates. The sinkhole is filled with crudely bedded, poorly sorted polymict breccia (detailed picture).

In addition a small fenestrate bryozoan mound is also present. A continuous section of breccia more than 100m thick occurs above this sharp base. Exposures along the beach just below the Raudmose-pynten lighthouse, show presence of black to dark brown bitumen staining in the intra clasts pores.

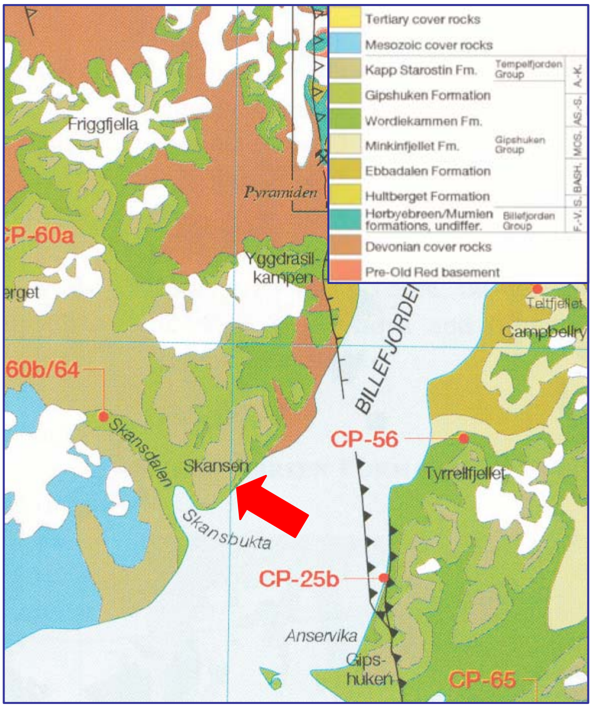
In the basin centre, the upper limit of the brecciated section lies within the Black Crag Beds. This limit is vertically irregular and laterally inconsistent. Here the breccias commonly occur as pipes 20-200m high, circular in plane view and funnel-shaped in vertical section. Clast composition in the breccia pipes is identical to that of the surrounding and unbrecciated rocks, implying *in situ* brecciation and short transport.

Abrupt termination of an anhydrite bed towards a carbonate breccia bed, Fortet Mountain.

Direct evidence of gypsum dissolution is seen at outcrop in a few localities (picture above), and is well exposed (although not accessible) immediately east of the Fortet site. It is reasonable to presume that the area of thick brecciated units in the central Minkinfjellet Basin was caused by dissolution of the thicker and more abundant gypsum beds originally deposited in this area. Large boulders of gypsum up to tens of meter in size are locally incorporated in the breccias and are interpreted as remnants of the primary gypsum beds. In several locations the transition from gypsum to breccia beds are linked to faults and presumably open fractures associated with faults have acted as conduits for fresh water.

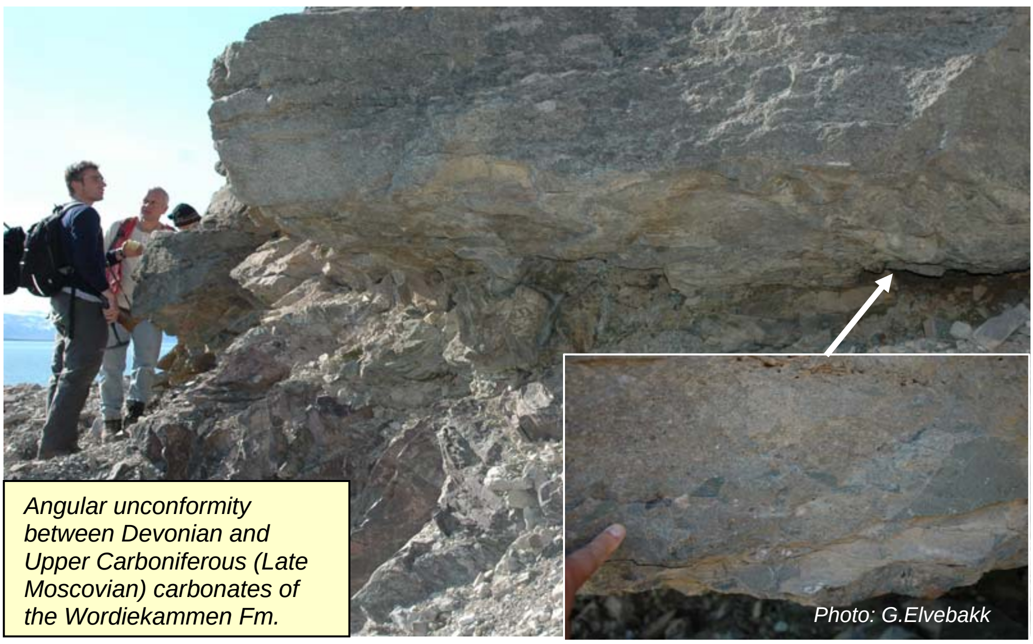
Timing of the karst development.
The timing of the gypsum dissolution and brecciation was most likely related to major periods of exposure of the overlying carbonates. The most obvious unconformity, associated with regional karstification of the underlying Gipshuken Fm, representing a major break between the mid-Sakmarian and Late Permian (e.g between the Gipsdalen and Tempelfjorden groups). If this is the case, the Fortet Member breccias were formed c. 500m below the surface.

Day 2, ASVINDALEN (Optional locality)



The Asvinddalen site shows excellent exposures of carbonate development on a structural high, the Nordfjorden Block. The **Kapitol Member** of the Wordiekammen Formation is confined to the Nordfjorden Block west of the Billefjorden Trough. The basal boundary towards Devonian strata is an angular unconformity with a thin conglomerate bed at the base (picture below). The lower part of the overlying section consists of porous dolomite mudstone to packstone cycles typically a few meter thick gradually overlaid by carbonate grainstone cycles with abundant *Microcodium*. The Member is of Late Moscovian to Late Kasimovian age.

The **Tyrellfjellet Member** extends over both the Nordfjorden and Ny Friesland fault blocks east of the Billefjorden Trough. Although the basal boundary has been debated, it marks a transition to more open marine deposits with common palaeoaplysinid-phylloid algal build-ups**.** As such it appears to represent a distinct transgressive episode in the late Gzelian. The lower part consists of predominately open marine dolomite cycles with an upward increase in thickness, consistent with an overall transgressive



Angular unconformity between Devonian and Upper Carboniferous (Late Moscovian) carbonates of the Wordiekammen Fm.

Photo: G.Elvebakk

development. The upper part of the Tyrellfjellet Member consists of a series of restricted to open marine cycles. *In situ Microcodium* are common close to the top of each cycle. In the upper part of the member, two distinct shallow marine sandstone units are present, demonstrating that the Nordfjorden Block represent an attached carbonate platform; i.e. carbonate platform attached to a siliciclastic shoreline.

The Asvinddalen section demonstrates how important diagenetic processes are in carbonates, particularly early diagenesis. The originally most porous intervals, the grainstones, consist today of tight limestones, while originally mud-rich rocks are dolomitized and porous. The dolomitization took place early, perhaps from evaporite-modified sea water where calcium and sulphate ions concentrations have been lowered due to precipitation of Ca-sulphate mineral(s) in a restricted marine setting.

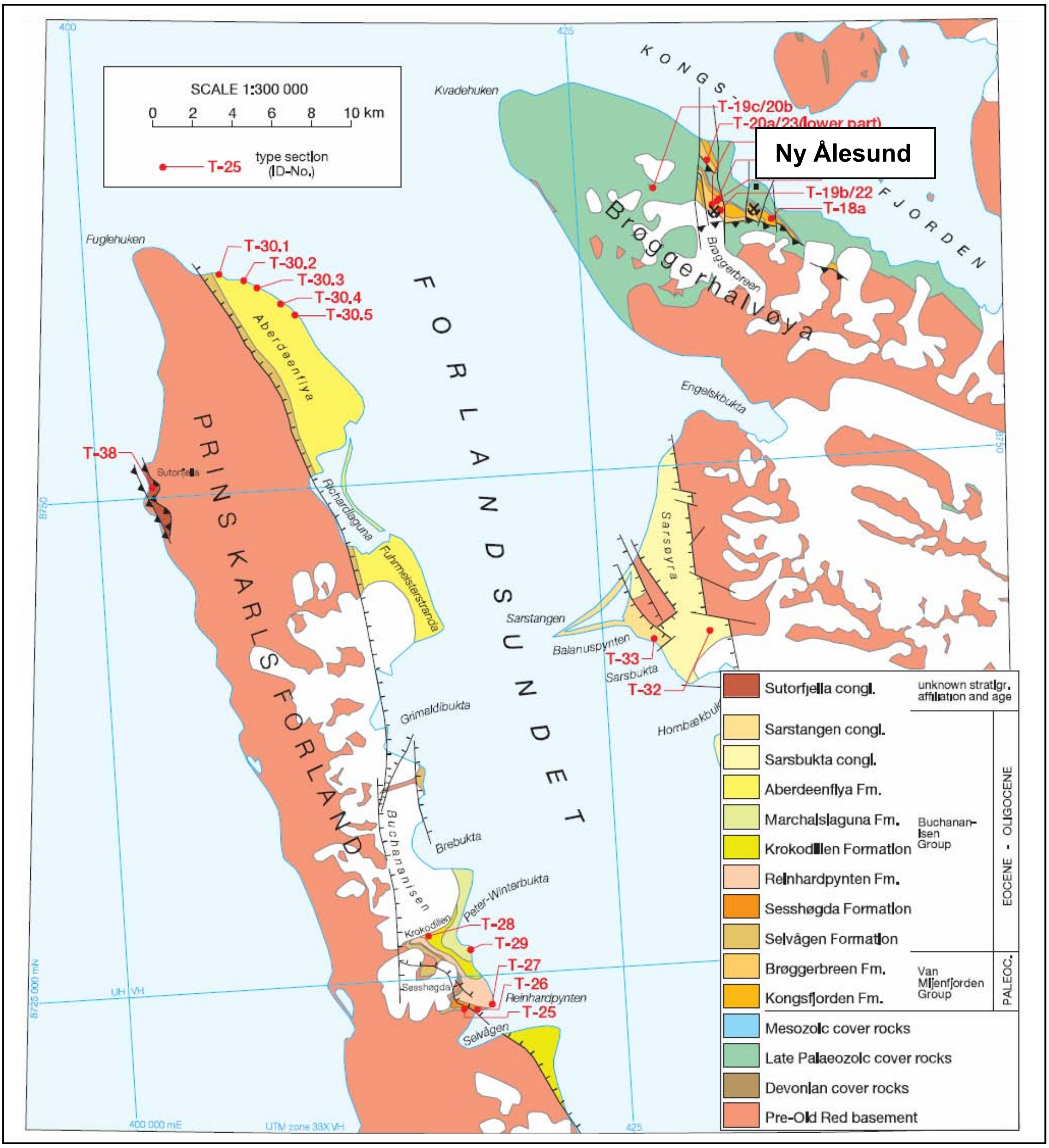
Porous dolomite with large vugs and fracture-enlarged pores in the lower part of the Wordiekammen Formation, Asvinddalen.

Carbonate grainstones with Microcodium (black grains), Asvinddalen

Dolomitized palaeoaplysinid boundstone buildup with large vuggy pores, Asvinddalen

Isfjorden – Forlandssundet - Brøggerhalvøya

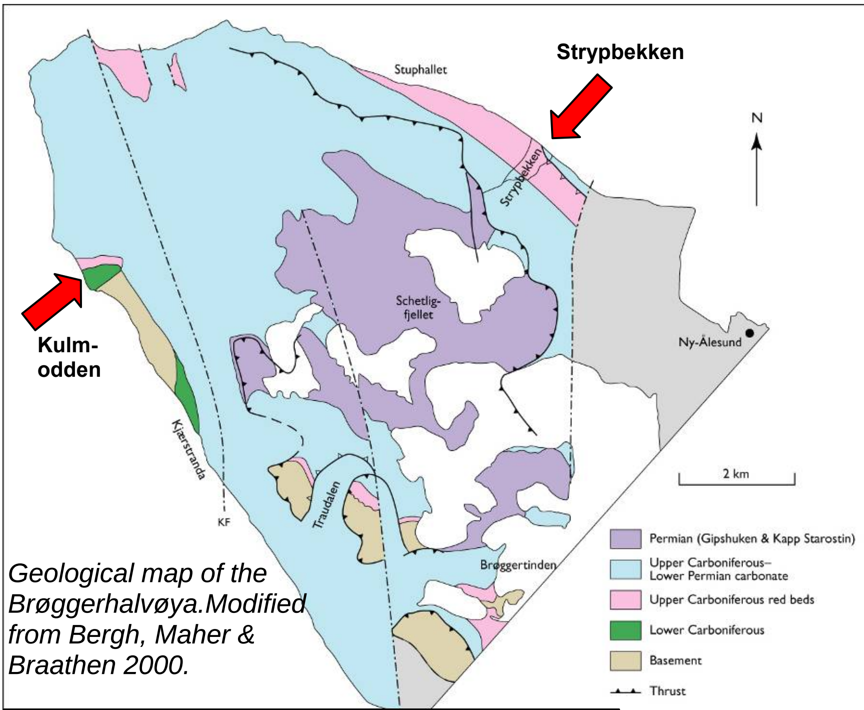
From Longyearbyen, *Origo* sails northwards to Brøggerhalvøya, following the Cenozoic fold-and-thrust belt from Isfjorden to Kongsfjorden. Caledonian complexes outcrop on both the eastern and western sides of Forlandsundet, with eclogites and blueschists (470 Ma) occurring on Motalafjallet, south of St Johnsfjorden. The belt of Cenozoic deformation along the western margin of Svalbard's Central Cenozoic Basin strikes out to sea on the south side of Kongsfjorden, with klippen of Heckla Hock schists capping the tops of some mountains southeast of Brøggerhalvøya.



Forlandssundet Graben

In the earliest Oligocene, after the opening of the Fram Stredet between Greenland and Svalbard, a trantentional regime was created by extensional and compressional stages. A 12 to 18 km wide graben structure parallel to the Tertiary fold belt was developed within the western basement uplift between Oscar 2 land and Prince Karl Forland. Down faulted Tertiary sedimentary rocks of Eocene to Oligocene age occur on the eastern and western margin of the Forlandsundet, with most of the succession situated below the strain. In general, the beds incline towards the graben, with a weak north-south fold trend and shallow plunges (see map on opposite side). Based on a surface magnetic anomaly and fault-plane observations, basement rocks on Sarsøyra (eastern part of Forlandsundet) are considered to have been pressed up along faults made by transpressive oblique strike-slip faulting during the initial stage of the Forlandssundet Graben formation.

Day 3, BRØGGERHALVØYA; Stop 1, Kulmodden, Stop 2; Strypbekken

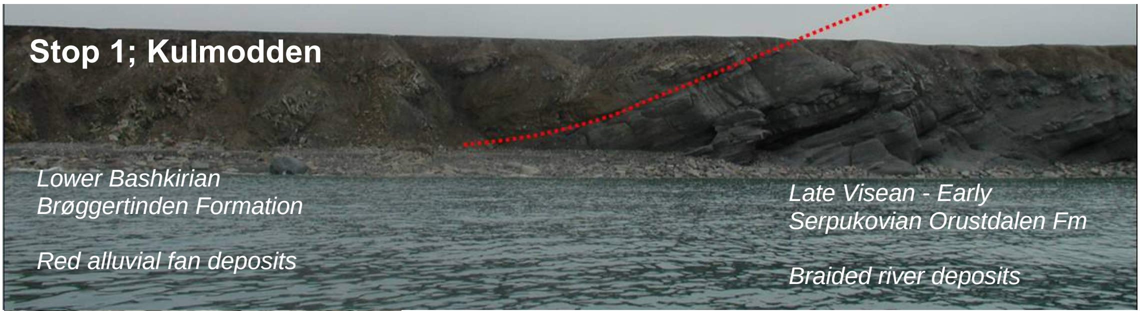


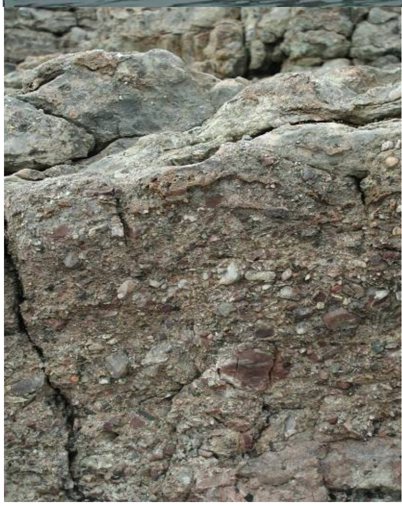
Geological map of the Brøggerhalvøya.Modified from Bergh, Maher & Braathen 2000.

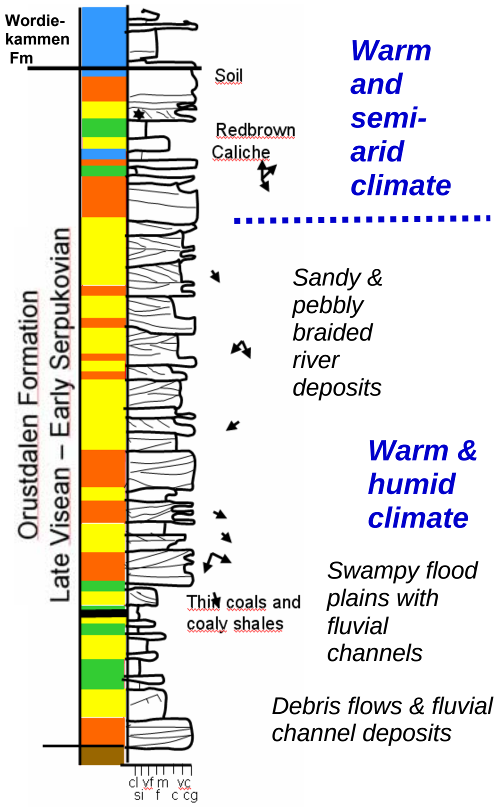
PERIOD	GROUP	FORMATION	LITHOLOGY
Tertiary		Ny Ålesund	Sandstone shale & coal
Lower Triassic	Sassendalen	Vardebukta	Shale
Upper Permian	Tempelfjorden	Kapp Starostin	Shale & chert
Lower Permian	Gipsdalen	Gipshuken	Dolomite & breccia
Upper Carboniferous		Wordiekammen	Limestone, dolomite subord. silisiclastics
		Scheteligfjellet	Redbeds & carbonates
		Brøggertinden	Red conglomerates, sandstones & shales
Lower Carboniferous	Billefjorden	Orustdalen	Gray conglomerates, Sandstones, shales & coals
Precambrium	Kongsvegen	Hecla Hoek: Nilsenfjellet	Phyllites

Geological setting: Part of the northwestern terminus of the Spitsbergen's fold-thrust belt underlain by Caledonian-deformed Basement. Three nappes; 1) Lower nappe; low angle to bedding-parallel imbricates, 2) Middle nappe; macroscopic anticlines and synclines, rotated imbricated fans and duplexes within Palaeozoic and Mesozoic cover strata, 3) Upper nappe; overthrusted Caledonian Basement rocks.Upper Palaeozoic strata rests with an angular uncunformity towards the underlying Basement, mainly phyllites. Main exposures part of the lower nappe.

All photos: G. Elvebakk





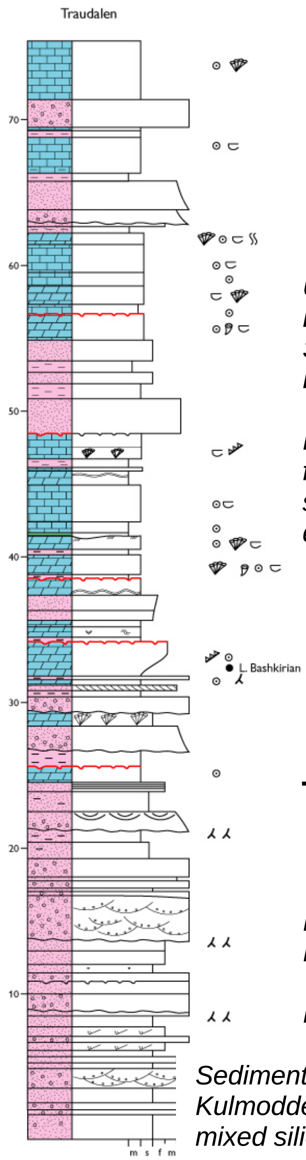


Kulmodden:
Good exposures of the westward tilted Orustdalen Formation and mid-Carboniferous alluvial red beds of the Brøggertinden Formation are exposed at the beach. Here the lowermost part of the Gipsdalen Group consists of a complex interfingering of alluvial red beds and shallow marine shales and limestones. 2 km inland of Kulmodden beautiful exposures of flat-lying poorly sorted carbonate debris flow filled channels are seen. The debris flow deposits correlate to the slump deposits in Simlestupet. Walk a few hundred meters to exposure of a matrix-supported carbonate breccia filled sinkhole in peritidal dolomites within the Lower-?Middle Permian Gipshuken Formation (Gipsdalen Group).

Inland Kulmodden. Debris flows and slump deposits in basinal setting along Kiærstranda, contemporaneously with extensive karstification in shallow platform areas as Strypbekken (Stop 2, see below).

Lower Moscovian Wordiekammen Formation exposed in the background above the yellow lens-shapes in the picture above. Canalized and wedge of carbonate-clast dominated debris flow and slump deposits up to 30m thick. Exposed in the cliffs along Kiærstranda from 2 km inland Kulmodden to Traudalen for a length of 4 km.

Slump deposits, Simlestupet, Kiærstranda



Upper Bashkirian – Lower Moscovian Scheteligfjellet Formation

Interfingering of alluvial fan deposits and shallow open marine deposits

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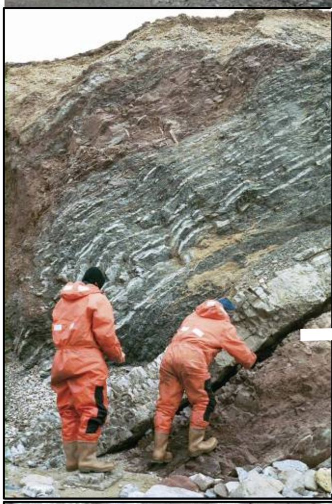
Lower Bashkirian Brøggertinden Formation

Red alluvial fan deposits

Sedimentological log from Traudalen (SW of Strypbekken and SE of Kulmodden) showing Bashkirian red alluvial deposits and Moscovian mixed siliciclastic carbonate deposits (from internal StatoilHydro-report).

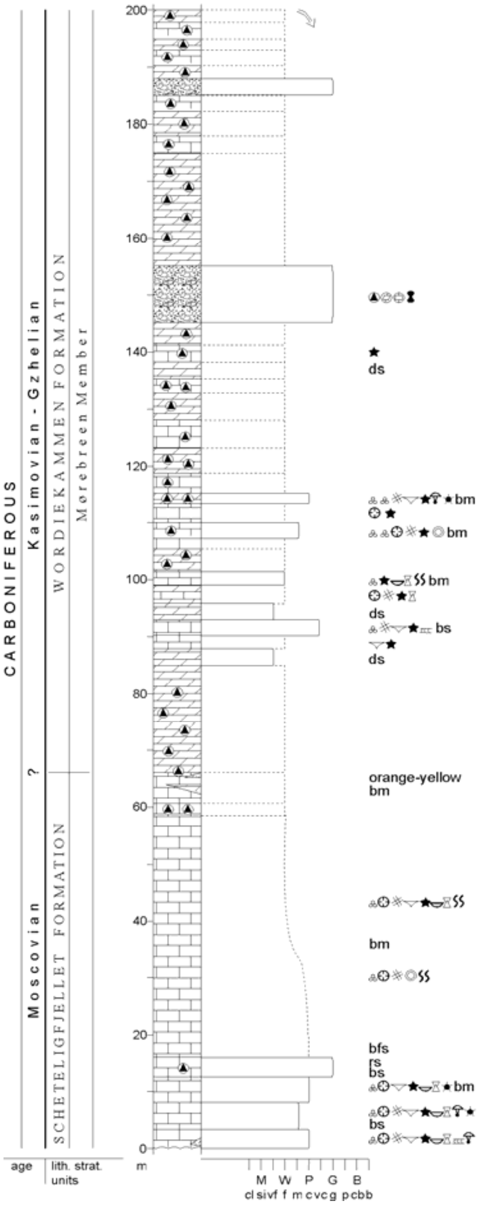
Stop 2; Strypbekken

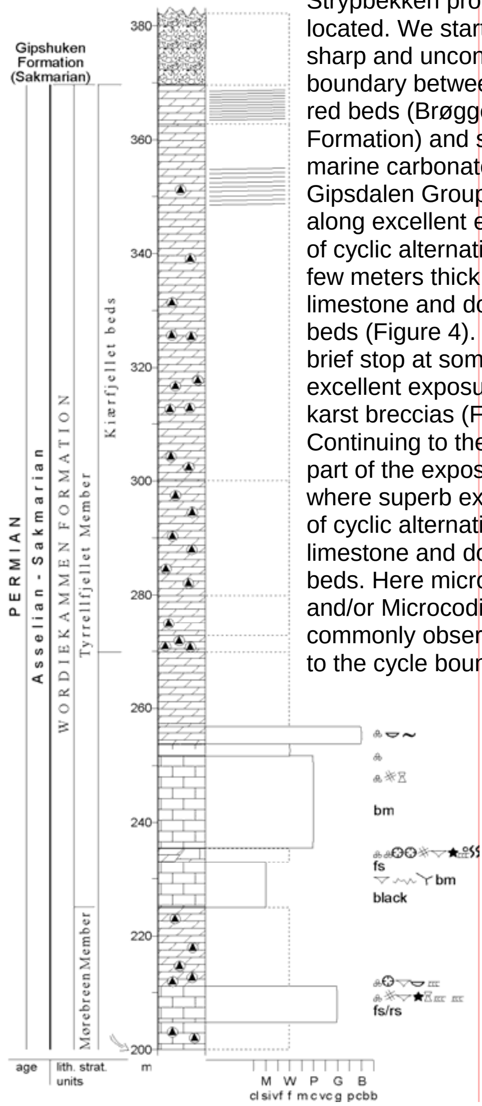
Late Bashkirian – Early Moscovian Scheteligfjellet Formation
Mixed alluvial red beds and shallow marine carbonates and siliciclastics



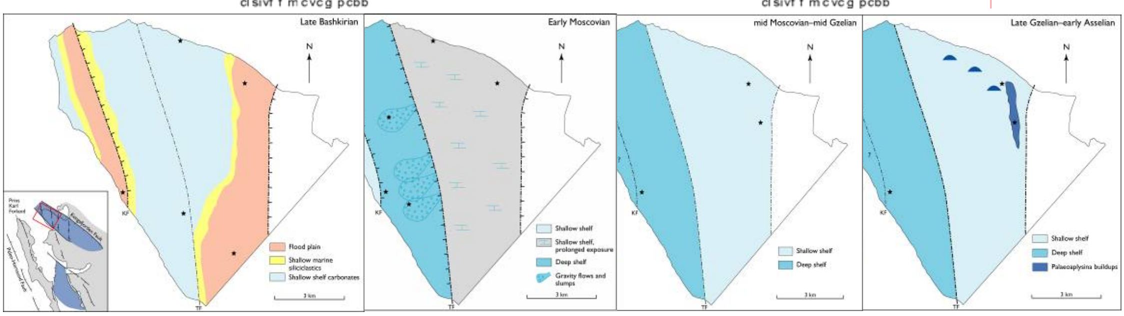
Unconformable boundary between Lower Bashkirian caliche of the Brøggertinden Fm. and Upper Bashkirian/Lower Moscovian carbonates of the Wordiekammen Formation

Strypbekken locality. Exposures of Late Carboniferous (Moscovian) to Early Permian (Sakmarian age). Stratotype for Mørebreen Member, Kiærfjellet beds. Reference: Sidow 1988 (unpubl).

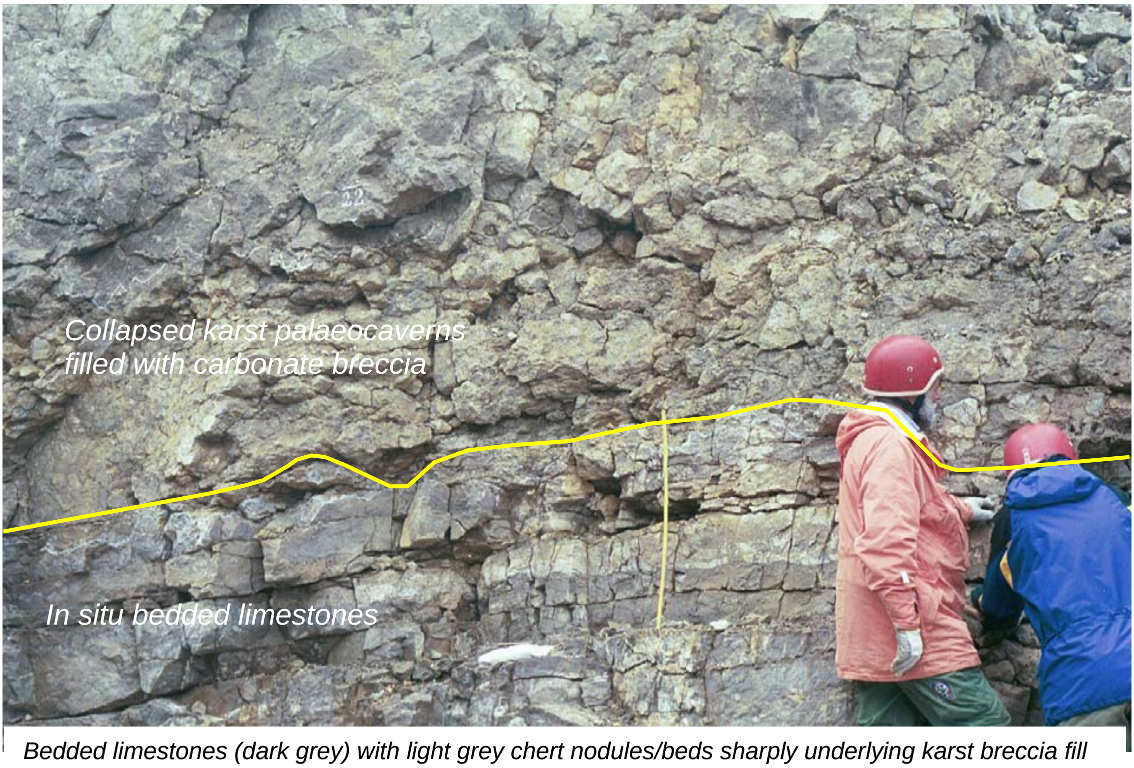




Approximately 4 km WNW from Ny Ålesund the Strypbekken profile is located. We start with the sharp and unconformable boundary between alluvial red beds (Brøggertinden Formation) and shallow marine carbonates of the Gipsdalen Group. Walk along excellent exposures of cyclic alternations of a few meters thick limestone and dolomite beds (Figure 4). Make a brief stop at some excellent exposures of karst breccias (Figure 5). Continuing to the upper part of the exposures where superb exposures of cyclic alternations of limestone and dolomite beds. Here micro-karst and/or Microcodium are commonly observed close to the cycle boundaries.



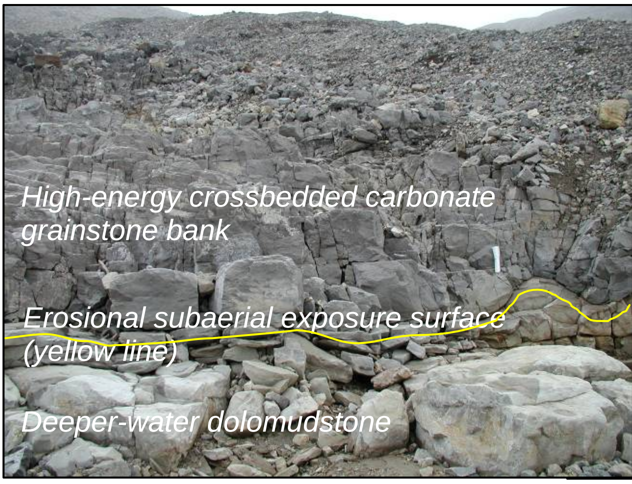
Late Palaeozoic paleogeographic reconstruction of the Brøggerhalvøya area (from internal StatoilHydro-report).



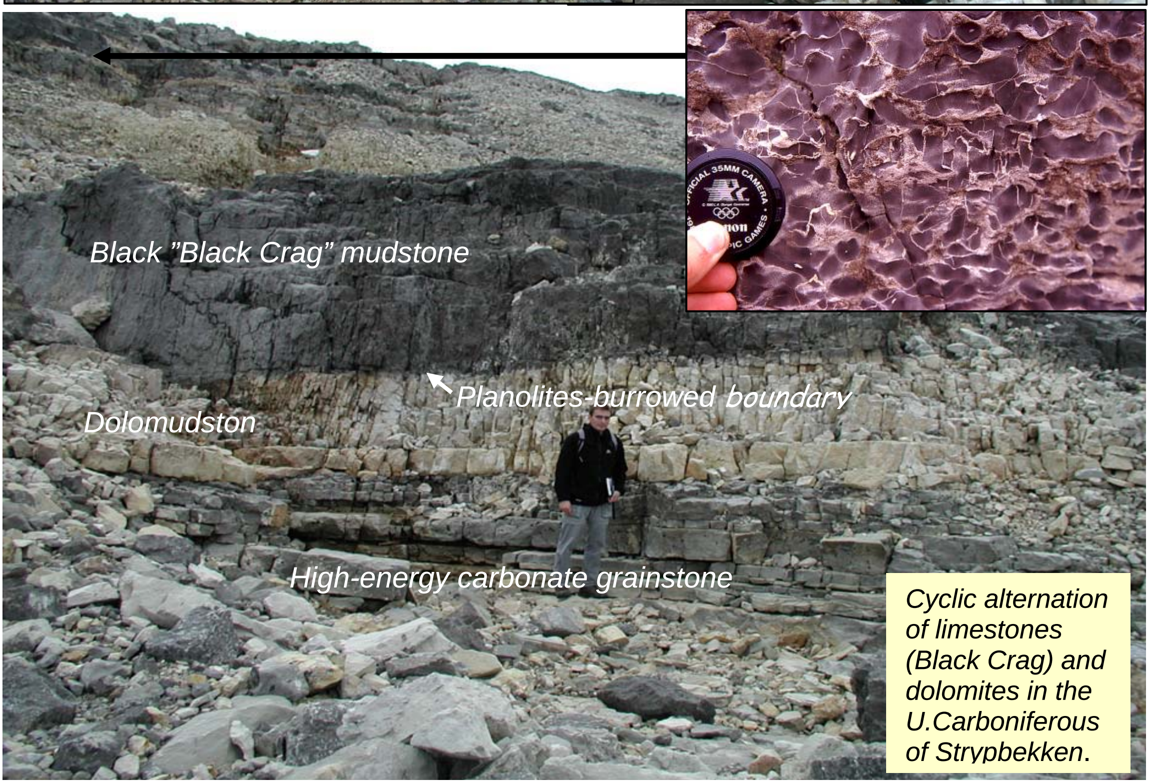
Bedded limestones (dark grey) with light grey chert nodules/beds sharply underlying karst breccia fill of palaeocaverns, Upper Carboniferous, Strypbekken. Extensive karstification in shallow platform areas in Strypbekken (contemporaneously with debris flows and slump deposits in basinal settings along Kiærstranda (see above, Stop 1).


Restricted basinal dolomite mudstone with partially chertified evaporite nodules.


Deep shelf chert-rich carbonate mudstones; a drilling challenge!!


High-energy crossbedded carbonate grainstone bank
Erosional subaerial exposure surface (yellow line)
Deeper-water dolomudstone


Algal-laminated tidal flat


Black "Black Crag" mudstone
Planolites-burrowed boundary
Dolomudston
High-energy carbonate grainstone
Cyclic alternation of limestones (Black Crag) and dolomites in the U.Carboniferous of Strypbekken.

Thick <u>Palaeoaplysina</u> buildups approximately 1 km east of the Strypbekken profile.

Day 3, NY ÅLESUND (optional stop)

We will make a short stop on a couple of ours to visit his world's northernmost permanent settlement. A local guide will meet us at the harbour, there will be possibilities to buy souvenirs at the local souvenir-shop.

Ny Ålesund is situated only 1,200 km from the North Pole, it accommodates a modern research centre with facilities and infrastructure of a high standard (text and pictures from Kings Bays home page www.kingsbay.no)

Easily accessed by several flights a week, you might be surprised finding yourself in unspoiled arctic nature only steps away from your comfortable bed.

Each year scientists from at least fifteen nations come here to work on a different research projects. Norway, Germany, Great Britain, Italy, Japan, France, South Korea and China have all established their own research stations in Ny-Ålesund.

Kings Bay AS runs and operates Ny-Ålesund. During the mining period (then still named Kings Bay Kull Company - KBKC) the firm ran the company town with up to 400 inhabitants. Shortly after the coal mining activity had been stopped in 1963 (due to a gas explosion in the mine), the Arctic Research station started developing, mainly due to the Norwegian Polar Institute starting permanent scientific work in Ny-Ålesund, and the so-called Norwegian Research Council (NTNF) was commisoned to run the station. KBKC resumed primary responsibility for the practical operation of Ny-Ålesund by 1974. In 1998 Kings Bay Kull Company changed its name to Kings Bay AS and still owns and runs the research station on a full year basis.

Heading North

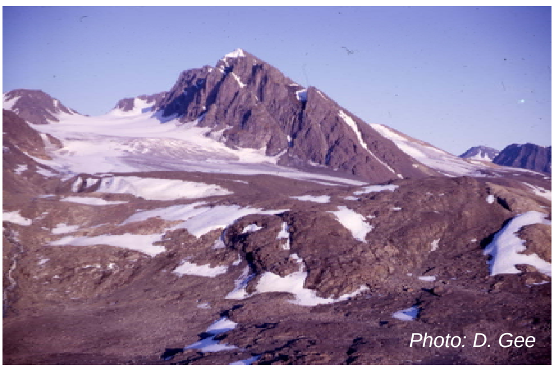
After visiting Ny Ålesund we continue northwards. Spitsbergen's bedrock geology changes dramatically across Kongsfjorden, from Ny Ålesund, located in the Cenozoic thrust belt on the south side of the fjord, to N-striking Caledonian complexes on Blomstrandhalvøya and Kapp Mitra and around Krossfjorden on the northern side of the fjord. *Origo* sails northwards to the scenically most spectacular part of Svalbard in the northwestern corner of Spitsbergen. It was in these northwestern bays and on the islands that much of the whaling industry was concentrated three hundred years ago; also it was from here than Andree's team started its balloon expedition to the North Pole (1897), from which they never returned.

Svalbard's Caledonian rocks, ranging in age from Early Palaeozoic to Palaeoproterozoic (Archaean in one small area) are referred to as the Heckla Hoek Complex. Northwesternmost Spitsbergen (Albert I Land) is dominated by high grade Heckla Hoek metasedimentary units of mainly Mesoproterozoic and possibly Neoproterozoic age that have been subject to extensive migmatization and intruded by late- to post-tectonic granites. North of Kongsfjorden, the greenschist facies formations of schists and marbles are well-preserved, occurring in gently S-plunging, W-vergent major antiforms and synforms. Up-plunge to the north, the metamorphic grade increases and the metasediments are migmatized at lower structural levels. Particularly resistant lithologies, such as marbles and amphibolites are well represented in the migmatites and can be followed deep into this anatectic complex. In northernmost areas of these migmatites, late Grenvillian-age (c. 950) granites have been identified, indicating that some kind of pre-Neoproterozoic basement complex exists within this Caledonian mobile belt.

Looking west across Raudfjorden to the Hecla Hoek migmatite complex of northeastern Spitsbergen. The Raudfjorden Fault defines the west coast of Raudfjorden and Old Red conglomerates are exposed at Konglomeratodden (southernmost exposures in picture).

Day 3, RAUDFJORDEN (optional stop)

Origo rounds the northwestern islands of Albert I Land and enters Raudfjorden (Red fjord). A narrow (c. 10 km wide) N-trending trough, the Raudfjorden Graben, dominates the structure of this fjord, with the major Raudfjorden Fault defining the western margin and Old Red Sandstones successions occupying the fjord and eastern side. These late Silurian and Devonian sediments overlie, with major unconformity, another Heckla Hoek complex, outcropping to the east within the Biscayerhalvøya – Holtedahlfonna Horst.



East side of Raudfjorden, looking south from Rabotdalen at Lilljeborgfjellet and the W-dipping Siktefjellet Group basal conglomerates and sandstones overlying Hecla Hoek gneisses, marbles and eclogites of the Biscayerhalvøya - Holtedahlfonna Horst

Looking south from Richarddalen (east side of Raudfjorden), at basal Siktefjellet Group conglomerates on Puddingen, overlying Hecla Hoek schists and gneisses

Eastern side of Raudfjorden, looking southeast at Rivieratoppen and the basal Old Red Group conglomerates and sandstones which overlie dark schists of the Hecla Hoek basement

The Old Red Sandstones successions of Raudfjorden are famous for their fish fauna and have a well defined Early Devonian (Lochkovian and younger) age. Two unconformities have been recognised. One at the base of the succession, separates Siktefjellet Group basal conglomerates and sandstones from high grade, eclogite-bearing (c. 450 Ma) Heckla Hock rocks; the other is an angular unconformity (c. 30º) at the base of the overlying Red Bay Group, within which the earliest Lochkovian fishes have been identified.

Towards the north (e.g. along the east side of the Raudfjorden), the Red Bay unconformity overlaps onto the Hecla Hoek basement.

From Raudfjorden, *Origo* sails eastwards, passing the narrow Biscayerhalvøya - Holtedahlfonna Horst and across another, major boundary, the Breibogen – Bockfjorden Fault. This important N-trending, mantle-penetrating fault structure was established in late Caledonian times and influenced Old Red Sandstone deposition; it remains active today with hot springs, some volcanics and a remarkable occurrence of lower crustal and mantle-derived xenoliths. The Breibogen – Bockfjorden Fault defines the western edge of the Andreeland – Dicksonland Graben, the main region of Devonian sedimentary rocks on Svalbard. This 50 km wide trough extends from Spitsbergen's northern coast, southwards to the northern rim of the Central Cenozoic Basin where it is unconformably overlain by Late Carboniferous – Permian successions.

Day 3, Stop 3: MOFFEN

From the Breibogen – Bockfjorden Fault and the red beds of Reinsdyrflya, *Origo* leaves the

Devonian graben and sails north to Moffen (Quaternary) to visit a well-known walrus locality. We then turn eastwards again for Hintopenstretet. En route, we cross the eastern boundary of the Andreeland – Dicksonland Graben, marked by another high angle fracture zone, the Billefjorden Fault Zone. All these major N-trending faults (Raudfjorden, Breibogen – Bockfjorden and Billefjorden) are high-angle structures with some strike-slip movement (unambiguously sinistral, in the case of the Billefjorden Fault). Horizontal displacements of several hundreds of kilometres have been postulated for all three faults.

In northern Spitsbergen, the Billefjorden Faults zone can be followed the length of Wijdefjorden, separating the Devonian successions of Andreeland from high grade Heckla Hoek complexes in Ny Friesland; the latter are unconformably overlain by Early Carboniferous sanststones. The Heckla Hoek rocks are composed of Mesoproterozoic quartzite-dominated formations, tectonically interleaved with late Palaeoproterozoic (c. 1740 Ma) granitic gneisses, together composing the Atomfjella Complex. Amphibolites are common throughout most of the complex. The latter is polyphase folded and arched in a major N-trending fold, the Atomfjella Antiform that dominates the entire strata of western Ny Friesland.

In the eastern limb of the Atomfjella Antiform, the Atomfjella Complex is overthrust by E-dipping high grade schists (Planetfjella Group), which decrease in metamorphic grade upwards and are in fault contact (displacement thought to be essentially normal) with the classical Neoproterozoic Lomfjorden – Murchisonfjorden Supergroup successions of northeastern Svalbard. The latter are overlain by Vendian tillites and Cambro-Ordovician platform formations typical of the Laurentian continental margin, from northeast Greenland to the Appalachians of eastern Canada. All these Heckla Hoek rocks overlain with major unconformity by Carboniferous sandstones.

The Beluga is quite common at Svalbard. To catch sight of a group of these white whales is a thrilling experience.

Day 4, Stop 1, WILHELMØYA

Wilhelmøya is located in the southwestern end of the Hinlopenstretet. The profile between Tumlingodden at the beach and Keisarkampen at the top of the mountain reflects a stratigraphy from Upper Tschermakfjellet Formation of Lower Carnian age (Kapp Toscana Group) to the ?Bathonian-Callovian Agardfjellet Formation (the boundary between the Tchermakfjellet and De Geerdalen Formation is not exposed in the slope). The Wilhelmøya Subgroup is 109 m thick in the stratotype on Wilhelmøya, it reflects great similarities between the strata on Kong Karls Land (230 m thick) further east. The subgroup consists of texturally mature sandstones deposited on coastal plains and in deltaic through shallow marine environment; it shows an increasingly condensed development towards the west. On this excursion the Late Pliensbachian-Aalenian interval is a high light locality.

What to see:

The limited exposures of **Tchermakfjellet Formation** consist of black grey shale containing ammonites, mussels and fish fragment deposited in an open marine shelf.

The **De Geerdalen Formation** reflects sandstones and shales with interbeds of coal and weathered soil profiles. The deposits are interpreted as a tidal influenced coastal plain prograding upwards into lagoon/embayment with marsh interbeds. Notice a 12 m thick sill intrusion in the middle of the De Geerdalen Formation.

Flatsalen Formation. Photo: G.B. Larssen.

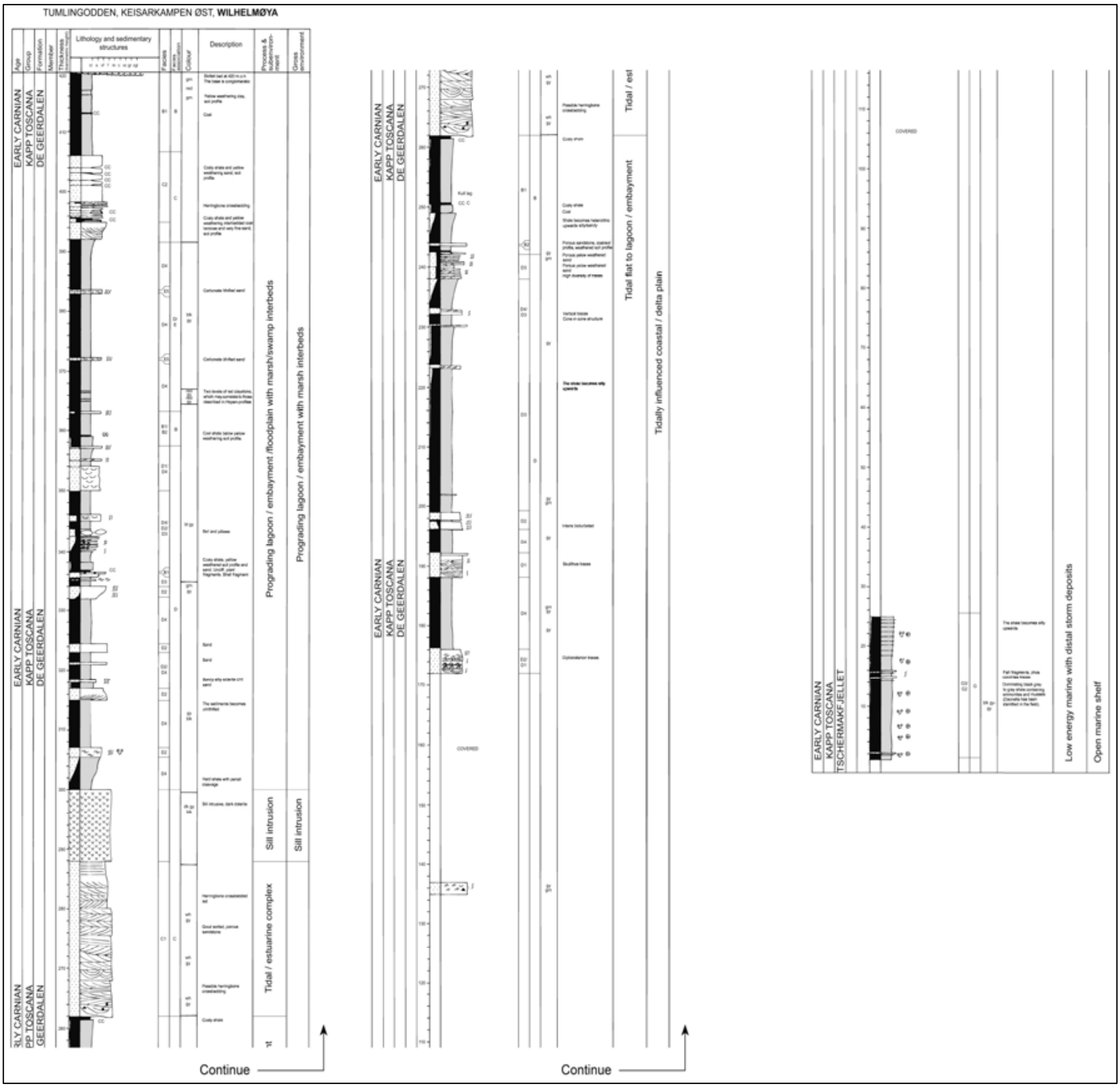
The conglomeratic **Slottet Member** of the **Flatsalen Formation** (Early Norian age) reflects a condensed shelf deposit, with following marine shelf shales and interbedded storm introduced hummocky cross stratified fine grained sandstones. *Pleisosaurus* sp. bones are identified in the lower part of the formation. Large scale through crossbedded sandstones of the **Svenskøya Formation** (Late Pliensbachian) are extremely low consolidated, reflecting tidal influence structures interpreted as deposited in an outer estuary channel complex.

The **Kongsøya Formation** (Late Toarcian-Aalenian) reflects a transgressive unit with some conglomeratic horizons deposited in a lower shoreface to open inner shelf. The sandstones are completely mottled and coalified logs are abundant in the lower part.

Mottled bioturbated sandstone in the Flatsalen Formation, 450m. Photo: G.B. Larssen

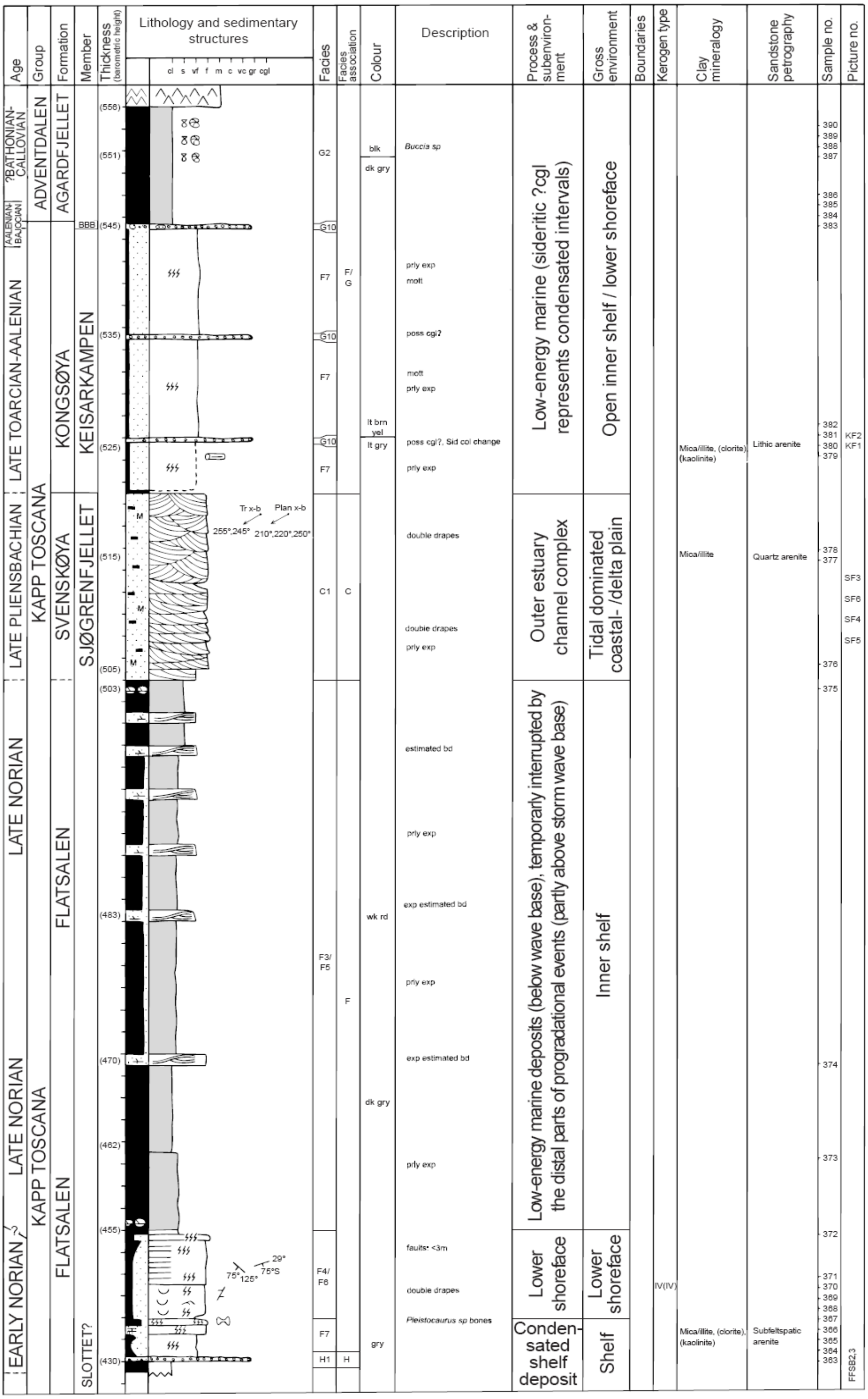
Bioturbated sandstone with double drapes. Flatsalen Fm, 452 m. Photo: G.B. Larssen

The **Agardhfjellet Formation** consists of a transgressive 11 m thick black mottled claystone with ammonites and mussels. Notice possible sideritic conglomerates along the weak inclined slope (condensed intervals). The unit is terminated by basalts that have protected the underlying unconsolidated sediments from erosion.



From Larssen et al., 1995

TUMLINGODDEN, **WILHELMØYA**



From Larssen et al., 1995

Svenskøya Formation at Wilhelmøya, Tumlingodden-Keisarkampen profile.

Planar cross stratification in the Svenskøya Formation, Wilhelmøya. Notice the frequency of clay drapes(often mud couplets) and concentration of clay drapes along the toeset. 510 m.

The Kongsøya Formation on Wilhelmøya

Mottled unlithified sandstone in the Kongsøya Formation.

Fossil coalified logs in a bioturbated unlithified sandstone, Kongsøya Formation

Day 4, BRÅSVELLBREEN (Optional stop)

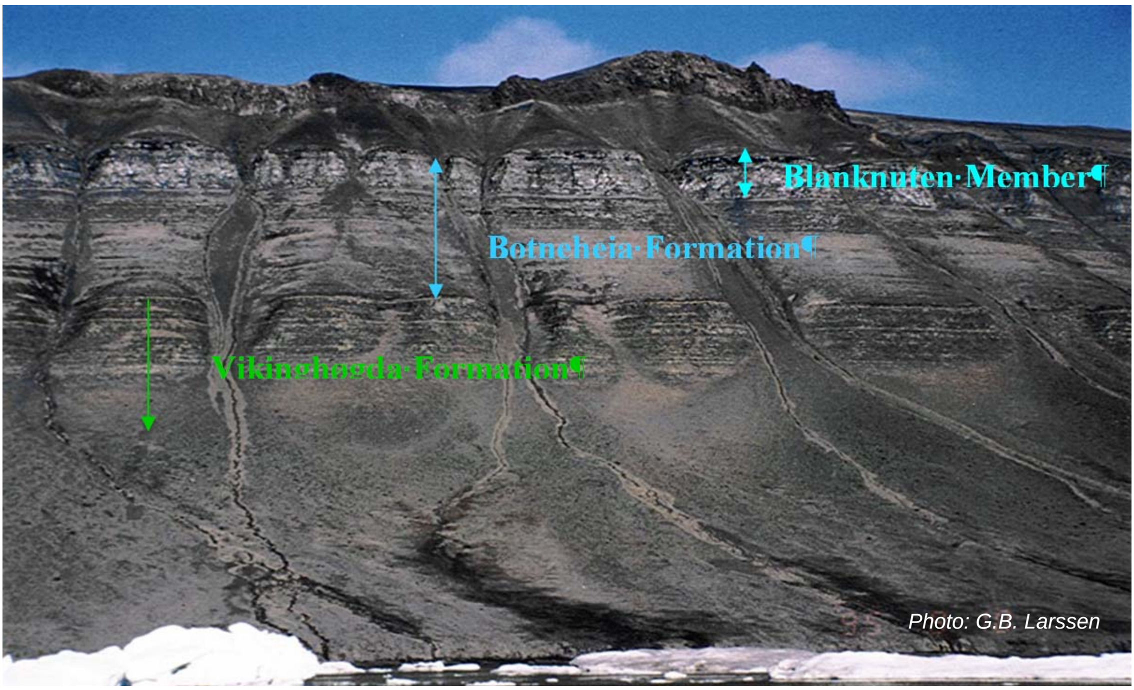
If time and sea-ice conditions permit, Origo will make a short stop in front of the Bråsvellbreen, an offshoot of the enormous glacier Austfonna on Nordaustlandet. This glacier gained distinction in1937-38 when the largest surge known on Svalbard happened. The glacier advanced 20 km into the sea with a 30 km wide front.

Bråsvellbreen forms a steep impregnable front against the sea on the southern side of Nordaustlandet. Photo: J.Henriksen.

The front of Bråsvellbreen. Rivers of melting water forms waterfalls against the sea. Photo: J. Henriksen.

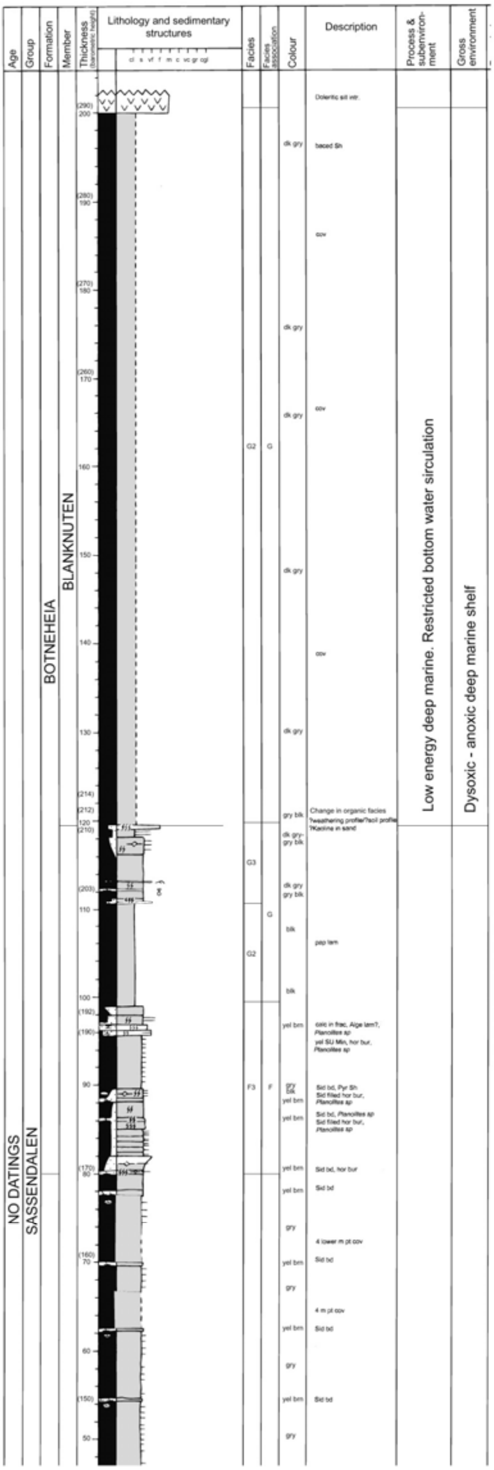
Day 5, Stop 1; *BARENTSØYA*

Sailing through Freemansundet between Barentsøya and Edgeøya (probably very early morning) we can study the outcrops of the Triassic Sassendalen Group from distance (boat). At the southwestern Barentsøya in the slope of the mountain Høgrinden, the deposits of the Vikinghøda Formation (Olenekian age) and the Botneheia Formation (Anisian-Ladinian age) are exposed. The Vikinghøgda Formation reflects a storminfluenced open marine shelf, while the deposits in the Botheheia Formation have a more dysoxic – anoxic deep marine shelf origin.



The Sassendalen Group with the formations Vikinghøgda- and Botneheia in the slope of the Høgrinden Mountain at the Freemansundet southwest on Barentsøya. Notice the steep Blanknuten Memberin the upper part of the slope.

HØGRINDEN, **BARENTSØYA**



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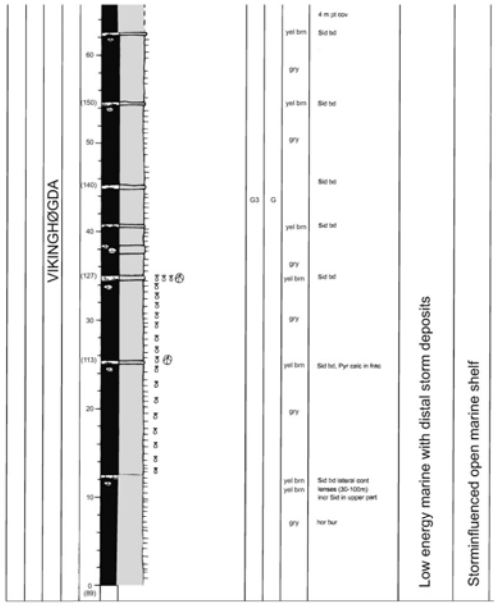
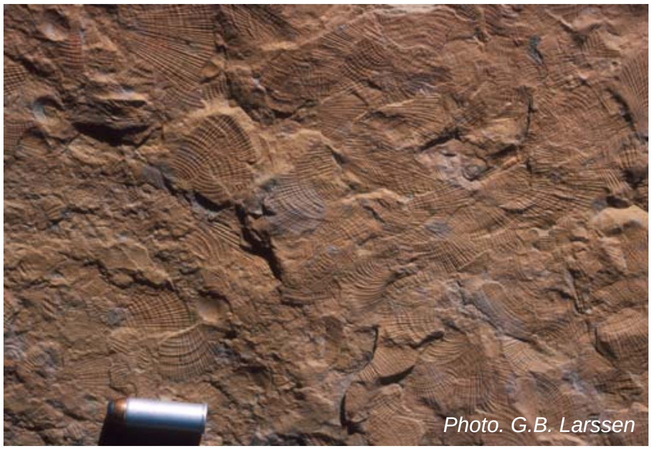


From Larssen et al., 1995

The profile Høgrinden on Barentsøya. The person on the picture are standing on the boundary to the Early Triassic Vikinghøgda Formation.

Pictures with details in the Early-Middle Triassic Høgrinden profile on Barnetsøya:

Papershale morphology in mudrocks with intercalated sitlltstone layers in Vikinghøgda Fm (8m).



Mussels in the Vikinghøgda Fm., level 35 m.

Planolithes sp.bioturbation (big picture) and sand-filled phosphatised ?Thallesanoides sp. burrows in Lower Botneheia Fm, level 88 and 89 m.

Thin silt layers and lences in a greyish black mudstone in Lower Botneheia Fm, 90 m.

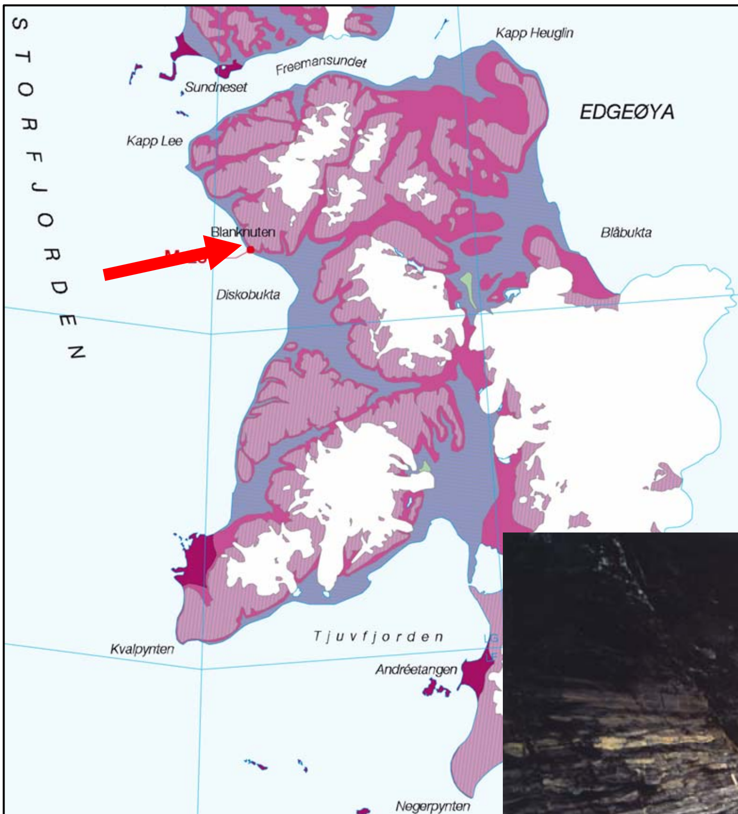
Calcified sandrich bioturbated mudstone with a lence-shaped lithology in the Barentsøya Fm, level 96m.

- No climbing in cliff Show
- Look out for falling rocks

Day 5, *Stop 2*: BLANKNUTEN, EDGEØYA

We will land at Blankodden and walk a profile along the beach and up along a ravine in the slope. Four formations are exposed; Vikinghøgda, Botneheia, Tschermakfjellet and De Geerdalen formations, displaying a rock record from Early to Late Triassic.

Photo: L.B. Henriksen



The **Vikinghøgda Formation** (Induan-Olenekian) displays dark grey to black pyretic shales and silty shales with subordinate siltstones and carbonate beds. The sediments were probably deposited on a storm influenced shelf. Observe fish-fragments. Also notice hydrocarbon smell when crushing the shale.

Vikinghøga Formation. Photo: P.E.Eliasen

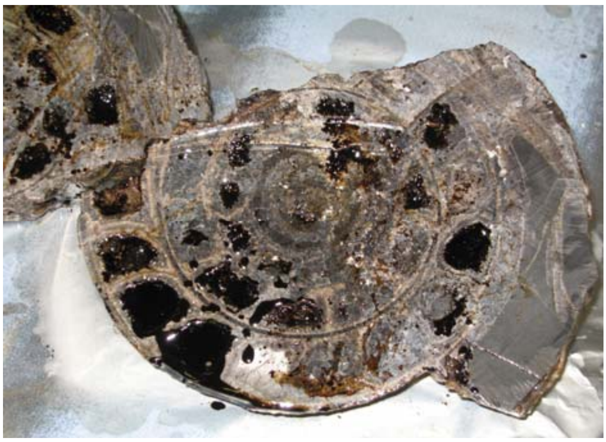
The **Botneheia Formation** forms a faint coarsening-upward succession, where the basal overall brownish paper shale grade into more silty shale. The formation consists mostly of bluish weathering black shale with abundant small phosphate nodules and laminae. Thin to medium thick, yellow weathering carbonaceous siltstone beds and concretions occur throughout the unit and *Thallassanoides* sp. burrows are abundant. The upper part (Blanknuten Member) is highly calcitic due to numerous contained thin-shelled bivalves, and this beds form a pronounced cliff. The top is marked by a silststone bed with phosphate nodules, and overlain by grey shale with purple weathering siderite nodules of the Tschermakfjellet Formation.

Vikinghøgda-, Botneheia-, Tchermakfellet & De Geerdalen formations. Photo: G.B. Larssen

Upper part of Botneheia Formation, Blanknuten Member. Photo: G.B Larssen

Marine fossils and reptile bone fragments occur and are abundant in the upper intensively bioturbated part. The formation is rich in organic material (TOC 1-10%), especially in the upper part. It represents, together with the time-equivalent, but more silt- and sandrich Bravaisberget Formation, the most promising hydrocarbon source rocks of Svalbard (notice the pronounced hydrocarbon odour in the Blanknuten Member).

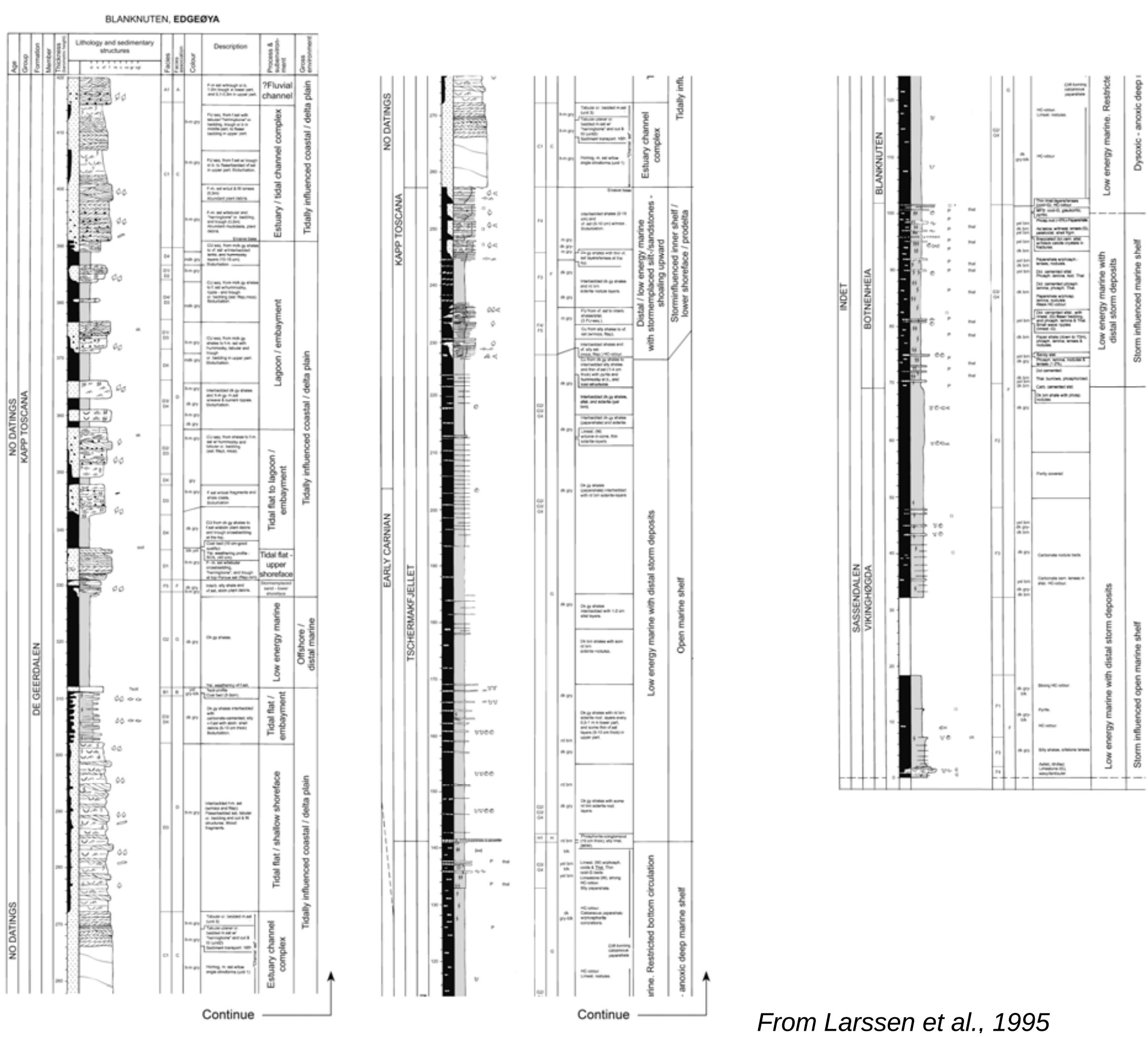
The Botneheia Formation is interpreted as a deltaic influenced, regressive shelf deposit, with partly restricted environments in terms of water circulation.



Ammonite (Aristoptychites trochleaeformis) of Late Anisian age with oil in the chambers. Found at Blanknuten, Edgeøya. From Smelror & Sollid, 2007.

The **Tschermakfjellet Formation** displays dark grey shales with upward increasing intercalated siltstone laminae and corresponding decrease in siderite nodules. Near the top of the formation fine-grained sandstone beds with ripple lamination occur. Fossiliferous beds with ammonoids, bivalves, gastropods and brachiopods are abundant. The formation represents a shale-dominated low energy open marine shelf with storm influenced inner shelf to lower shoreface depositional environment.

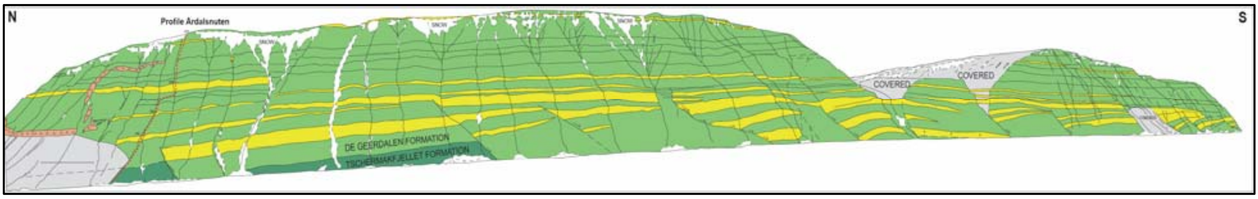
The **De Geerdalen Formation** consists of repeated coarsening upward successions from shale to sandstone. Silty shales that contain siderite nodules alternate with sandstones. The sandstones are texturally and compositionally immature, in contrast to the sandstones of the Sassendalen Group and Wilhelmøya Subgroup. Thick sandstones form cliffs in the mountainsides. Two main types of sandstone occur: (1) Massive, argillaceous, medium-grained, locally greenish, pale grey weathering sandstones that coarsen upwards; they are mostly structureless, although some bioturbation and linguoid ripples occur. (2) Upward-fining sandstones with sharp lower contacts, some with intraformational mud conglomerates or gravelstones. Ripple structures and cross-bedding alternating with parallel bedding are common, and channel structures prevail locally. These sandstones weather with a brownish colour. Minor sandstone beds showing desiccation cracks, raindrop imprints and flaser bedding are locally found. In western and central to eastern Spitsbergen, the upper part of the De Geerdalen Formation is dominated by multicoloured shales, alternating with minor coarsening-upward units terminating in silt or sandstone beds (Isfjorden Member). Some reddish siderite beds which contain plant fossils, fossilised logs, coal fragments and cone-in-cone structures are also present. The De Geerdalen Formation was deposited in shallow shelf to deltaic environments.

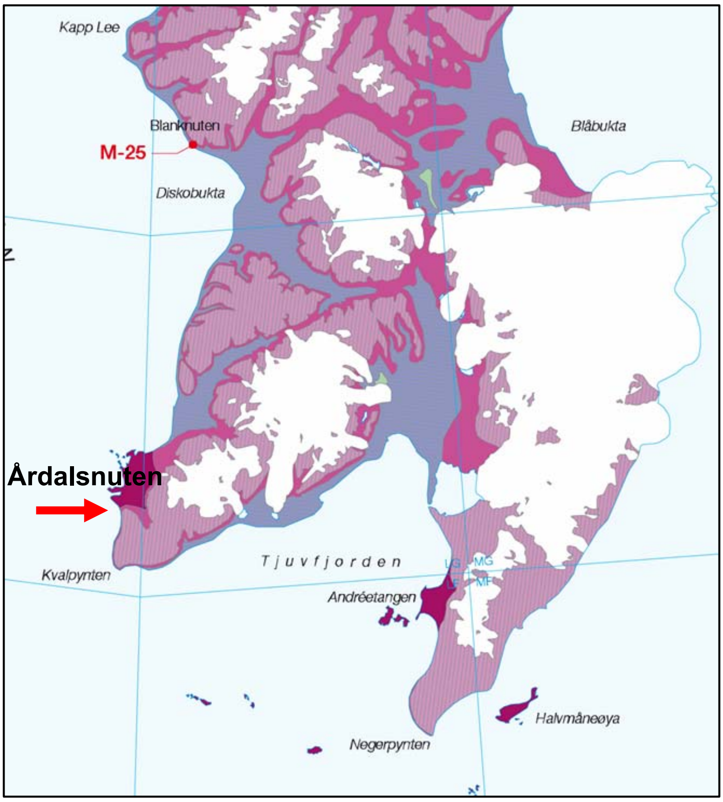


From Larssen et al., 1995

Day 5, Stop 2: KVALPYNTEN, EDGEØYA

World Class Locality



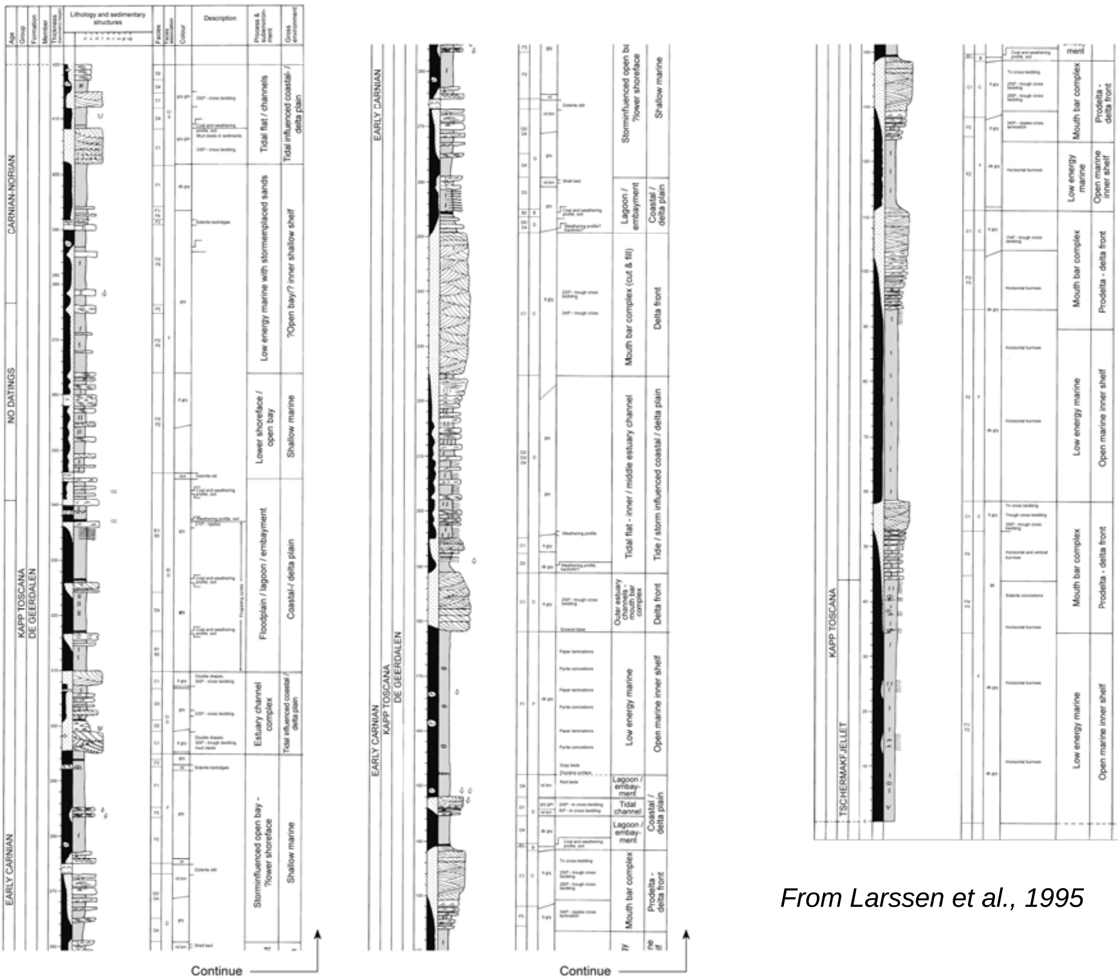


Grow faults, rollovers, and shale anticlines affecting Upper Triassic deltaic coarsening-upward sequences are excellently exposed in coastal cliffs on Edgeøya. A measured profile (Larssen et al, 1995) on Årdalsnuten in the left of the above mosaic-picture and another at the right end of the picture describes the sediments. Upper part of the Botheheia Formation, a complete Tchermakfjellet Formation and an almost complete De Geerdalen Formation with repeated coarsening upward cycles are exposed in the cliffs. Study of photographs of the cliffs shows fault configuration, reservoir variations, and internal features of shale anticlines. On downthrown blocks the strata were tilted and rollovers were formed. Beneath the concave-upward grow faults shale anticlines developed and relative uplift of the up thrown block resulted in erosion of some of the newly deposited sands. Subsequent shale deposition formed a local angular unconformity.

The faulting may have been initiated by a combination of (1) denser sands overlying less dense clays with excess pore-fluid pressure, (2) a southward prodelta slope and/or regional paleoslope slope, (3) differential loading associated with deltaic progradation, and (4) a triggering mechanism such as earthquakes.

The lithologies and depositional environments in the different formations on Kvalpynten reflects more or less the same type of facies as seen on Hopen.

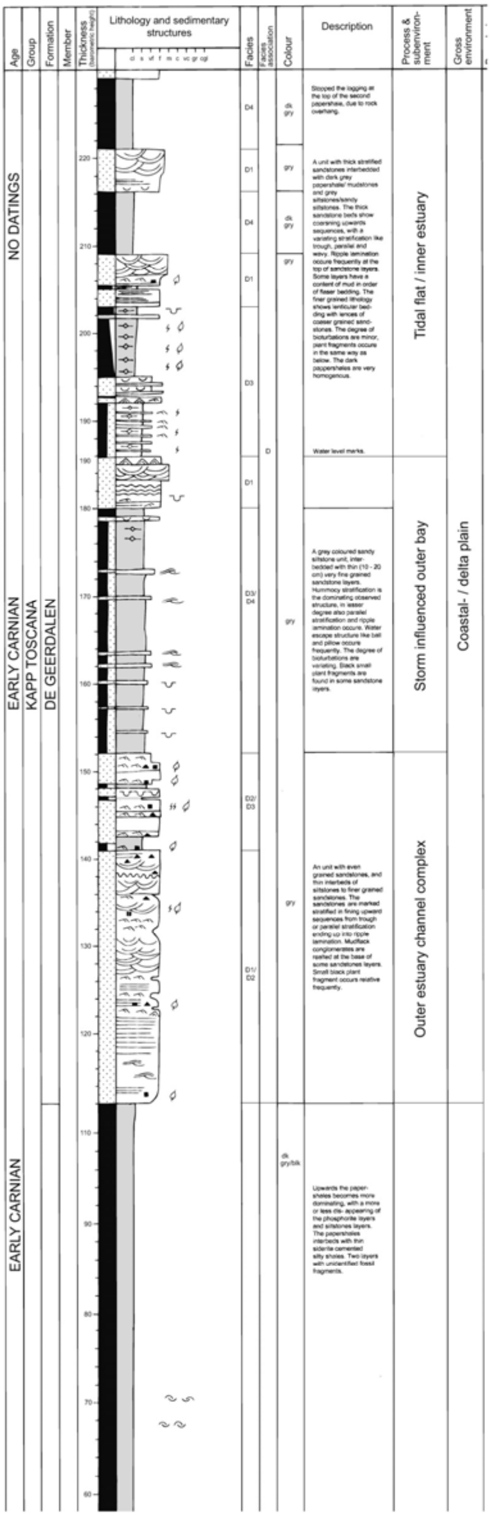
Årdalsnuten



From Larssen et al., 1995

Attenuating deltaic sandstone lobes with grow faults in the lower part of the De Geerdalen Formation, Kvalpynten, Edgeøya.

KVALPYNTEN VOGELFJELLET, **EDGEØYA**



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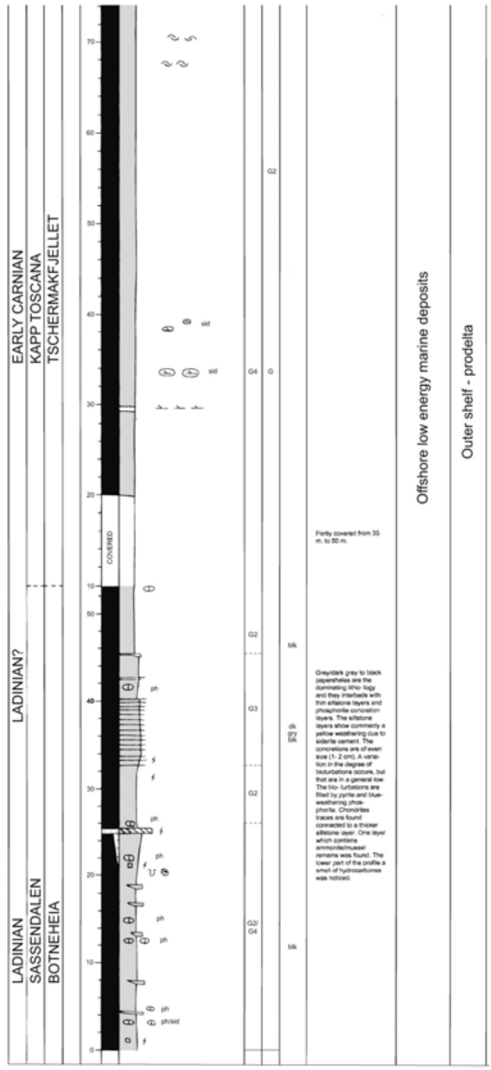


From Larssen et al., 1995

Early Carnian channeled sandstone incised into Early Carnian/-Ladinian marine mudrocks in Negerpynten southwest Edgeøya

Details in the profile Årdalsnuten at Kvalpynten.

Root stuctures in delta plain facies

Subaeril exposed and eroded waveripples

Hummocky cross-stratification

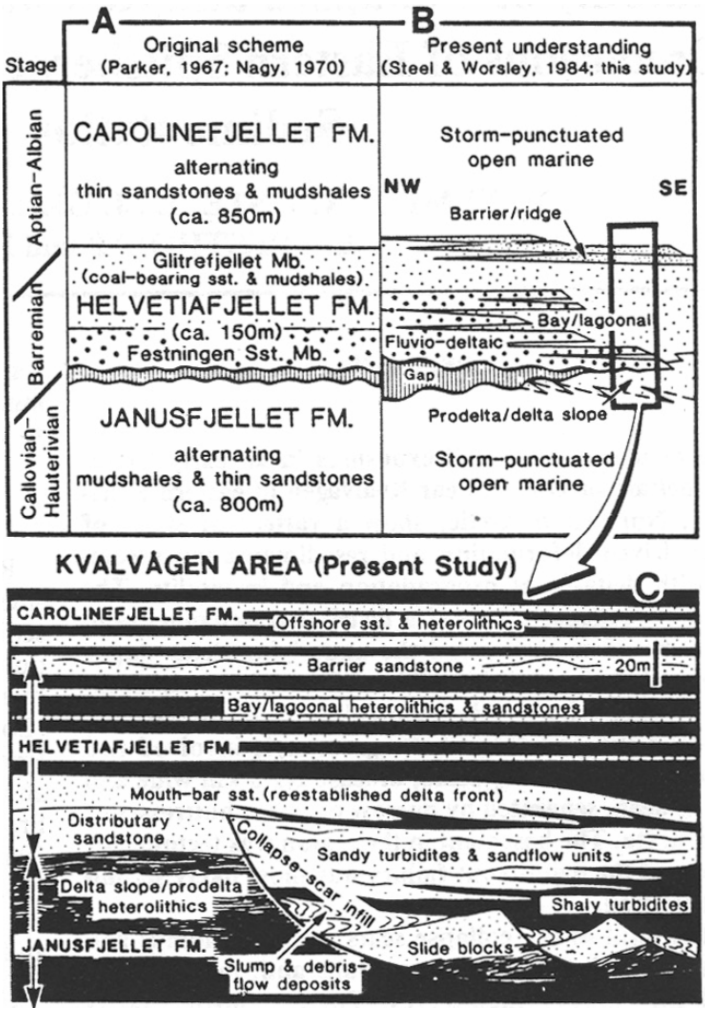
Weathering soil profile with coal and rootlets

Desiccation cracks

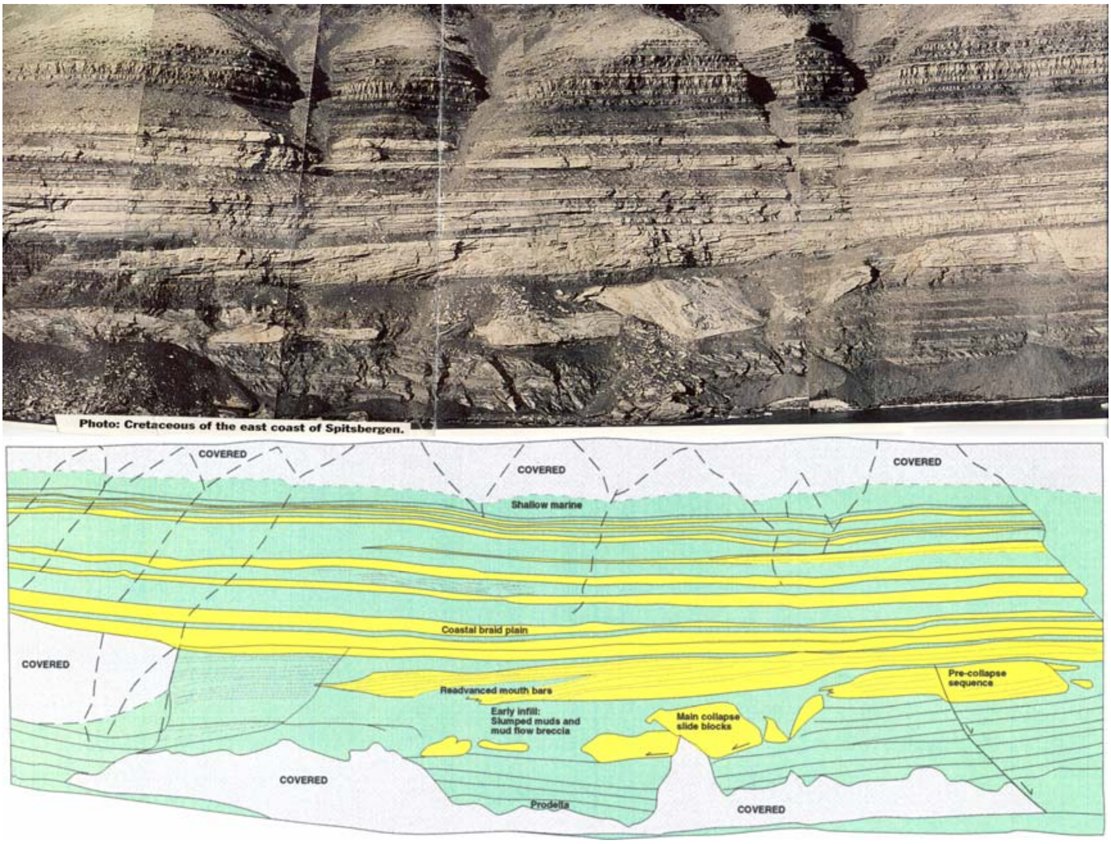
Small-scaled wave ripples superimposed on a hummocky cross-stratified sandstone

Day 5, Stop 3: KVALVÅGEN

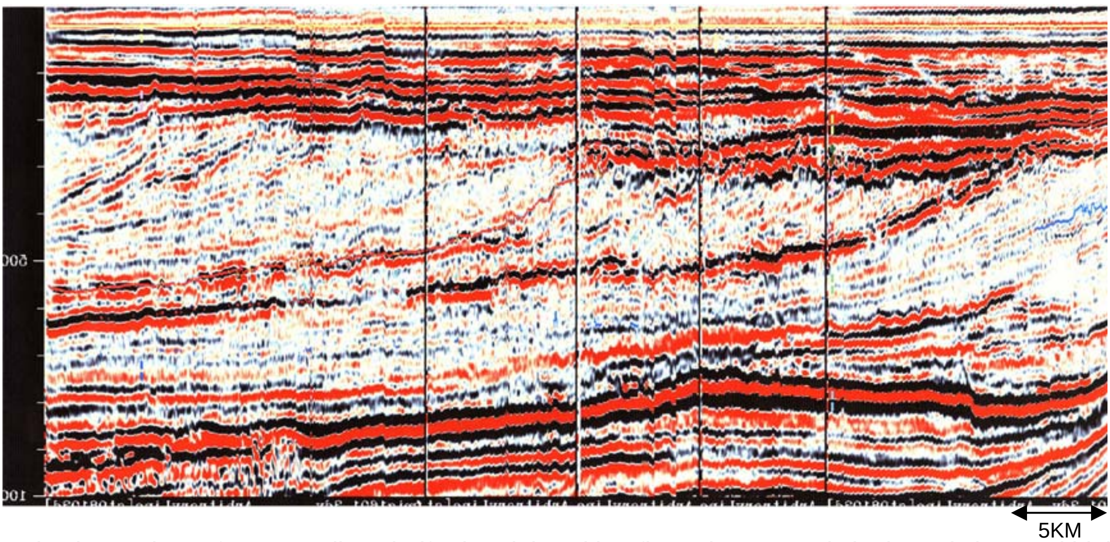
Spectacular coastal cliff exposures in an early Cretaceous deltaic succession near Kvalvågen in Eastern Spitsbergen, show a variety of styles of gravity-driven deformation and resedimentation associated with delta-front progradation and instability (Nemec et al., 1988). The outcrop contains three formations of the Adventdalen Group with the Agardfjellet-, Helvetiafjellet- and the Carolinefjellet formations. The large-scale collapse involved a distributary-channel sand unit, some 20m thick, and the underlying delta slope/prodelta shaly heterolithics. The deformation was essentially brittle, whereby large blocks of the delta-front succession slid and rotated. Its gross style involved two large scale cuspate tear-away scars, at least 1-1,5 km wide and 50-60 m deep., separated by narrow remnant buttresses of in-situ strata. The basement in the region was tectonically active, and the delta-front failure was most likely seismically triggered.



Initial infill of the collapse scars involved slumps and debris-flows, derived from scar walls and, locally, from the sliding blocks themselves. These deposits partly smoothed the local topography created by the slide blocks. This early infill was followed by deposition of thin, mainly muddy turbidites, probably shed from the scar walls by small localized failure. Renewal of fluvial supply of sand led to the main infill of the scar depressions. This stage involved effluent-generated turbidites (heterolithic), and increasingly sandier turbidites and liquefied sandflows derived from unstable, oversteepened distributary mouth bars. The mouth-bar systems eventually achieved stability and prograded across the infilled scars. They were affected by periodic storm-wave attack and sudden increases of water depth. The scar infill at that stage was subject to minor grow faulting, possibly related to new seismic tremors.

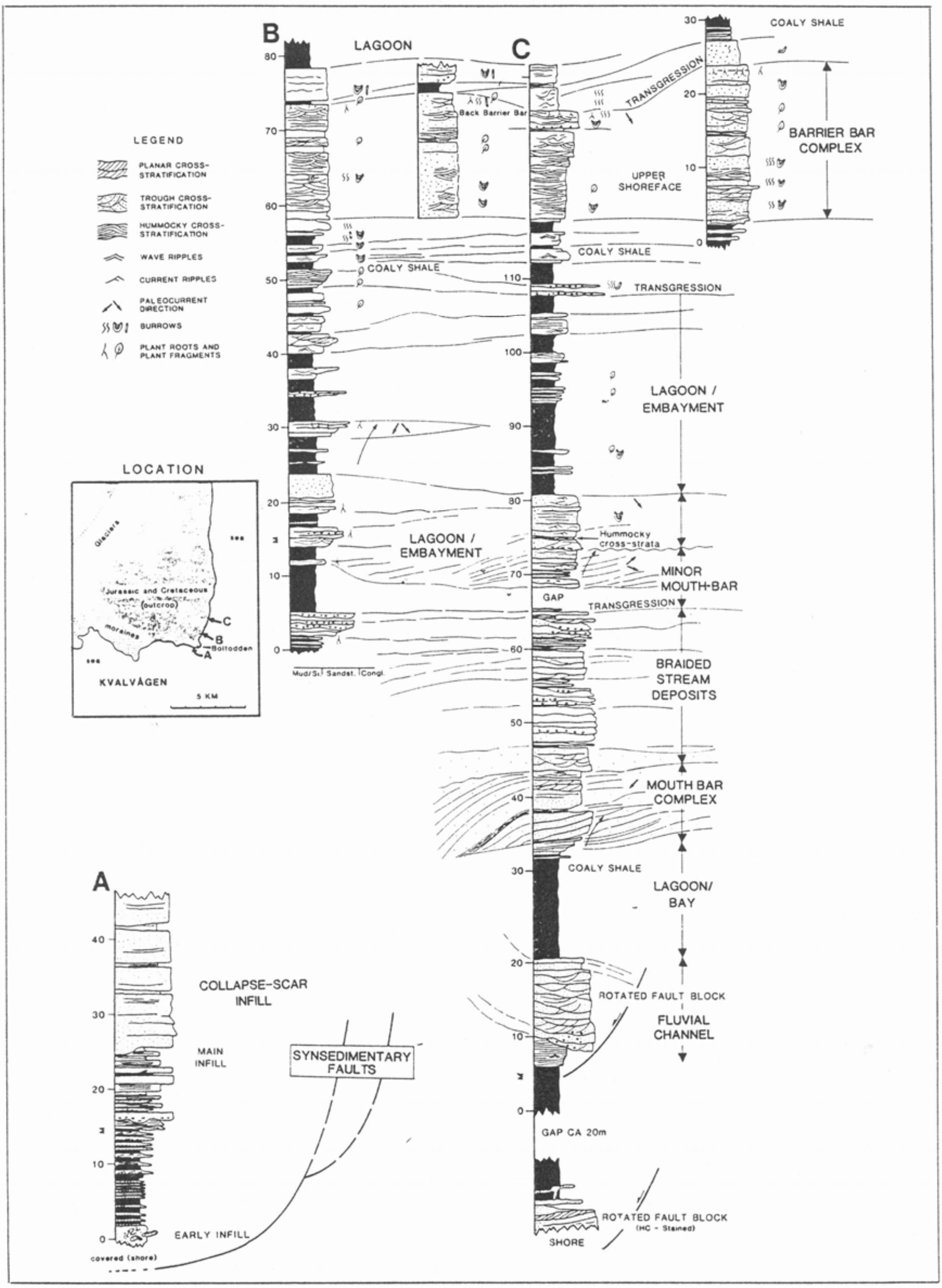


Portion of cliff section showing two main elements of collapse pattern: slipped rotated blocks of delta-front deposits and detachment surfaces along which these blocks were displaced. Note chaotic nature of initial infill above rotated blocks, and mouth-bar deposits of re-established delta front above in filled collapse scar.



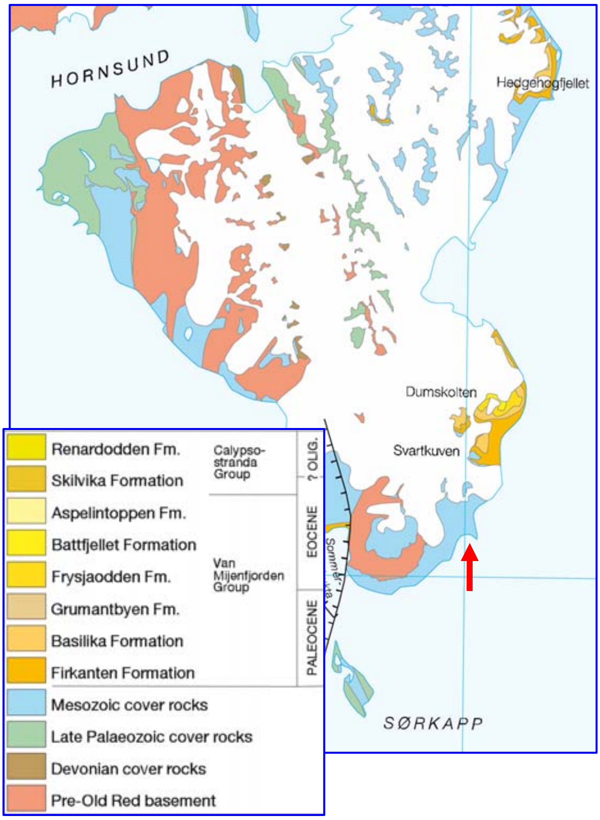
Seismic “analog" of a prograding shelf edge delta with a flat trajectory and single and clustered high amplitudes (channel-lobe sandstones) on the slope area, suggesting sand on the clinoform slope. Scattered and clusters of high-amplitude reflectors may represent sandy slope channels, gullies or debrites deposits. Example from Porcupine Basin (from Johannessen and Steel, 2005).

Delta Front in Lower Cretaceous of Eastern Spitsbergen

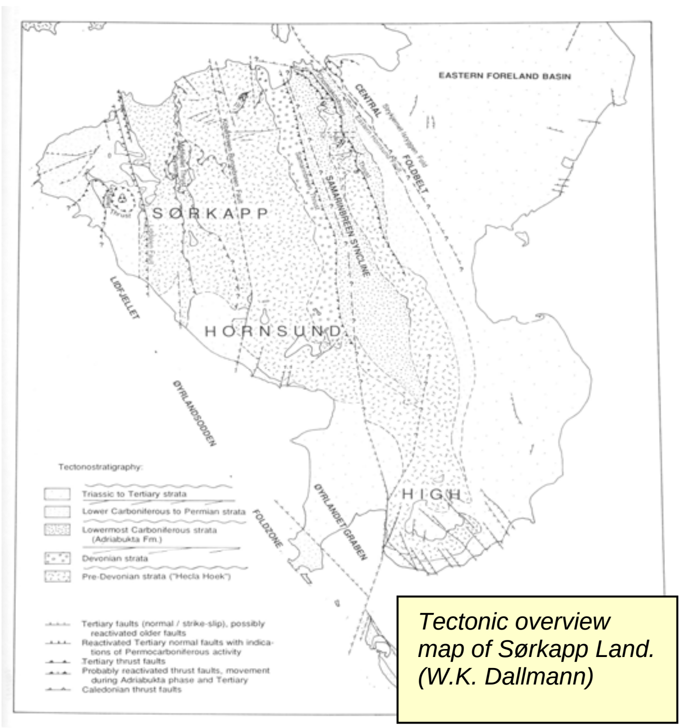


Vertical log through Helvetiafjellet Formation in study area, showing succession of depositional facies and its broad interpretation (from Nemec et al, 1988).

Day 6, Stop 1: *KIKUTTODDEN-KEILHAUFJELLET, SØRKAPP*



The Sørkapp is a complexed structural area, subdivided into four main tectonic regions: 1) a complexely deformed basement high with unconformably overlying sediments in the west, 2) a downfaulted area with sedimentary strata, locally folded, in the southwest, 3) a central foldbelt in the northern middle, and 4) a foreland basin to the east (Dallmann 1993). We will however focus on startigraphy and sedimentology and the main locality to visit is the Kikuttodden – Keilhaufjellet. Optional localities are Sørkappøya and/or Mathiasbreen.



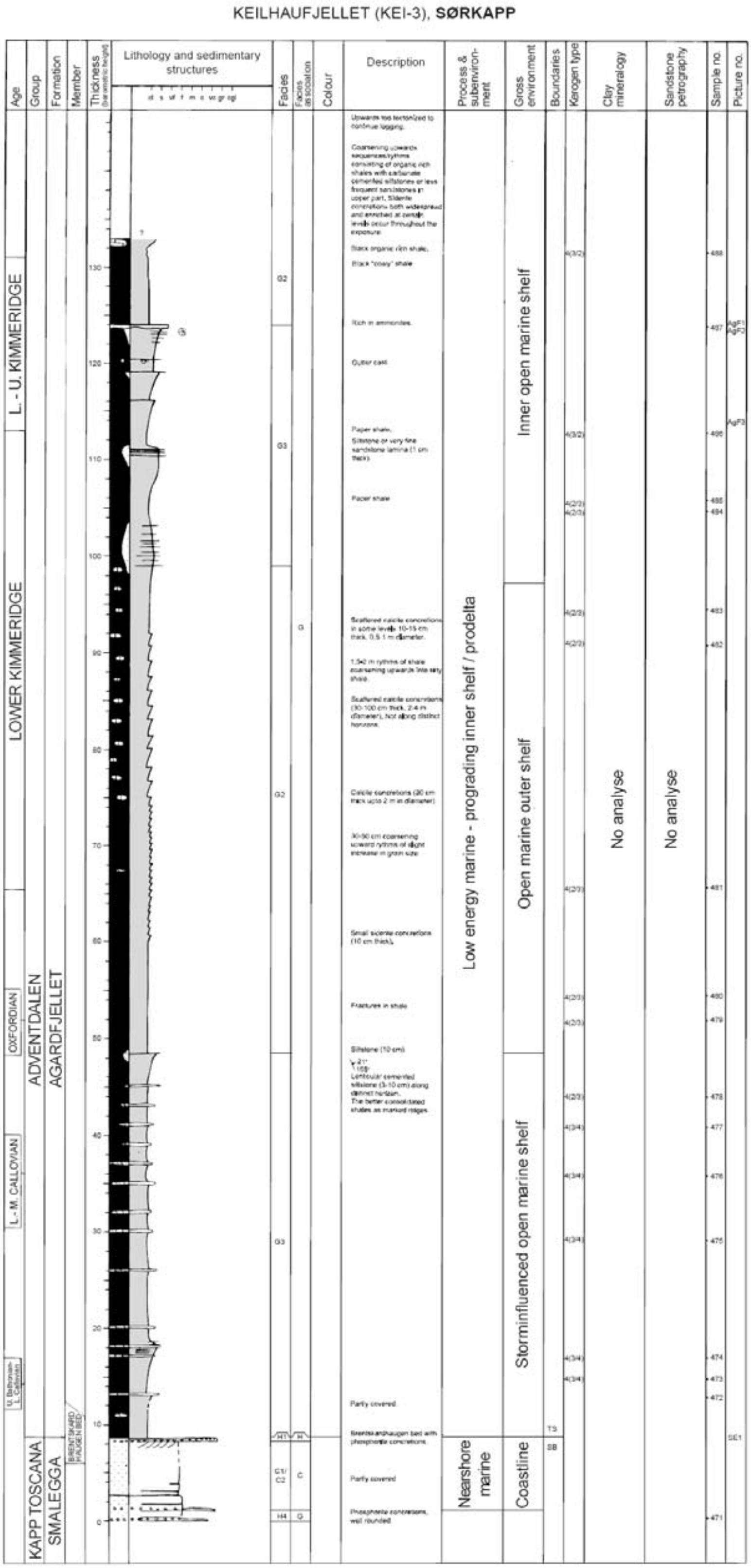
Tectonic overview map of Sørkapp Land. (W.K. Dallmann)

Kikuttodden-Keilhaufjellet

The outcrops of Keilhaufjellet comprise marine shales, siltstones and sandstones of the Late Jurassic to Early Cretaceous Adventdalen Group. The group is widely exposed along the margins of the Central Tertiary Basin on Spitsbergen, as well as in eastern Spitsbergen (Sabine Land) and on Kong Karls Land. It continues across the Barents Sea Shelf to the Bjarmeland Platform, around the Loppa High and into the Hammerfest and Nordkapp basins. The group is dominated by dark marine mudstones, but includes also deltaic and shelf sandstones as well as thin, condensed carbonate beds. Important hydrocarbon source rocks occur in the Upper Jurassic succession, both in Svalbard and in the Barents Sea Agardhfjellet, Fuglen and Hekkingen formations). A Barremian fluvio-deltaic sandstone unit near the top of Keilhaufjellet (Helvetiafjellet Formation) have a slightly erosive contact to the underlying marine sandstones as a result of northern uplift and a following deltaic progradation.

The Adventdalen Group was eroded down to varying levels during the late Cretaceous uplift. On the southern Barents Sea Shelf, this hiatus comprises only the Cenomanian and part of the Turonian, while the entire Upper Cretaceous is lacking on Svalbard.

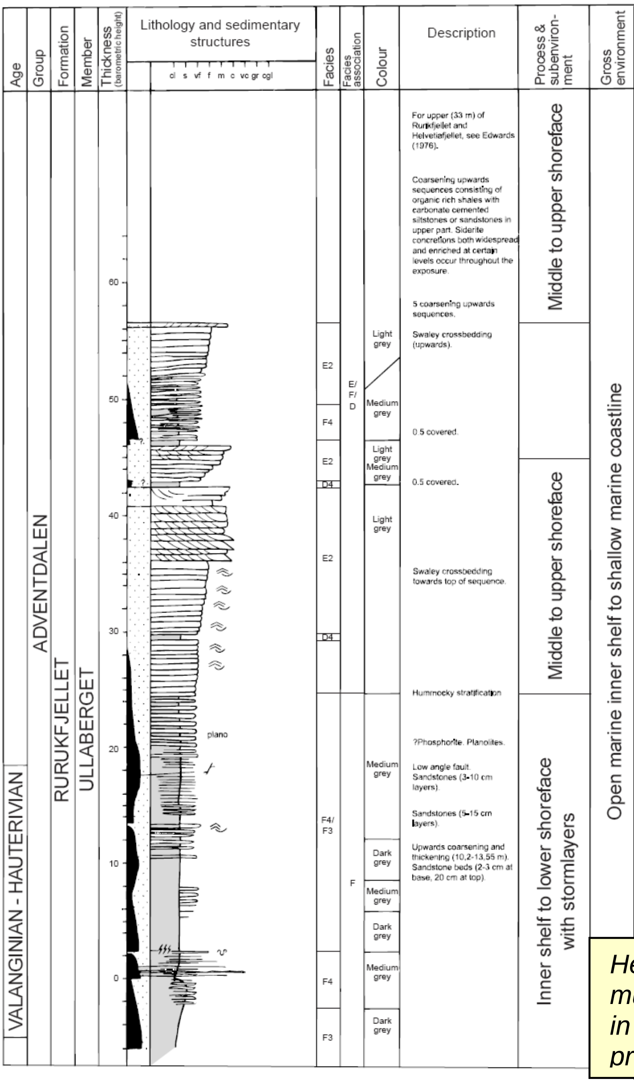
Ammonites in siltstones in the Agardfjellet Formation in the profile Keilhaufjellet. Photo: I. Laursen



From Larssen et al.. 1995

Exposed part of the Adventdalen Group in the Keilhaufjellet, seen from west. Photo: S.Bergh.

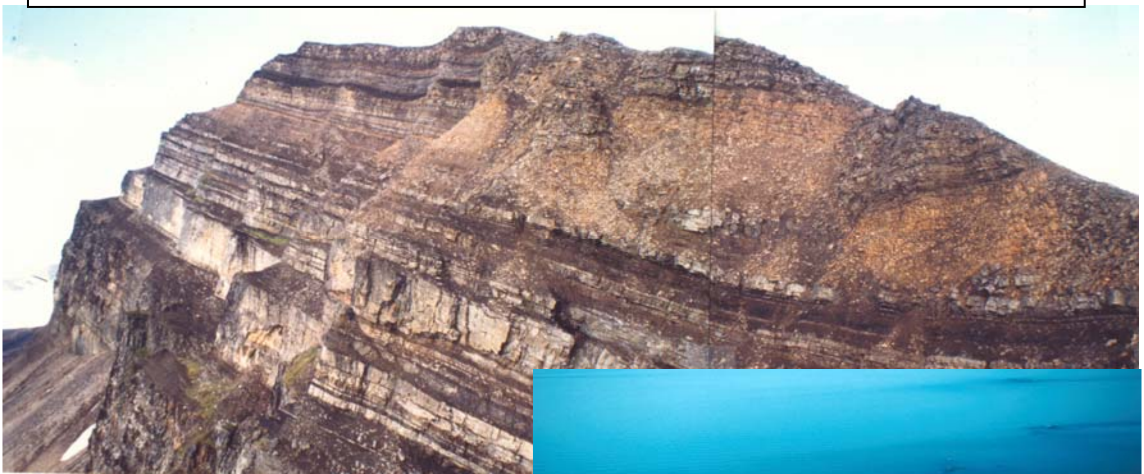
KIKKUTODDEN v/FOTEN AV KEILHAUFJELLET (KIK-3-1), **SØRKAPP**

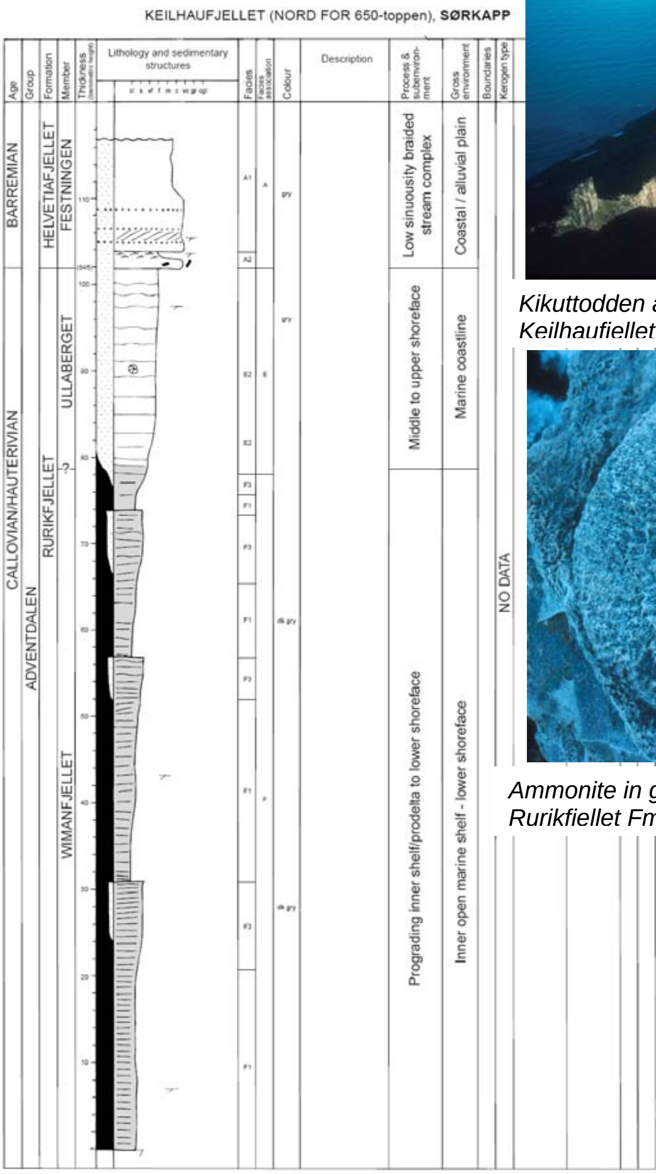


Heterolithic unit with alternating mudstones and fine-grained sandstones in the the Rurikfjellet Formation at the profiel Kikuttodden. Photo T. Hellem.

From Larssen et al., 1995

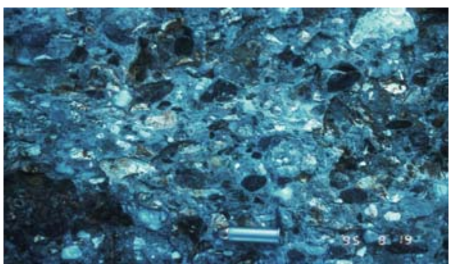
Possible syn-sedimentary normal fault in the Carolinefjellet Formation, Keilhaufjellet seen from south. Notice inclined layering against east. Photo: S. Berg.





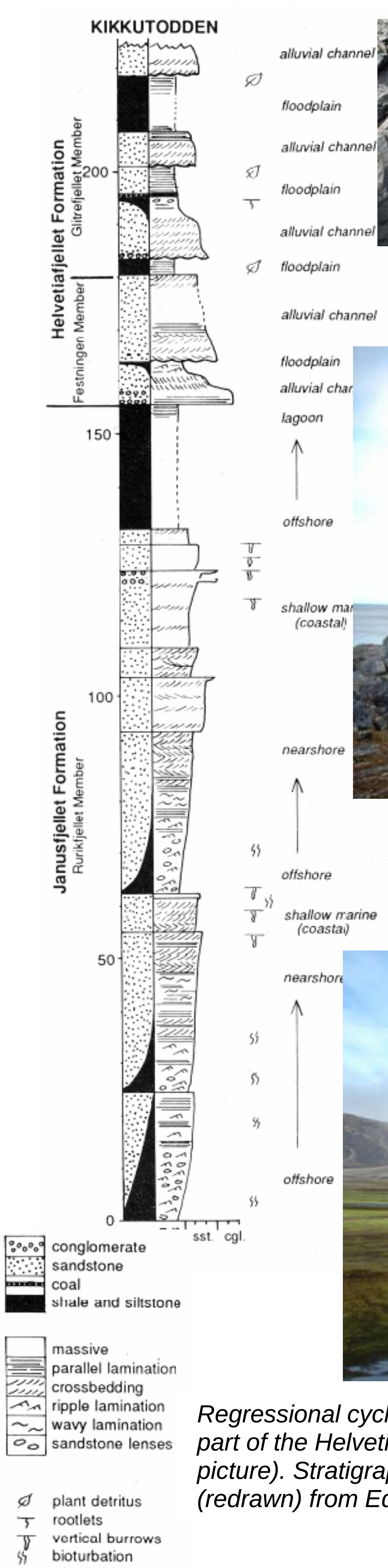
Kikuttodden at Sørkapp seen from north at the top of the Keilhaufjellet. Photo. G.B. Larssen

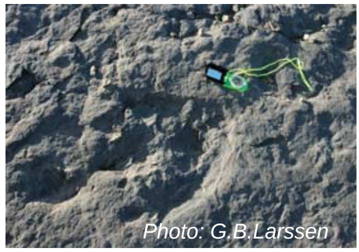
Ammonite in grey massive thin-bedded sandstone in the Rurikfiellet Fm. Scale 4 cm. Photo G.B. Larssen



Polymictic conglomerate at the base of the Helvetiafjellet Fm in the profile Keilhaufjellet. Scale 4 cm. Photo: GB. Larssen

From Larssen et al., 1995



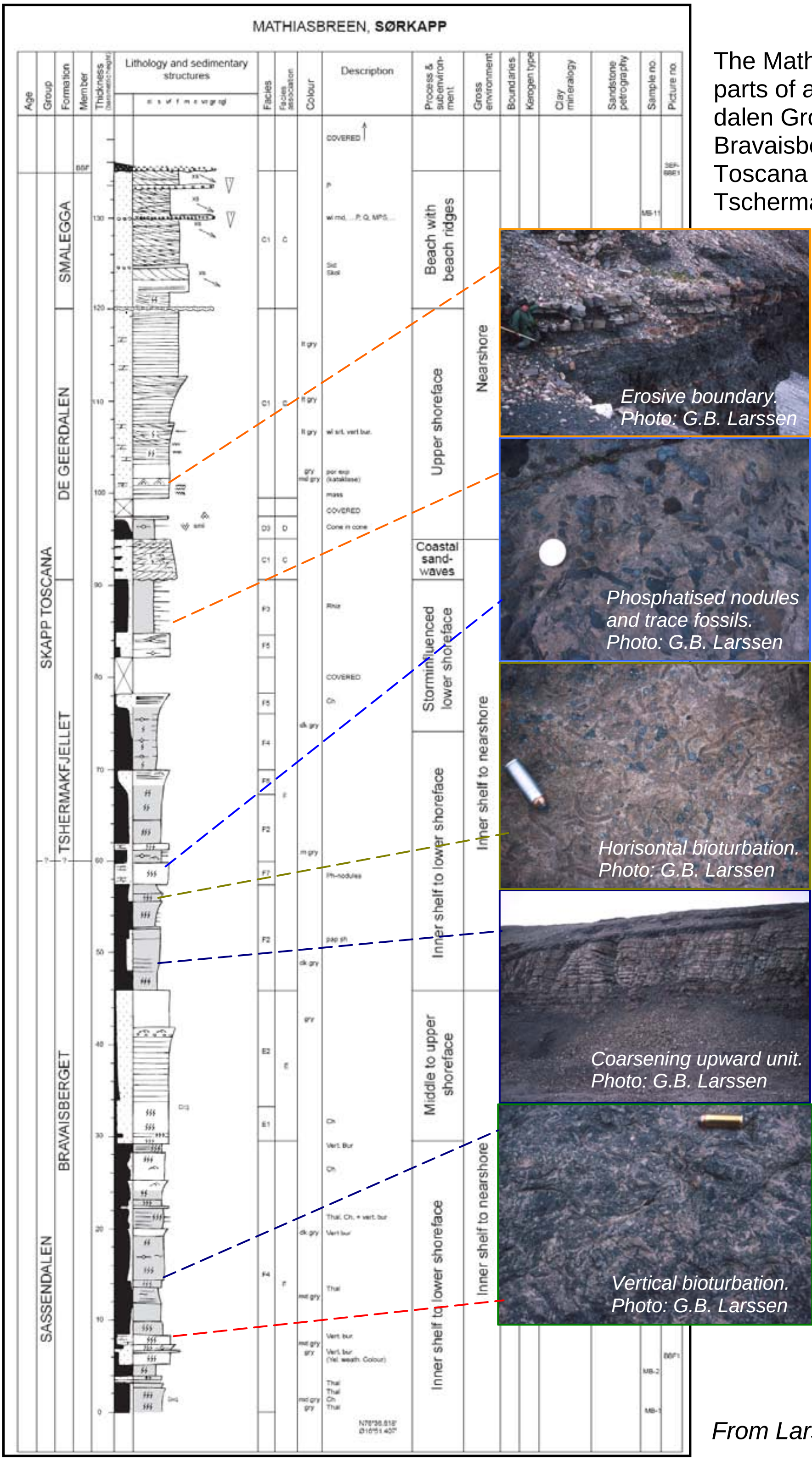


Fossil trees (left) and a dinosaur footprint (right) in the Helvetiafjellet Formation at Kikuttodden.

Alternating alluvial channels and flood plain deposits in the Helvetiafjellet Formation at Kikutodden (Edwards 1976)

Regressional cycles in the upper part of the Rurikfjellet Formation and lower part of the Helvetiafjellet Formation at Kikuttodden/Keilhaufjellet (lower picture). Stratigraphic section (left) measured near by, at Kikutodden (redrawn) from Edwards 1976 in Dallmann et at., 1993.

Day 6: MATHIASBREEN, SØRKAPP (Optional locality)



The Mathiasbreen profile displays parts of a condensed Sassen-dalen Group (Middle Triassic Bravaisberget Fm) and the Kapp Toscana Group (Late Triassic Tschermakfjellet, De Geerdalen and Smalegga formations).

The sediments in the Sørkapp area are believed to have a westerly provenance. It is located closer to the source area (Greenland) than the equivalent depositions on the eastern parts of Svalbard (which are believed to have an easterly source area).

The sediments are interpreted to represent inner shelf to shoreface and beach environments. Notice similarities and differences with time equivalent sediments east on Svalbard studied earlier on the excursion.

From Larssen et al., 1995

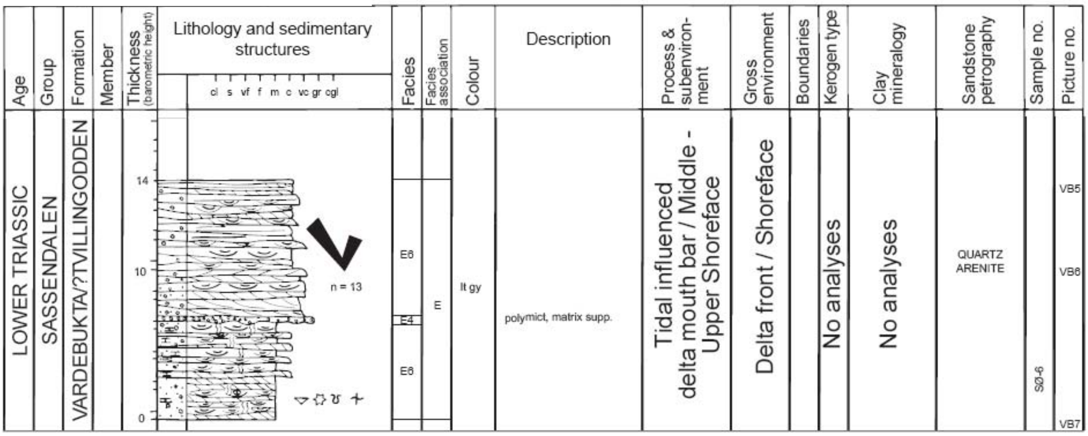
Day 6: SØRKAPPØYA (Optional locality)

Sørkappøya looking north-west.

Exposures belonging to the Vardebukt Formation on Sørkappøya.

From Larssen et al., 1995

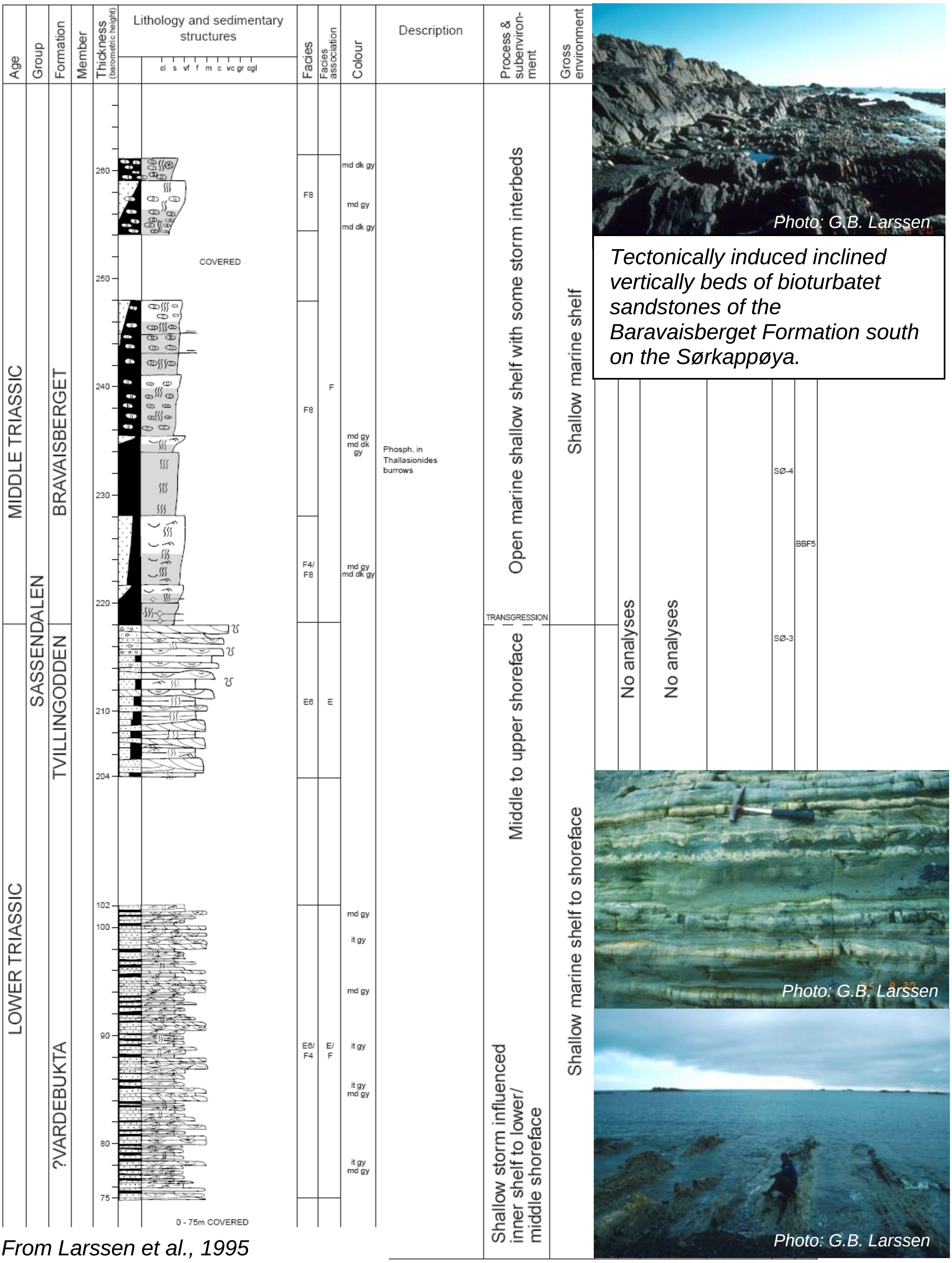
TRONDSENNESET, **SØRKAPPØYA**
GPS 76°28,003' 16°35,139'



Steep foresets in a coarse-grained cross stratified heavily silica cemented sandstone on the Trondsenneset, Sørkappøya. Hammer for scale.

Sporadic brachiopods in sandstone in the lower part of the profile Trondsenneset. Scale 4 cm.

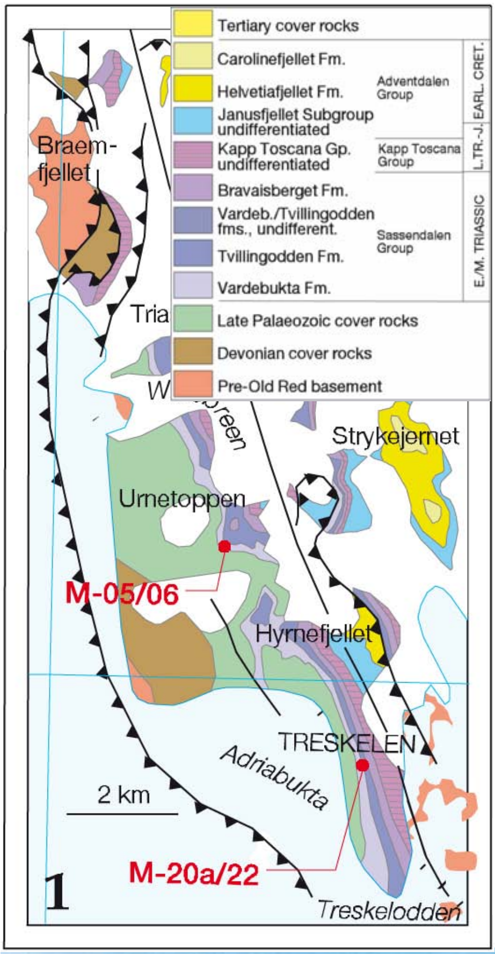
SØRKAPPØYA
GPS 76°30,516' 16°31,254'



Tectonically induced inclined vertically beds of bioturbatet sandstones of the Baravaisberget Formation south on the Sørkappøya.

From Larssen et al., 1995

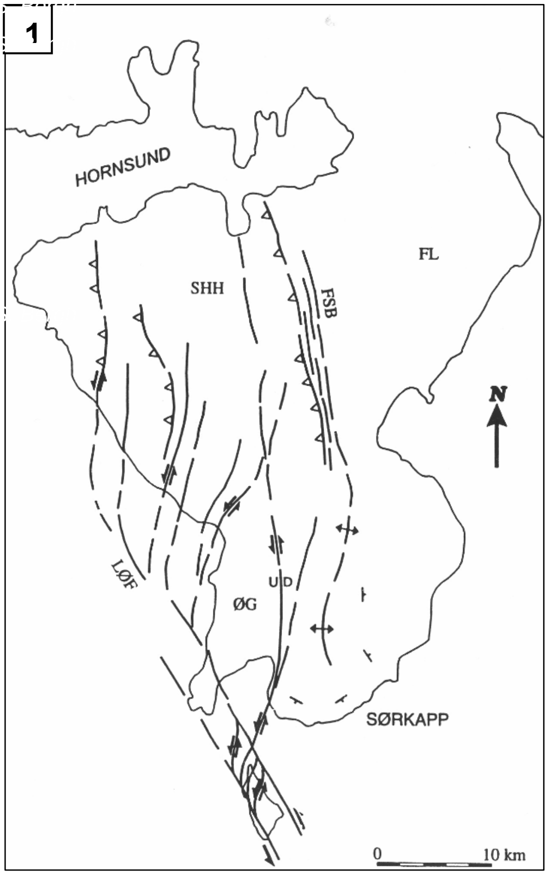
Day 7, Stop 1: *HORNSUND, TRESKELEN*

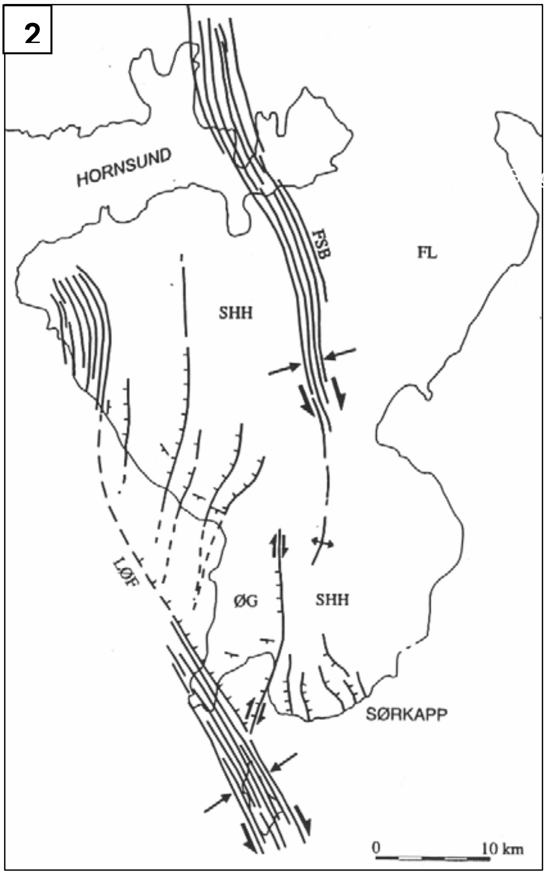


We will land close to a small hunting lodge in the Adriabukta and walk along the beach of Treskelen on the well exposed outcrops. Before we reach Base Triassic we will move through exposures of Late Paleozoic age. The Mid-Late Carbonifeous Hyrnefjellet Formation is situated in the centre of the Hyrnefjellet anticline above the Adriabukta Formation near the beach. This unit is followed by the Late Carboniferous-Early Permian Treskelodden Formation of the Gipsdalen Group and the Late Permian Kapp Starostin Formation of the Tempelfjorden Group.

The magnificent mountain Hornsundtind in the background.

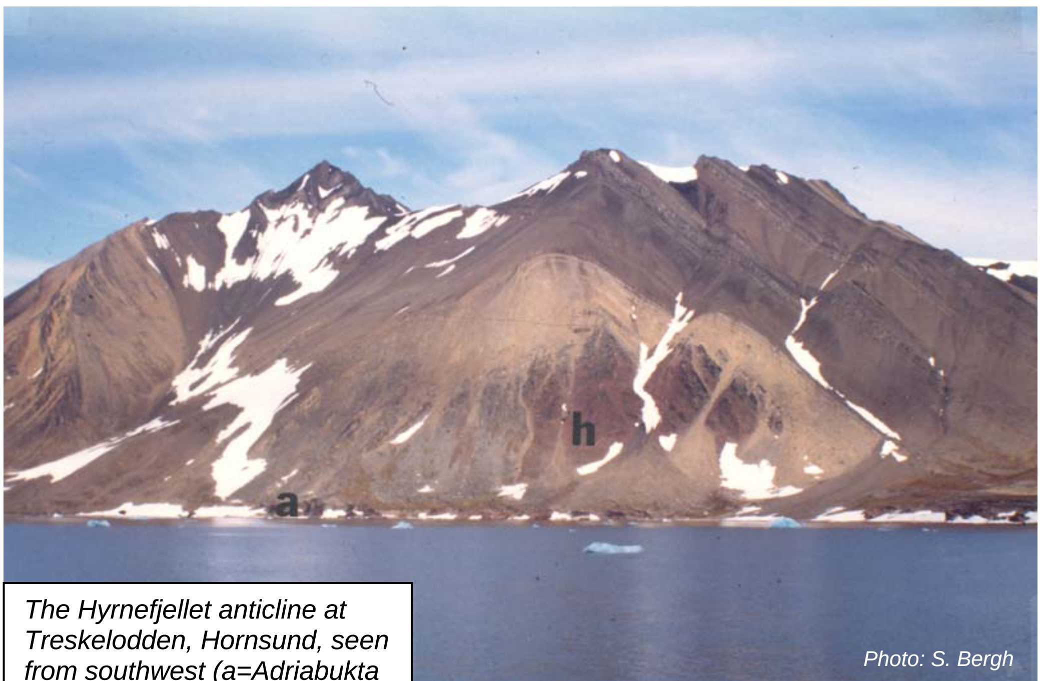
The Hyrnefjellet anticline at Treskelodden, Hornsund, seen from south (h-Hyrnefjellet Fm, t-Treskelodden Fm, k Kapp Starostin Fm, tr-Triassic





1) Compression and dextral transtension (from S. Berg, internal report)

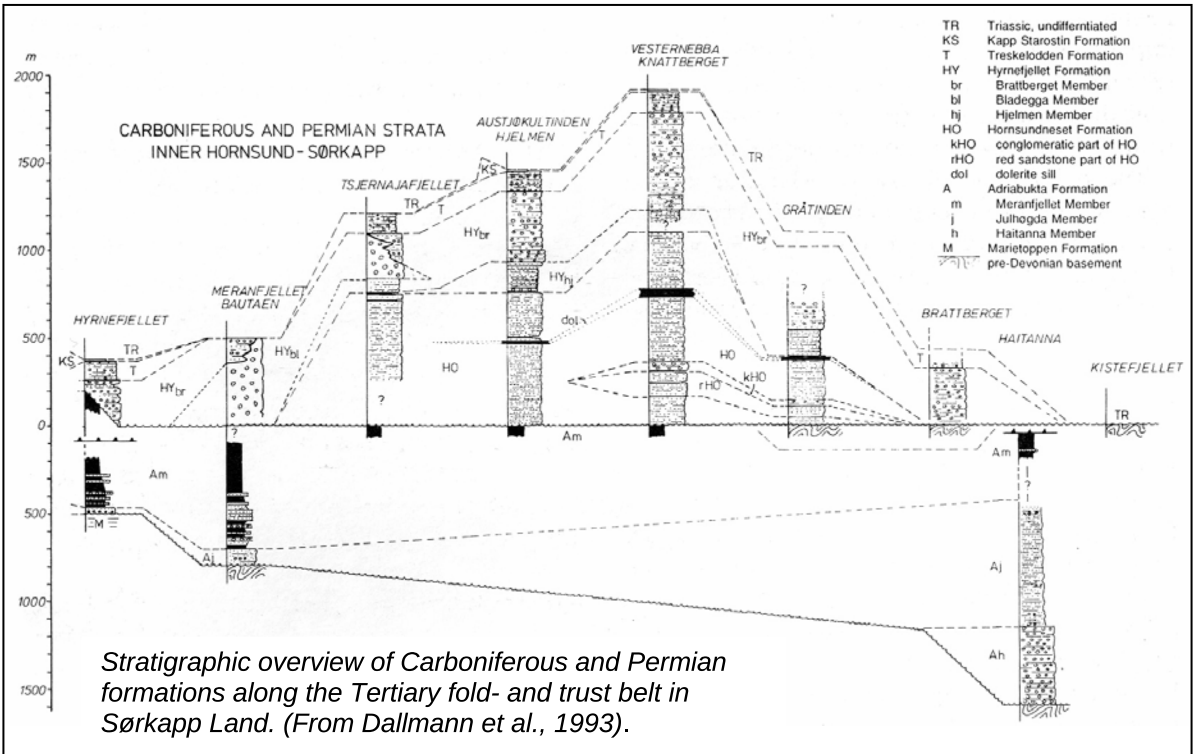
2) Sinistral transpresion



The Hyrnefjellet anticline at Treskelodden, Hornsund, seen from southwest (a=Adriabukta Fm, h=Hyrnefjellet Fm

Hyrnefjellet Formation (Brattberget Member)

The Middle-Late Carboniferous Hyrnefjellet Formation (Brattberget Member) north of Hornsund (270m) consists of red gravel- to bolder-size clast supported conglomerates, frequently graded. They may form channel fills and laterally interfinger with sandstones. The depositional facies reflects an alluvial, distributary channel and interdistributary bay (overbank deposits) environment (Birkenmajer, 1984 a). Climatic conditions were warm and arid. All detriatl material are derived from near-by source rocks (Siedlecka, 1968), i.e. the Proterozoic basement, Devonian and Early Carboniferous sedimentary rocks of the Samarinbreen area. The sudden upward coarsening at the base of the Brattberget Member is thought to indicate synsedimentary fault activity along the Inner Hornsund Fault zone (Gjelberg & Steel, 1981) that proceeded uplift during the Adriabukta event.



Stratigraphic overview of Carboniferous and Permian formations along the Tertiary fold- and trust belt in Sørkapp Land. (From Dallmann et al., 1993).

The Treskelodden Formation

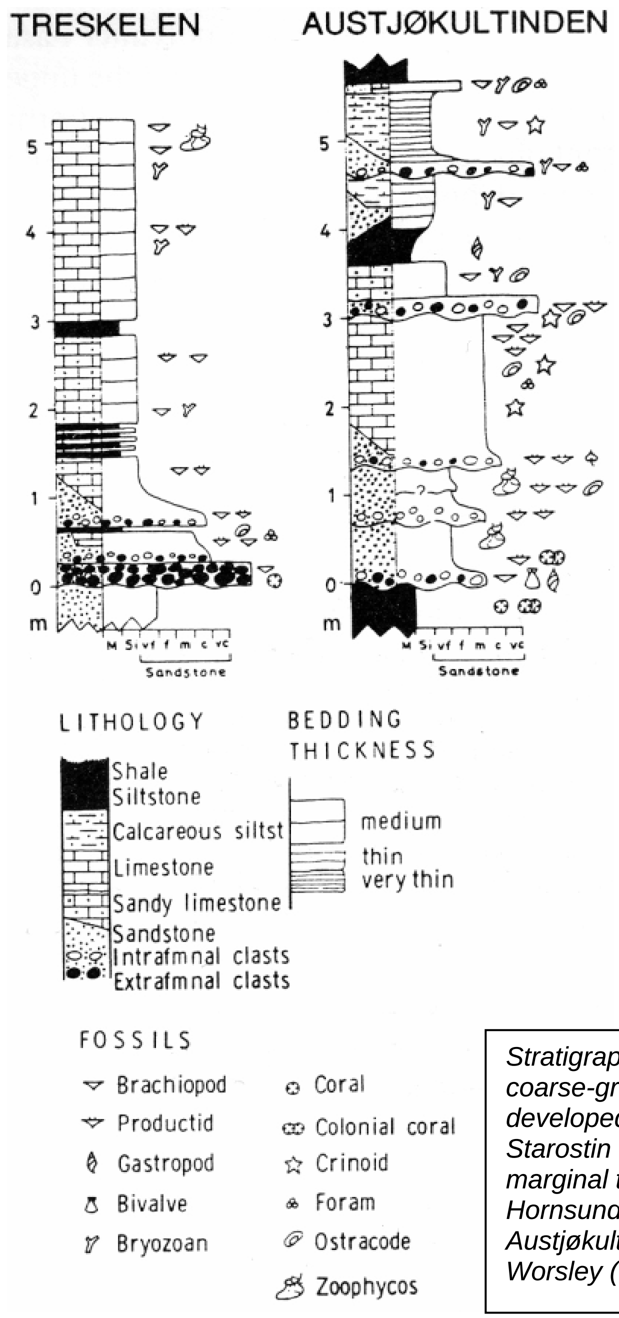
The Treskelodden Formation north of Hornsund represents a Late Carboniferous to Early Permian, mainly yellow, carbonate cemented, clastic succession. The thickness is around 100 m at Hyrnefjellet and Treskelen. The sediment types are alternating quartz sandstones (mostly calcerous), quartsites, gritstones, gravels and pebble conglomerates. Sandstones are usually sorted to well sorted and both texturally and compositionally more mature than those of the underlying Hyrnefjellet Formation. Gridstones and gravels show often graded bedding, and multiply graded units may have either fining- or coarsening-upward trends. Conglomerates are unevenly deposited and poolly sorted. Ripple marks, cross bedding, erosional unconformities and small channels are frequently observed, and mud cracks occur. Siedlecka (1968) and Birkenmajer (1984b) point out a distinct cyclicity of the depositional sequence. With the exception of the lower alluvial cycle, the facies passes repeatedly from shallow-marine to lagoonal and alluvial environment Birkenmajer (1984b). Czarniecki (1966, 1969), however,

Coarse clastic sandstones and conglomerates of the Carboniferous Treskelodden Formation at Treskelen. Bird in front for scale.

regards the formation as entirely marine. An interesting phenomena is the presence of up to five coral horizons on Treskelen, partly within intercalated dolostones and limestones.

Tempelfjorden Group
The Kapp Starostin Formation

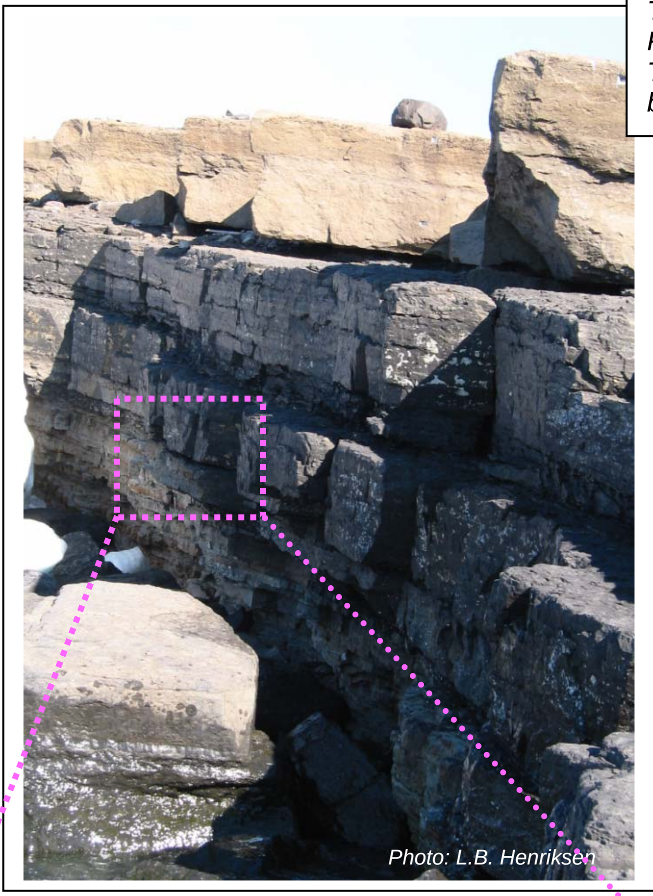
The Kapp Starostin Formation (equivalent to the Røye and Ørret Formation in the Barents Sea) is the only representative of the Late Permian Tempelfjorden Group on the island of Spitsbergen. It is 300-450 m thick in central Spitsbergen and gradually thins southward along the foldbelt. It is missing on the Sørkapp-Hornsund high and only 5-6 m on Treskelen. On Øyrlandet and Sørkappøya, however, the formation has a thickness of at least 450 m, though incontinously exposed (Siedlecki 1964, 1970).



On Treskelen, a polymict basal conglomerate fills in a karst surface on the uppermost coral limestone of the Treskelodden Formation. It contains quartz and other extraformational sediment pebbles as well as some bioclast debris in a fine-grained, mixed sandy-carbonate matrix. Two thinner conglomerate horizons immediately above contain abundant intraformational bioclasts (brachiopods, corals, gastropods, ostracods, forams, bryozoans, sponge spicules), phosphorite nodules (phoshorized sponges and other fossils) and some cm-sized extraformational quartz and limestone pebbles. The overlying sediments are twofold, the lower part formed by sandy limestones with shaly intercalations, the upper part by dark grey, spiculitic and silicified limestones, all containing spiriferid, productid and coral faunas. *Zoophycos* trace fossils occur in the top layer. The sediments is by Siedlecka (1970) interpreted to have been deposited in an epicontinental marine environment with a maximum transgression during the deposition of the cherts under relatively deep, quiet, restricted conditions, probably within depressions on the outer shelf.

Stratigraphic sections of the coarse-grained abnd very thinly developed Late Permian Kapp Starostin Formation at locations marginal to the Sørkapp-Hornsund High (Treskelen and Austjøkultinden). From Hellem & Worsley (1978).

The Kapp Starostin Formation at Treskelen. Treskelodden Fm at the base of the picture.



The lower picture shows a close up of the transition between the Treskelodden Formation and the Kapp Starostin Formation. Notice the vertical bioturbation (borings) in the top of the Treskelodden Formation.

Laterally sediments of the Kapp Starostin Formation fill in a karst surface of the Treskelodden Formation. At this spot a polymict conglomerate (including a big basement pebble) with a brachiopod rich carbonate layer above.

Zoophycos sp dominates the bioturbation on the top carbonate surface of the Kapp Starostin Formation.

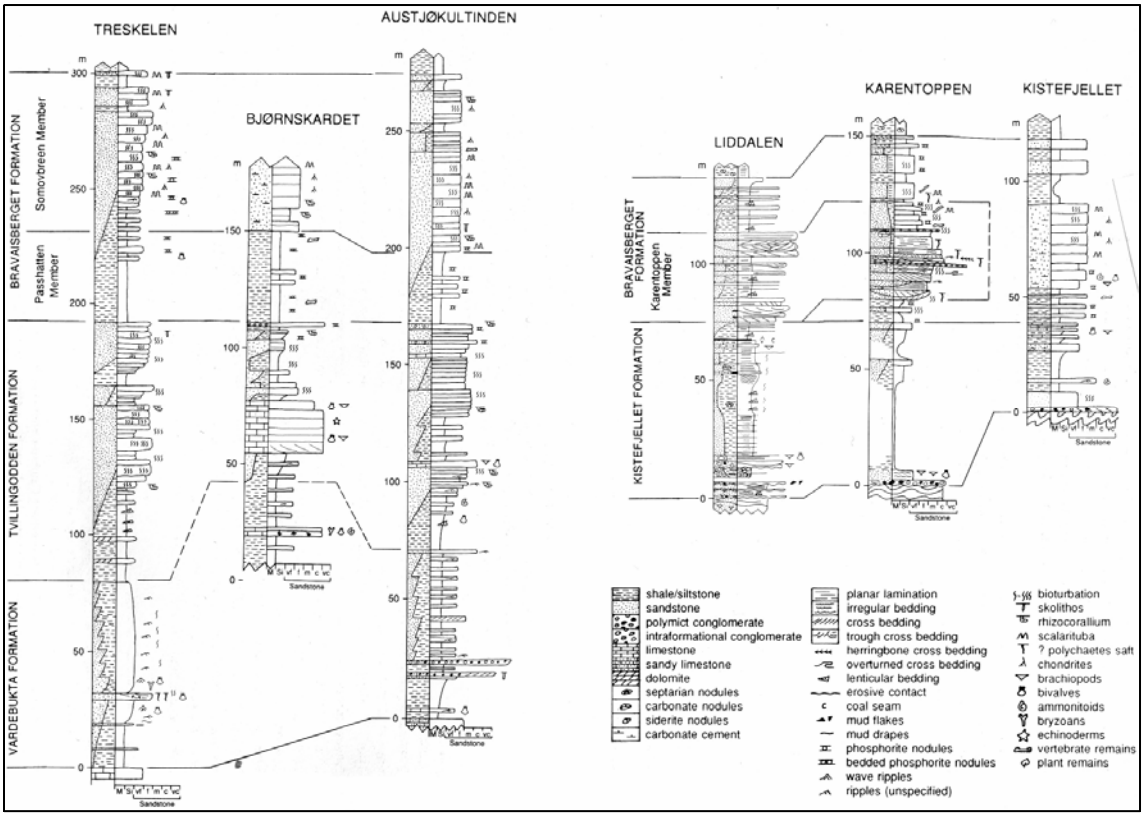
A Statoil geologist standing on top of the very condenced Kapp Starostin Formation at Treskelen.

The bioturbated top surface of the Kapp Starostin Formation.

Sassendalen Group
Early to Middle Triassic sandstones and shales of the Sassendalen Group have been deposited across the entire Sørkapp Land area. In the northern part of the Tertiary foldbelt, at Treskelen, the group is close to 300 m thick, but it thins slightly southwards. On the Sørkapp-Hornsund High, which was transgressed during the Dienerian (Birkenmajer, 1977; Nakrem & Mørk, 1991), the lower part of the Triassic succession is missing.

Vardebukta Formation
The Vardebukta Formation (equivalent to the Lower Vikinghøgda Formation in the eastern areas of Svalbard and the Havert Formation in the Hammerfest Basin) represents the lowermost 70-80 m of the Triassic succession between the Treskelen and Austjøkultinden. It consists of grey shales, siltstones and platy fine-grained, occasionally with medium-grained sandstone beds, carbonate cemented sandstone and thin conglomerates. The formation is thought to be deposited in a marine shelf environment.

Tvillingodden Formation
The Tvillingodden Formation (equivalent to the Upper Vikinghøgda Formation in the eastern areas of Svalbard and the Klappmyss Formation in the Hammerfest Basin) represents the 70-110 m thick parts of the Early Triassic succession between Treskelen and Austjøkultinden. The formation constitutes a major coarsening upward sequence composed minor (two to five) higher order sequences. The uppermost sandstone is medium-grained, locally coarse grained. The entire formation is of marine origin, deposited in moderately deep to shallow shelf environments.



Stratigraphic sections of the Early/Middle Triassic Sassendalen Group in Sørkapp Land. The thick succession of the foldbelt area is consistent from Hornsund to Austjøkulen, but with two distinct fossiliferous limestone horizons at Smaleggea/Bjørnskardet whick attenuate towards Austjøkulen.The comparatively thin Sassendalen Group on the Sørkapp-Hornsund High is more differentiated. (Figure from Mørk et al. in Dallmann et al, 1993).

The Lower Triassic heterolithic succession at Treskelen

Bravaisberget Formation

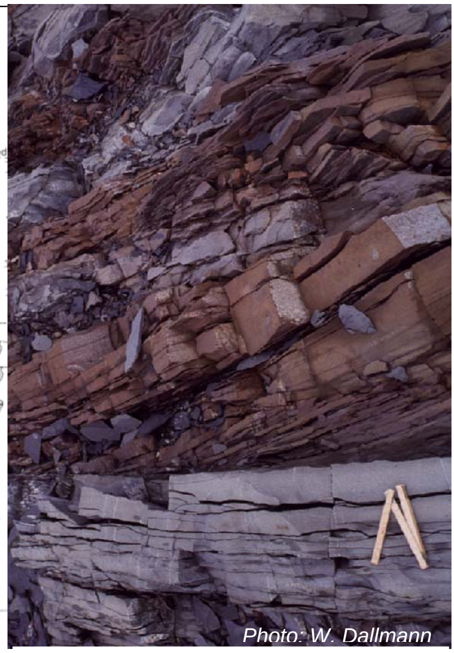
The Bravaisberget Formation (equivalent to the Botneheia Formation in the eastern areas of Svalbard and the Kobbe Formation in the Hammerfest Basin) is 110m thick within the foldbelt between Treskelen and Austjøkultinden, and 70-80 m on Sørkapp-Hornsund High. The lower part of the formation consistes of the shaley, bituminous Passhatten Member which coarsens upwards into the Somovbreen Member consisting of bioturbated, carbonate-cemented, yellow weathering, muddy silt and sandstones (Birkenmajer, 1977; Mørk et al., 1982). Both members are rich in phosphorite (nodules, phosphatised nodules and cement). Bioturbation is abundant throughout the formation, and ammonoids, bivalves and brachiopods (mainly lingulids) occur frequently. The Bravaisberget Formation represents pro-delta shelf sediments gradually being overlaid by deltafront sandstones which built out from a land area in the west (Dallmann et al., 1993).

Black shales in the ?Bravaisberget/Tchermak fjellet formations. Repeted thrusted black shales folded in younger strata.

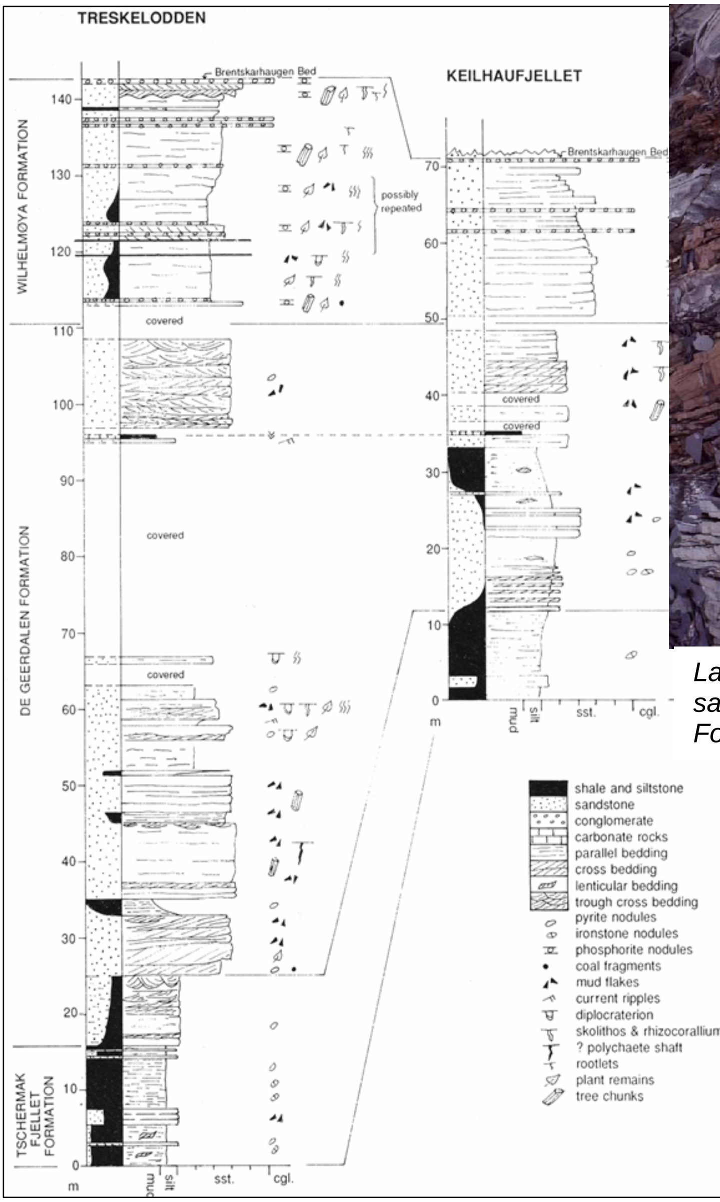
Lower pictures, Bravaisberget Formation, notice: steep fractures/shear plates and en echelon oriented tension fractures related to conjugated side faults with generally east-west strike.

Kapp Toscana Group
Tchermakfjellet Formation
The Tchermakfjellet Formation is 12-13 m thick at Treskelodden and consists of dark grey silty shales with an upward increasing content of siltstone laminae and laminated siltstone or very fine-grained sandstone beds. Small siderite and pyrite nodules occur abundantly in the lower part of the unit and decrease in frequency upwards. The sediment were deposited in a marine pro-delta environment.

De Geerdalen Formation
De Geerdalen Formation is 85 thick on Treskelen (Dallmann et al., 1993). It consists of fine- to medium grained sandstones with subordinate shales. The sandstones are often cross-bedded and mineralogical immature. Mudflakes are abundant, also plant fragments in some beds, while other beds show abundant bioturbation. Bibvalves are locally present. The formation is mainly deposited in shallow marine environments. The multicoloured beds may represent lagoonal deposits. Fluvial or distributary delta channels are indicated by some of the cross-bedded units (Dallmann et al., 1993).



Large crossbeds in deltaic sandstones of the De Geerdalen Formation at the Treskelen.



Stratigraphic sections of the Late Triassic to Early Jurassic Kapp Toscana Group. The thickness diminishes considerably from the fold belt area to the Sørkapp Hornsund High. (from W.K. Dallmann, 1993).

Wilhelmøya Subgroup, undifferensiated
The Wilhelmøya Subgroup is roughly 30 m at Treskelodden. It consists of light grey sandstones of mature (quartzitic) composition. Conglomeratic beds are common. They are quartz dominated, but also include phosphorite nodules. Beds enriched in (cemented by) phosphate are abundant in the upper part. Dispersed phosphate nodules also occur within the sandstone. Cross-bedding, *Diplocraterion* sp. trace fossils, plant remains, macrofossils and tree chunks, are abundant in the uppermost part of the unit.

The unit may contain several *hiati* and may have undergone syn-sedimentary erosion. It is regarded to be deposited in shallow marine, partly near shore environments.

The formation concludes upward with a phosphatic remainer conglomerate, the Brentskardhaugen Bed, which contains a condensed fauna (ammonites, bivalves, belemnites and tree fragments) of ?Bajocian-Bathonian age.

Smalegga Formation in the Wilhelmøya Subgroup. Planar to wedgeshaped crossbedding with tangential toeset in light grey sandstones.

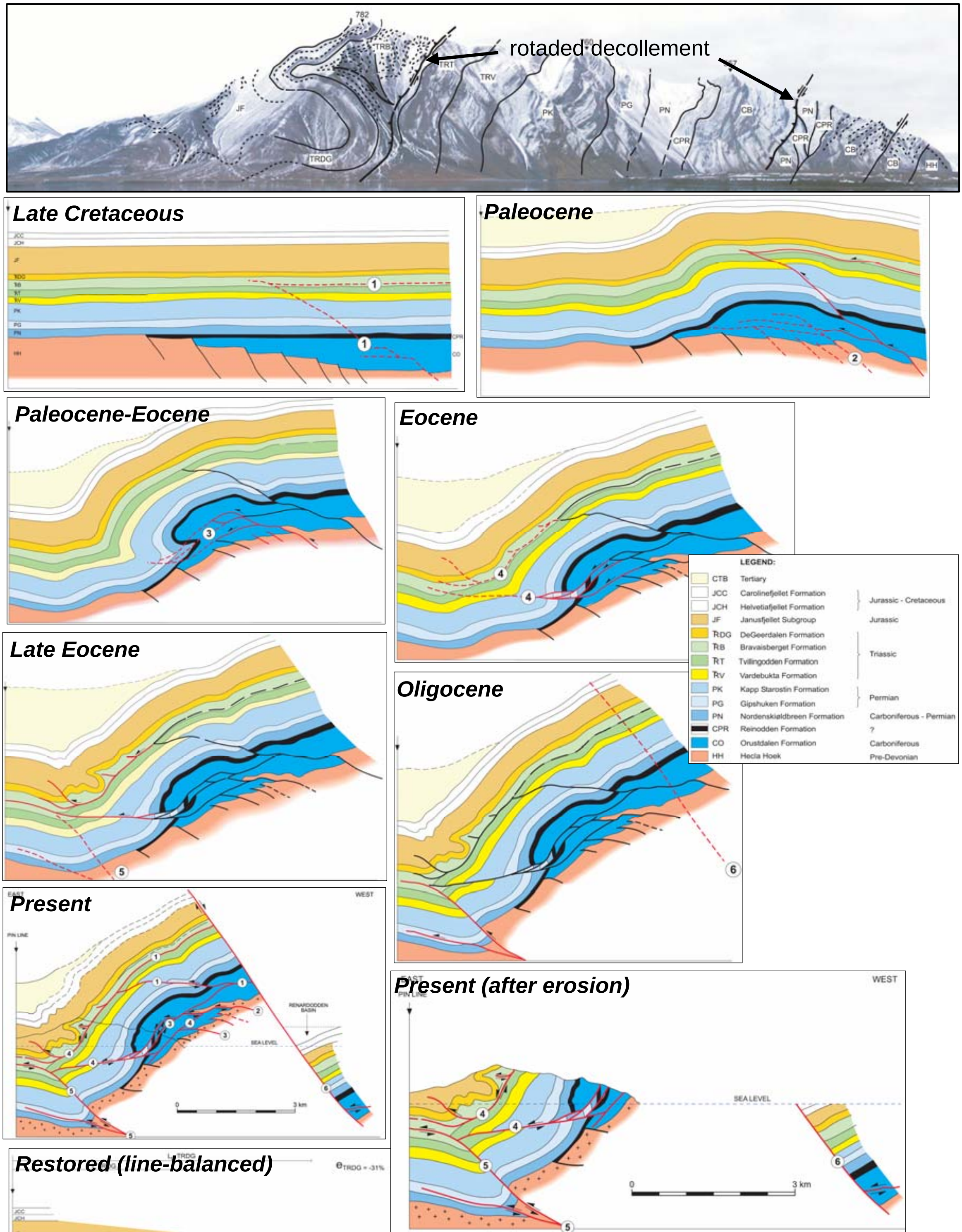
Polymictic conglomerate in the Smalegga Formation of the Wilhelmøya Subgroup. Quartz dominate, but also phosphorite nodules, plant remains and tree chunks occur.

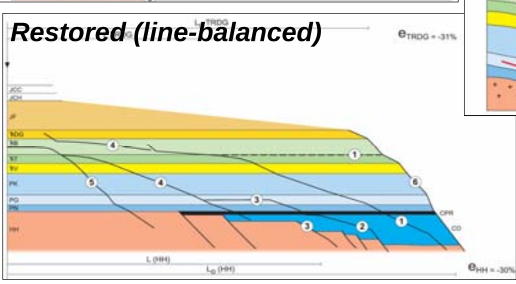
Day 8; Stop 2, MIDTERHUKEN Mountain

Photos from Svalex; A. Andresen

The northeren slopes of Midterhuken in Bellsund provide a striking example of structural styles within the Tertiary deformation zone. The exposed sequence young's from right (west) to left (east) from Early Permian to Late Triassic and deformation is concentrated within the incompetent shale dominated Sassendalen Group.

Restoring fold and trust belt – MIDTERHUKEN Mountain





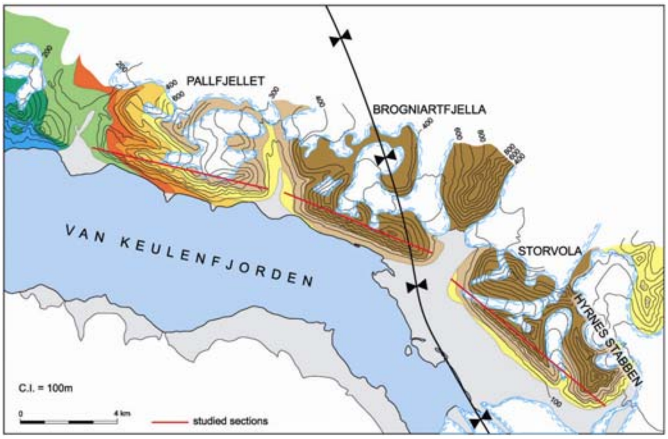
** Complete section from basement to Tertiary – tilted to the east.*
** Tilted trust detachement/ decollent – sediments above detachement folded and imbricated*

Van Keulenfjorden

From Hornsund Origo sails to the inner Storvola in the inner Van Keulenfjorden.

Day 8, Stop 1*, STORVOLA*

Clinoforms 12, 14 and 15 (Adapted from Mellere, D; Steel, R and Schellpepper, M; Wolf, 1999 and 2000, internal Wolf reports)



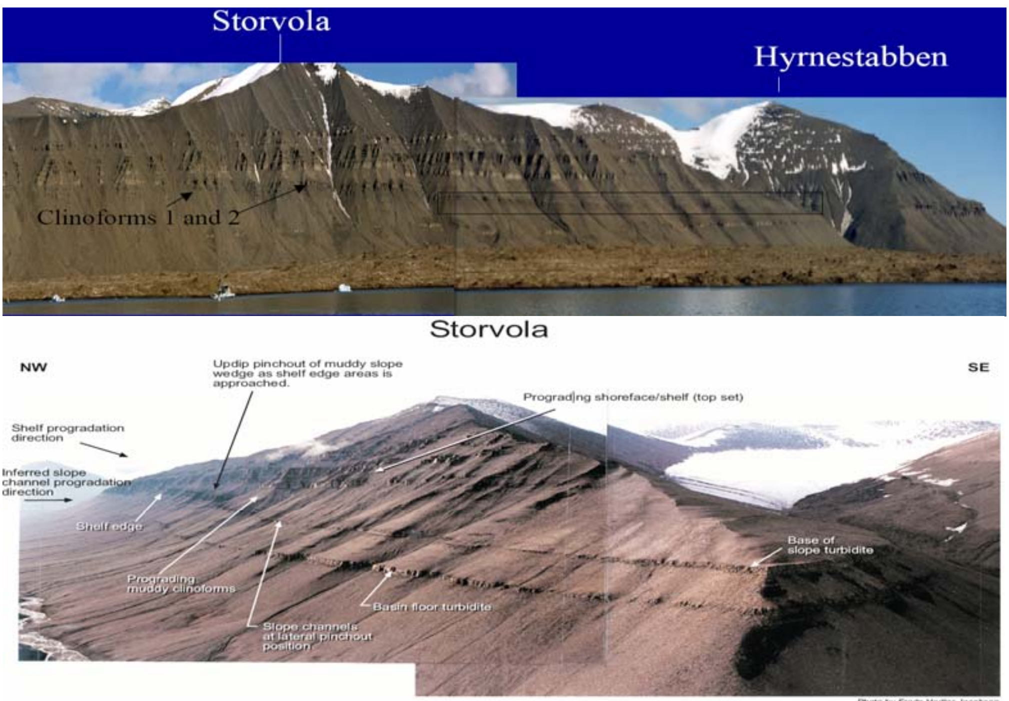
KEY Topics

- Linkage between delta front, upper slope turbidity channels and basinfloor fans
- Backstepping of lower slope channels (clino 14)- onlap (sidelap) of the slope channels
- Internal architecture of slope channel omplex.
- Identify shel edge

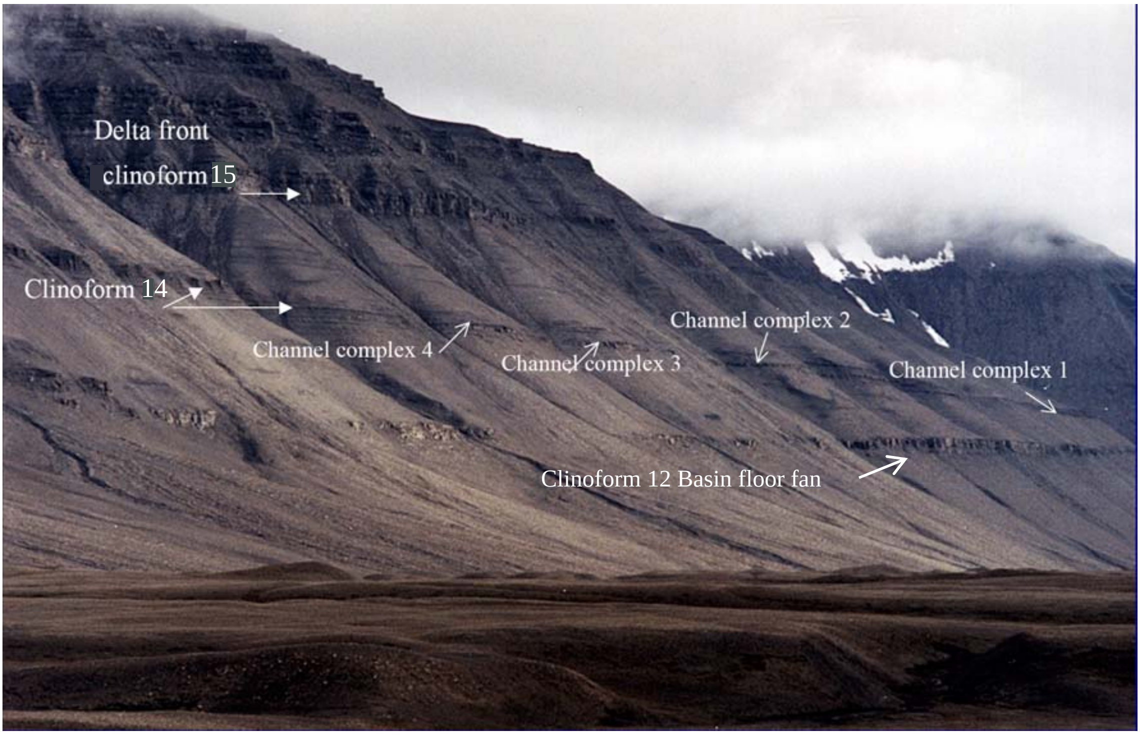
What to see

The objective of the day is the analysis of basin floor fan, the slope section and the shelf edge of clinoforms 12, 14 & 15 in Storvola.

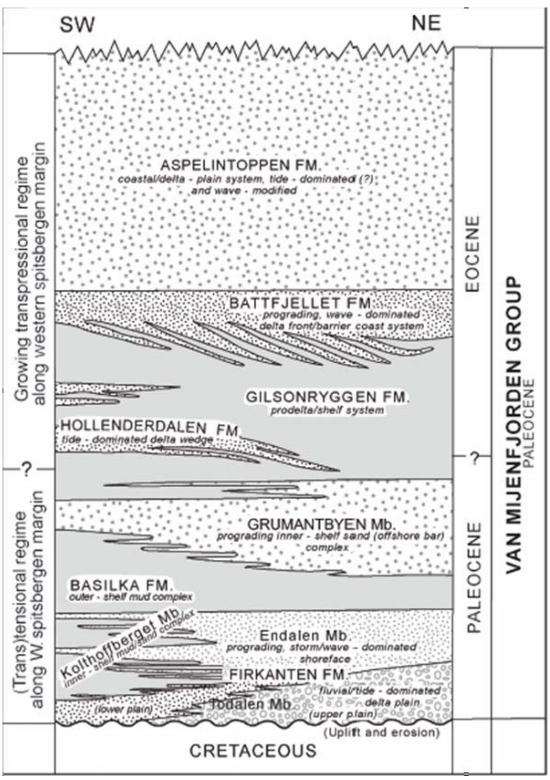
Further reading, see reference list:
Steel, R.J et al., 2001 and 2003, Mellere, D. et al., 2002 and 2003, Plink-Bjørklund et al, 2001, Johannessen and Steel 2005, Petter and Steel 2006 and Uroza and Steel, 2007



General overview of the outcrops in Storvola, with indication of the studied clinoform. Note how the clinoform can be easely traced through the slope into the base of the slope (east hand edge of Storvola) and basin floor (Hyrnestabben). The amplitude of the clinoform is ca 250m, calculated taking as datum the overlying clinoform topset. Storvola is ca 1km high, and photo length is ca 8km (upper picture).



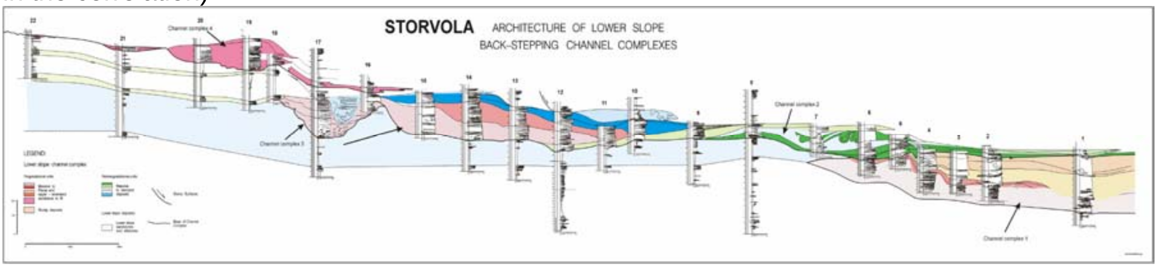
Clinoform 14 forms a 6 km long, shelf-slope-basin floor transect, and clinoforms 12-15 together form a vertical section from basin floor (clinoform 12) via slope/self edge (Clinoform 14) to shelf edge/shelf (clinoform 15). For most of its length the slope system is represented by shale, heterolithic thin-bedded prodelta turbidites with turbidite channels occurring only in the lower part of the section. At the base of slope (some 400-500 m of water depth, as inferred from unconpacted clinoform amplitude), turbidite channels form a wedge that progressively thins and onlaps the slope.



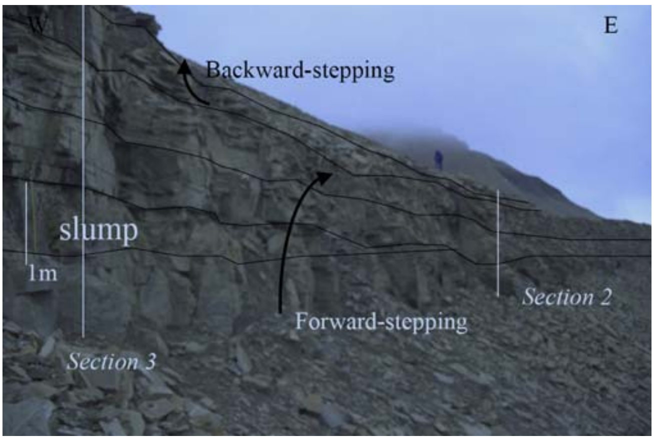
Clinoform 14
Three landward-stacked channels sets have been recognised. From the oldest to the youngest, these sets are indicated as channel systems 1, 2, 3 and 4. Within each set, channels are stacked progressively basinwards. Channel systems 1 and 3 are connected by slump deposits and by a series of channel/overbank units stacked landwards and indicated as channel system 2. We will walk from the most basinward system (channel complex 1) upslope though channel complexes 2, 3 and 4 to observe the stacking pattern of individual systems and the characteristics of the channel infill

Channel complex 1
The oldest channel complex (Channel complex 1) crops out near the base of the slope and consists of a multi-storey set of 4 channels, up

to 8 m thick and some 150 m wide, stacked progressively basinwards, and separated by thin (up to 1 m thick), silt-prone slump units.
Along most of the section, the base of the system can only be inferred. It is seen only in the lowermost section, measured at the edge of the Storvola slope, and it is marked by an erosive and abrupt contact between fissile black slope shales and thin-bedded, very-fine grained low-density turbidites, and channelled, medium-grained, high-density turbidite deposits (right section in the correlation).



The base of individual channels is strongly erosive with some 3-5 m of relief into the underlying deposits, and it is marked by lags of shale rip-up clasts. Channels 2 and 4 increase their thickness progressively basinward (from 0.5 to 10 m) eroding most of the underlying channelled units. Channel fill shows a typical fining-upward trend of ungraded to normally graded sandstone beds, often contained in shallow and broad scours (up to 50 cm of relief). Soft-sediment deformation, dish and other dewatering structures can mask completely original sedimentary structures.

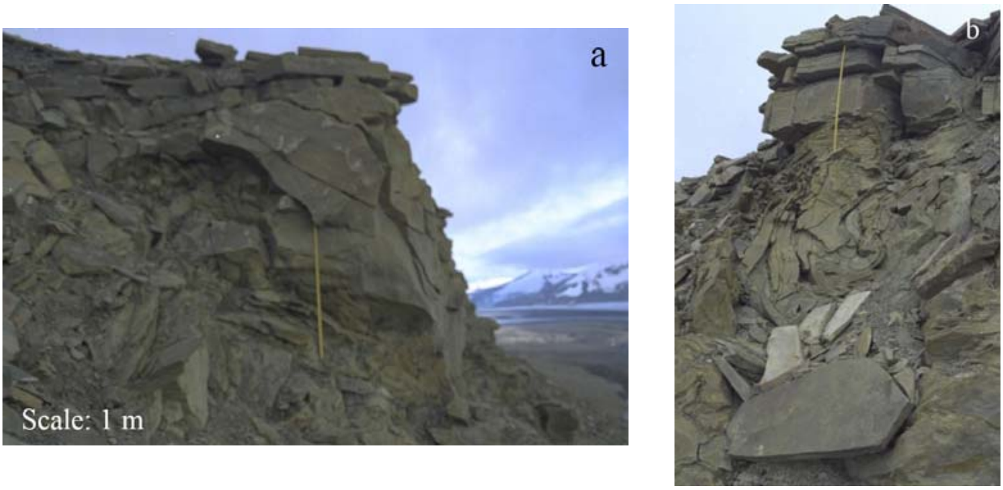


Overview of the lowermost channel complex, deposited near the base of the slope. The channels are organised in a forward stepping stacking pattern. Only in the uppermost part, the channels start to step landwards up slope. The channels are separated by silt-prone slump units and are infilled by high density turbidites and sandy debris flow deposits.

The channels were fed and infilled by sustained high density turbidity flows. Only in the uppermost part did waning flows prevail, the massive sand stones being overlain by thinner bedded, ungraded sand stones and laminated silt stones.

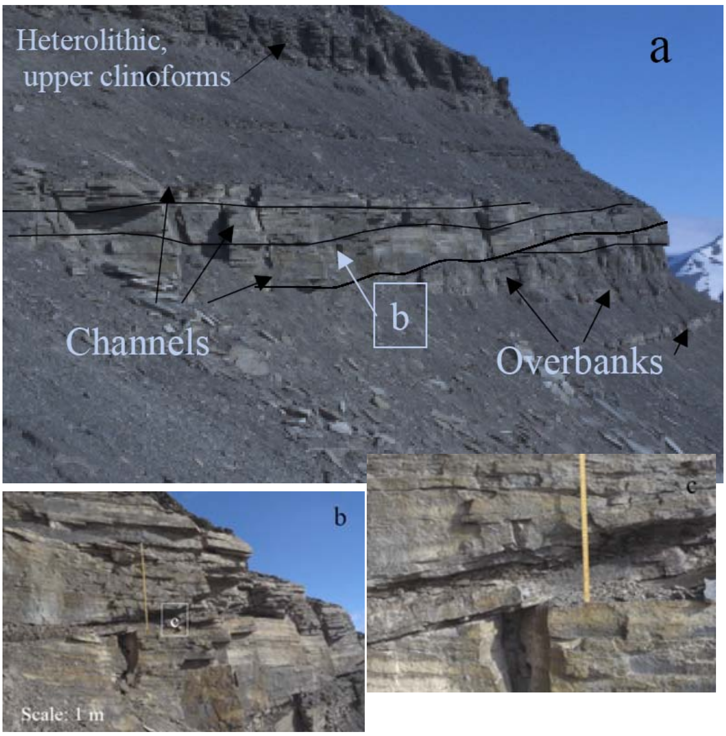
Channel complex 2

Complex 2 consists of a series of backstepping channel units and related overbank deposits that progressively onlap the slope, connecting channel complex 1 with channel complex 3 (correlation figure). The striking characteristic, with respect to the underlying, older complex, is the high percentage of sand-prone slump units onto which the first channels seem to sink, forming accentuated load casts along the margins. Most of the channel fill consists of massive, ungraded sand stones with water escape structures.



Channel complex 2 is organized as a series of channels that progressively backstep upslope. Details near section 6. Both channels overlie a slump unit. Note in (a) the accentated load cast at the channel margin. Channel fill consists of slumped, sandy debris flow. In (b) channel fill is formed by high density turbidites.

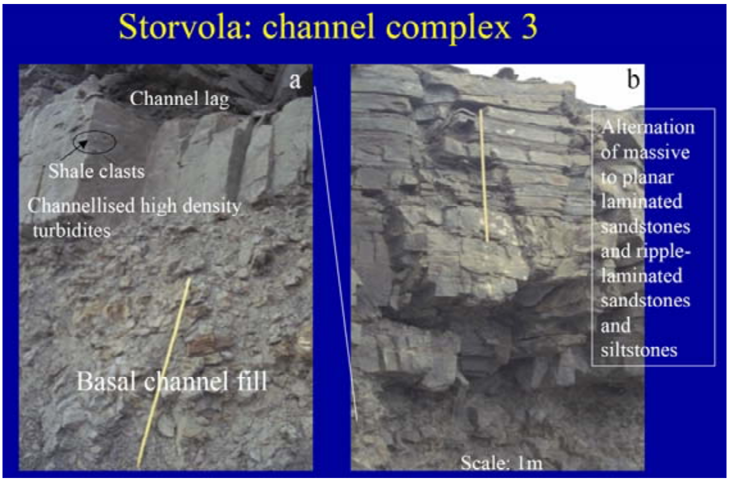
The youngest channel fill is better organised with ungraded to laminated sandstone beds (20-50 cm thick) with basal lag of shale rip-up clasts, separated by thin-bedded, laminated sand stones and shales. Laterally, further upslope, channel complex 2 develops a series of "wings" of overbank deposits formed by thinly planar and ripple-laminated sandstones. Channel complex 2 could be interpreted as the levee complex of channel complex 1. The slump units adjacent to channel complex 2 probable originated by the collapse of its upslope margin.



Outcrop overview (a) and details (b,c) of the backstepping channel complex between sections 9 and 10. The channel fill consists of thinly planar to ripple-laminated sandstones separated by thin siltstone drapes. Shale laminae (3-4 cm thick) commonly occur by the channel base (c).

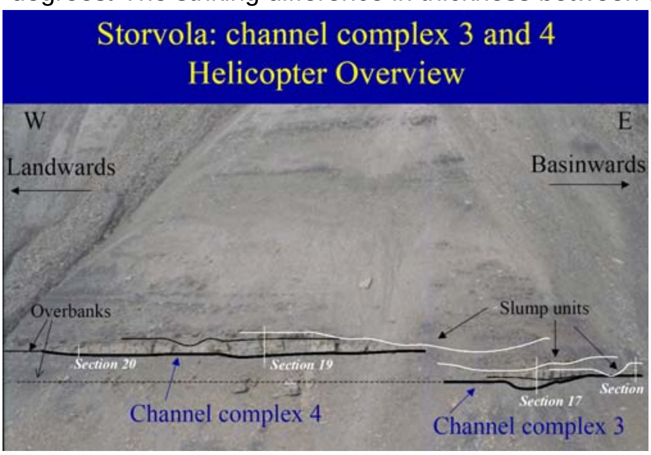
Channel complex 3

Channel complex 3 is a wedge-like body, 1 km long, up to 8 m thick, formed by 3 main channels, 3.5-7 m thick, stacked progressively basinward and separated by thin intervals of shales or heterollithic units of thin sandstones and shales. Downslope, the channels onlap the uppermost deposits of channel complex 2, and onlap the slope landwards. The base of the complex is easily recognized along its whole profile, between sections 9 and 17 (Storvola slope correlation), where thick-bedded, coarse-grained channelled turbidite deposits sharply overlie the slope shales. The lowermost channel of complex 3 is incised, with up to 6 m of relief into the slope shales, and displays a 2 m lag of matrix and clast-supported conglomerates.



Details from channel complex 3, section 17, Storvola panel. At the base, the channel is infill by a 2m thick, cobble-grade, matrix-supported conglomerate, likely emplaced by a debris flow process. Maximum particle size is 18cm (maximum clast, 40cm long axis). Clast composition reflects the unroofing of the nearby thrust belt and the cannibalization of the youngest basin fill units. (b) The uppermost part of the channel system is dominated by high-density flows.

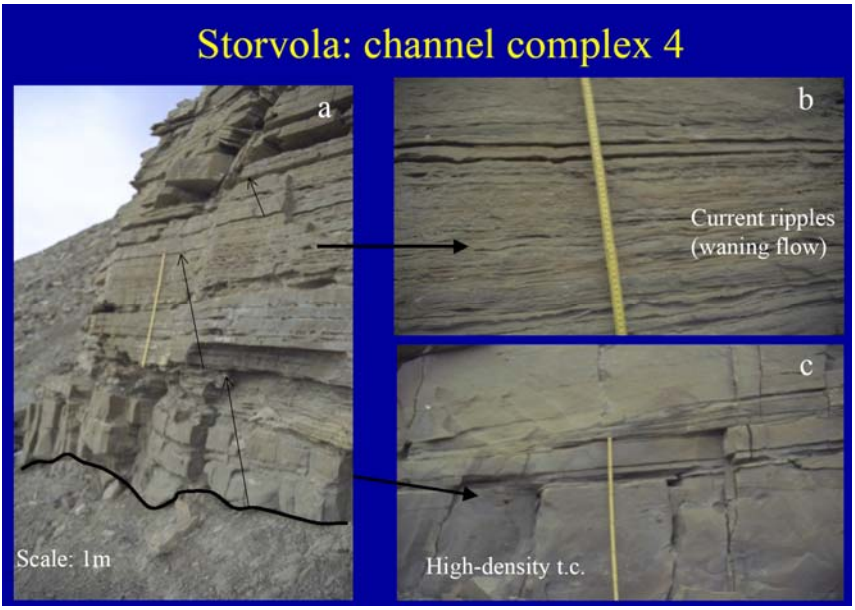
The channel shows a multi-story infill of alternating thick-bedded (15-30 cm thick), massive to planar laminated sandstones and thin-bedded (1-3 cm thick), ungraded to ripple-laminated sandstones and siltstones. Occasionally, cross strata occur. The general trend is fining- and thinning upwards, with thickest and coarsest sandstone beds overlying the channel lag. Palaeocurrents measured on flute casts at the base of sandstone beds, indicate a eastward direction, downslope, slightly oblique with respect to the outcrop direction. However, palaeocurrents measured along a few cross-bedded sets, suggest direction of flows at 60 degrees. The striking difference in thickness between section 15 and 17, suggests a slope sidelap configuration of the channel system.



Helicopter overview of the backstep stacking of slope complexes 3 and 4. Internally the complexes consist of a series of channels that step progressively downslope. The slump units were normally emplaced during the retrogradational phase of the systems.

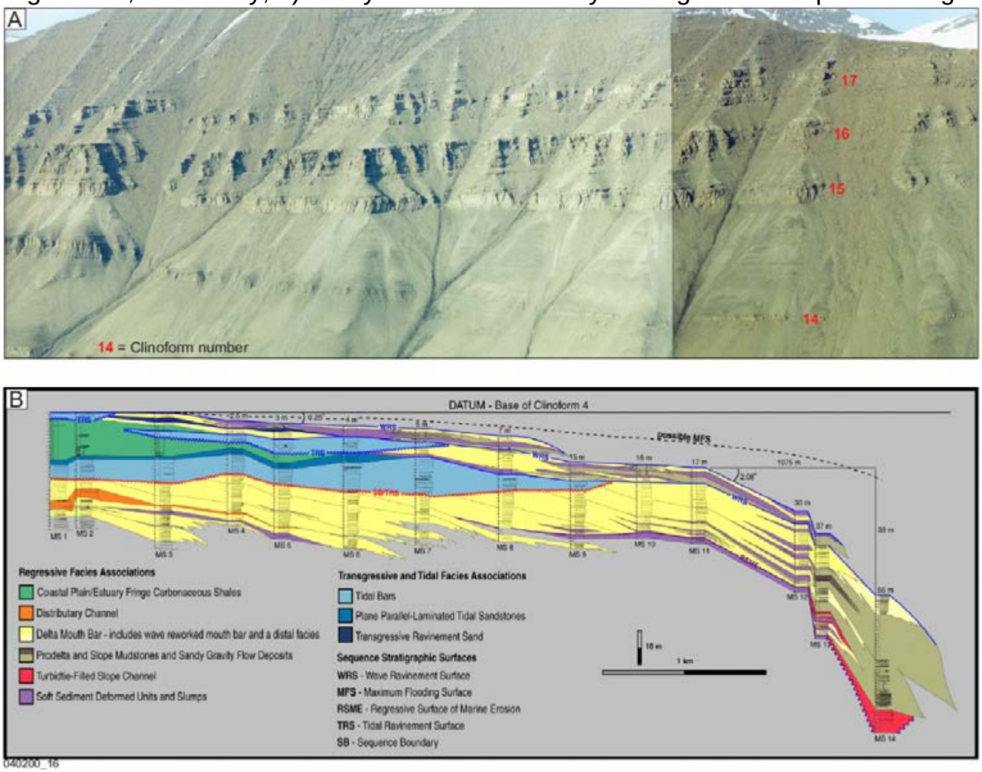
Channel complex 4

Channel complex 4 is located in a middle slope setting and shows an offlap of 6 m with respect to channel complex 3. (see helicopter overview photo above). Channel complex 4 is up to 4 m thick, onlaps the slope both landwards and basiwards and is multi story. The base is sharp and erosive into underlying shales. Channel infill is dominated by thick- bedded, 30 to 50 cm thick sets of current rippled, fine grained sandstones. Normally graded to planar laminated sandstone beds, 15-70 cm thick, separated by siltstone drapes or by thin-bedded planar laminated sandstone sets occur only in minor percentage and are localized near the base. The top of the channel is cut by a series of slump scars.



Details from the channel complex 4. (a) The channel is mulitstorey and it is formed by broad, shallow scours that decrease in thickness upwards (arrows). The scours are mostly infilled by waning, high density turbidity currents. At the base massive to planar-laminated high-density turbidites dominate (a). These are overlain by ripple-laminated sandstones (b), produced by the waning, high-density flow.

Clinoform 15
Stratigraphy and sedimentology of a wave delta/esturary couplet and correlation of upper slope channels.
Clinoform 15 is over 7 km and records one major and one minor episode of coupled transgression and regression across the shelf to upper slope. The sandbody that represents the clionform is a minimum of 23 m thick on the shelf edge, up to a maximum thickness of 42 m in the central portions of the clinoform. The main sand body is interpreted as a delta/estuary coupletthat records 1) wave delta progradation across the shelf during regression, 2) continued delta progradation, slope channel and gully formation, and slope instability during forced regression, and finally, 3) tidally-influenced estuary infilling on subsequent transgression.



Wave/Estuary dominated part of delta (see correlation section 5):
Moving through the wave-dominated lower portion of the section 5 you see heterolithic shales and hummocky sands at the base. These transition into stacked sandstone beds that typically contain plane parallel to low angle/swaley cross-stratification in the lower one-half to two-thirds, with the remaining bed consisting of ripples that have, in some cases, been bioturbated with Ophiomorpha and Thalassonoides ichnofossils. On the of this middle and lower shoreface are tidally-influenced fine to medium grained sandstones. Sigmoidal cross-stratification, mud drapes and landward (NW-directed) palaeocurrent directions indicate tidal influence.

Wave dominated part of delta, shelf edge delta (see correlation section 11):
The shelf edge delta is more dominated by slump deposits and plane beds: The coarsening upward part is capped by a wave ravinement surface (WRS). The distal end of clinoform 15, on the outer shelf and upper slope, has been interpreted as being deposited during forced regression. The first indication is sharp-based nature of sandstones (Plint and Nummedal, 2000), but the clinoform also contains much soft sediment deformation at its basal 10 meters on the outer shelf, that may also indicate forced regression (Fitzsimmons, 2000).

Upper Slope Channels (see correlation section 13 and 14):
The shelf break to upper slope of Clinoform 15 consits of sharp-based, confined channels that erode into the heterolithic shales, siltstones and thin, very fine grained sandstones of normal slope deposition. The photo shows the large scale architecture of Clinoform 15 in its distal positions, with three main units recognised. The lowermost, Unit 1, is very difficult to correlate both distally and proximally, and probably correlates to beneath the main sandy bench of the Clinoform. The correlation's for Units 2 and 3 are more robust, with a prominent flooding surface separating the two units.

Clinoform 15: Upper Slope

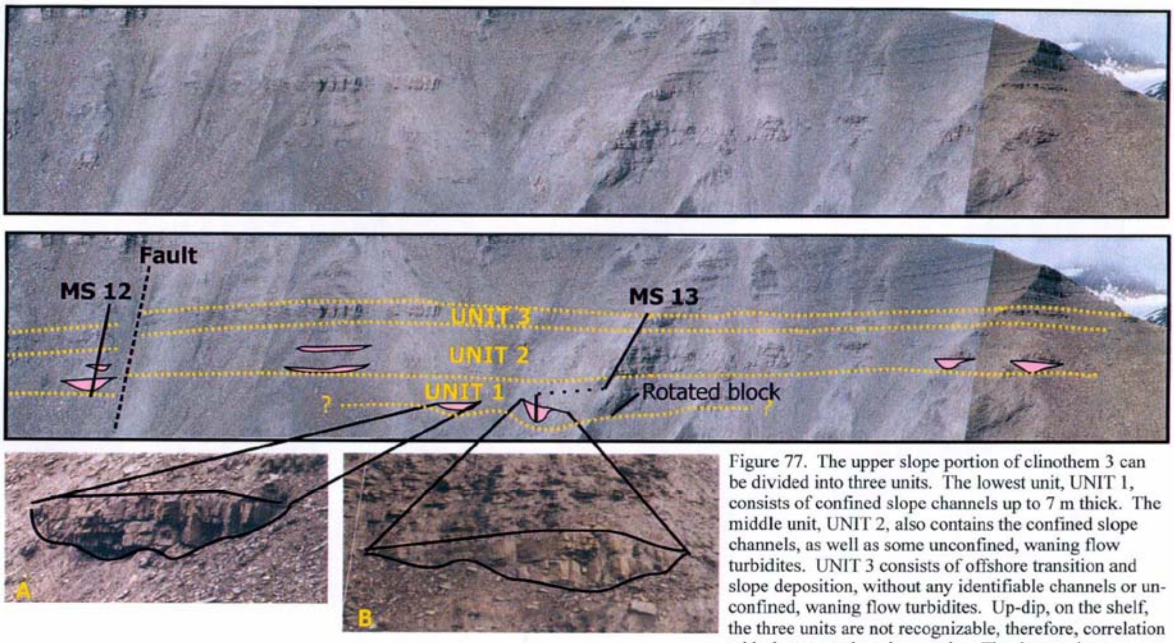
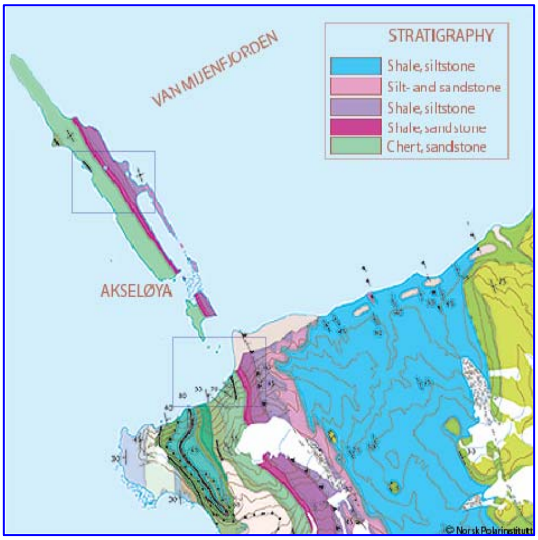


Figure 77. The upper slope portion of clinothem 3 can be divided into three units. The lowest unit, UNIT 1, consists of confined slope channels up to 7 m thick. The middle unit, UNIT 2, also contains the confined slope channels, as well as some unconfined, waning flow turbidites. UNIT 3 consists of offshore transition and slope deposition, without any identifiable channels or un-confined, waning flow turbidites. Up-dip, on the shelf, the three units are not recognizable, therefore, correlation with the upper slope is tentative. The three units are progradational, with the lower two units composed of upper slope channel and back-ground sedimentation, while the upper unit, unit 3, is more shelfal deposition of offshore transition.

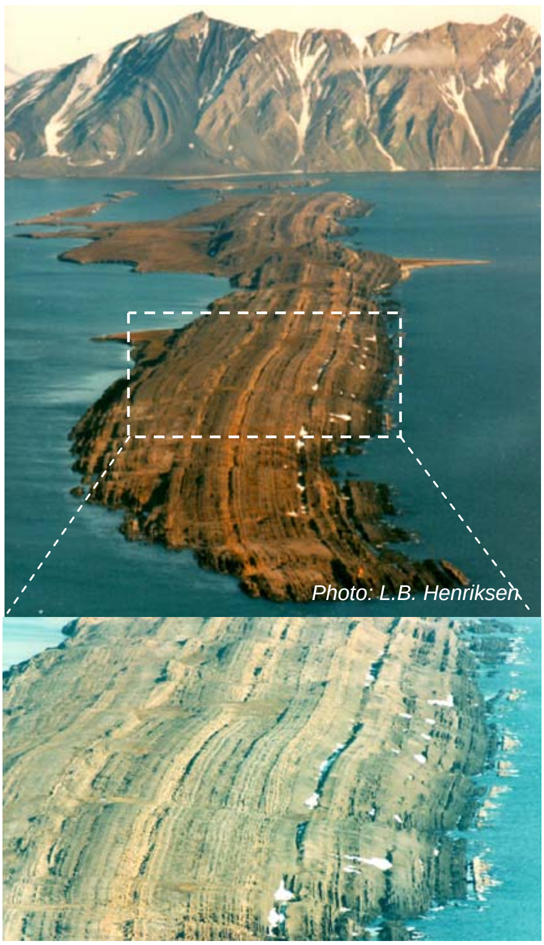
Confined channels of UNIT 1. Both A and B have erosive bases with mud clasts in a coarse sand matrix. The channel in B is multi-storied, with an upper and lower storey (also see Figure 79).

Day 8, AKSELØYA, BELLSUND (Optional locality)



The Kapp Starostin Fm (Late Artinskian – Ufimian/Kazanian) has been measured to be 400 m thick on Akseløya. The sediments are mainly of biogenic origin, and the siliceous sponge spicules represent the main rock constituent.

The formation is characterized by alternating beds of dark grey – bluish grey and occasionally light grey spiculites/spiculitic cherts and yellowish-brownish weathered, silicified bioclastic carbonates. Interbeds of fine grained siliciclastics appear throughout the entire formation, and dark grey, silicified claystones constitute the uppermost part. Argillaceous sandstones and thin glauconitic beds appear in some intervals. The individual lithological units are in general laterally extensive, and can therefore be followed continuously over the entire island.



The spiculitic dominated lithological units are measured to be 30 – 80 m thick. The spicule deposits are predominantly mud rich and heavily bioturbated (*Thallasinoides*, *Zoophycos*), indicating low-energy, deep shelf conditions. Episodic high-energy, storm deposits have been recorded in terms of graded beds and conglomerates containing phosphate nodules and skeletal debris.

A total of 5 carbonate dominated lithological units (thicknesses 10-25 m) are recorded. Vøringen Member represents the base of Kapp Starostin Fm, and appears as a distinct light grey unit 12-14 m thick. This is a shallow marine, transgressive brachiopod-grainstone shoal. Further upwards follows 4 carbonate wackestone-packstone units characterized by bryozoans, crinoids, brachiopods and siliceous sponges. These carbonates were deposited in storm influenced deep shelf environment. One of these units terminates on Akseløya, and may indicate a depositional relief in order of 15-20 m.

Overview picture of Akseløya seen from Ingeborgfjellet to the north. Kapp Starostin Fm represents the exposed rocks (Lowermost Triassic is partly exposed to the left). The small photo shows the details of the termination of the prograding bryozoan carbonate unit.

The siliciclastic interbeds may represent stagnation in biological productivity, and/or increased supply of siliciclastics from the provenance areas most likely located to the west (Sørkapp-Hornsund High) or northwest.

Above Vøringen Member the Kapp Starostin Formation is interpreted to have been deposited in an open marine, cold water continental shelf environment under relative low-energy conditions below normal wave base. However, episodic high-energy influence indicates prevailing depositional conditions above storm wave base.

The formation has undergone an extensive silicification process where the huge amounts of sponge spicules represent the silica source. The process was most likely initiated immediately after deposition. Deep burial has resulted in re-crystallization and formation of cherts. No porosity was preserved. However, in Isfjorden and in wells drilled on the Finnmark Platform porous spiculites are proven.

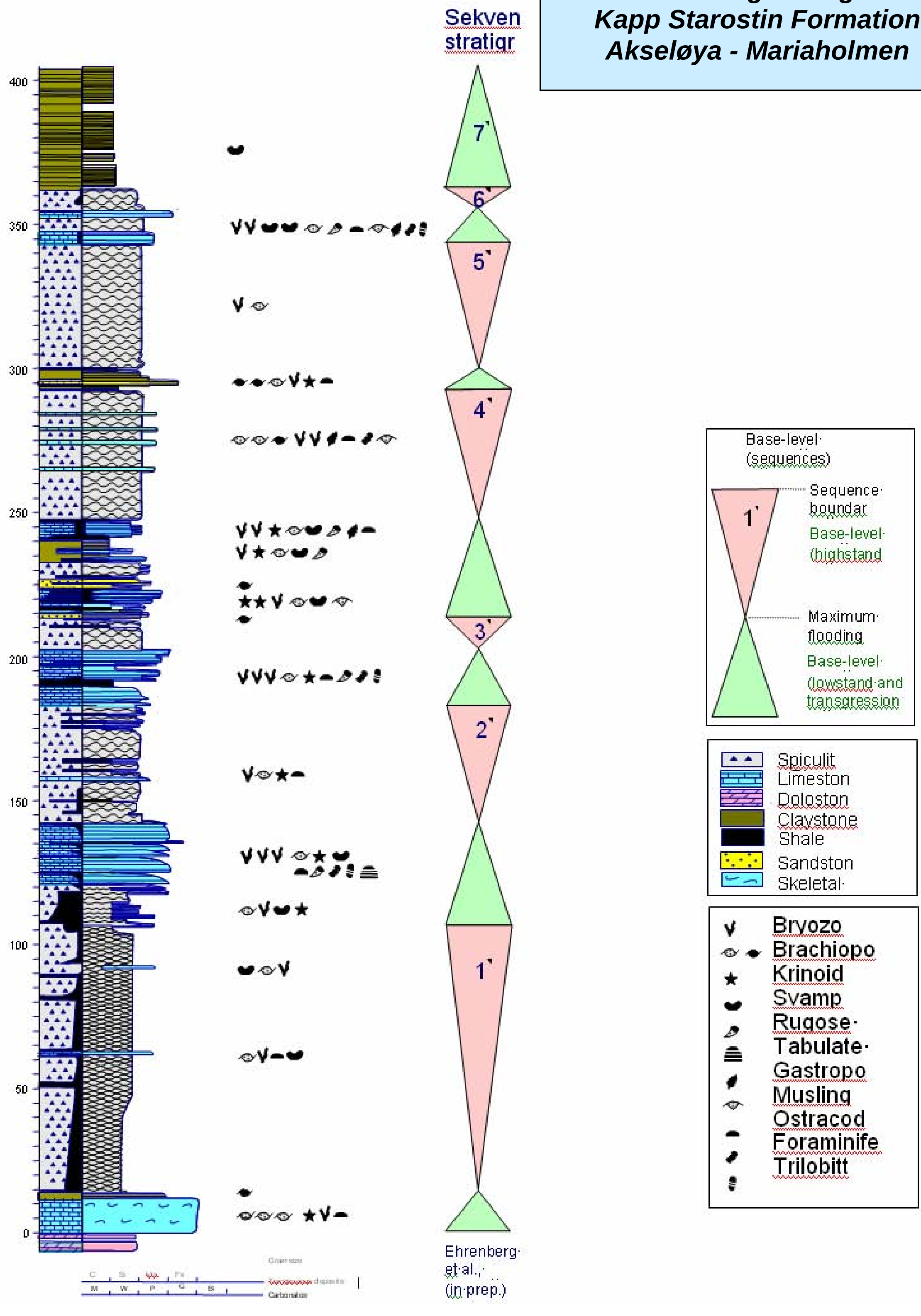
Exposure of the lowermost part of the Kapp Starostin Fm seen towards the north (in background is Ingeborgfjellet). Vøringen Member is exposed to the left.

Exposure of a bryozoan carbonate unit in middle part of Kapp Starostin Fm seen towards the south (in background is Midterhuken Mountain).

Branched lithistide sponge in shaly rocks

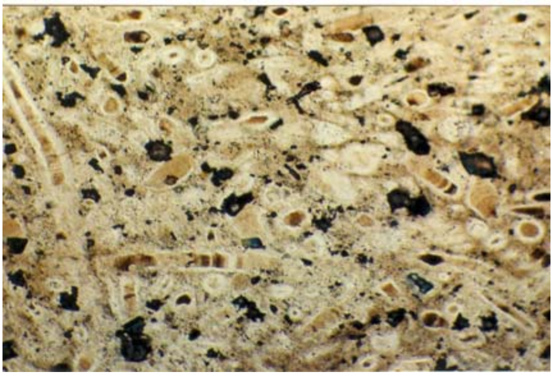
Phosphorite conglomerate

Lithological log
Kapp Starostin Formation
Akseløya - Mariaholmen

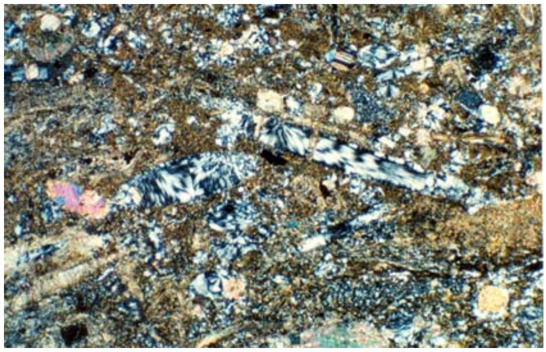


Vøringen Mb brachiopod grainstone bed (Spirifer limestone). Notice the weathered surface with silicified brachiopod fragments

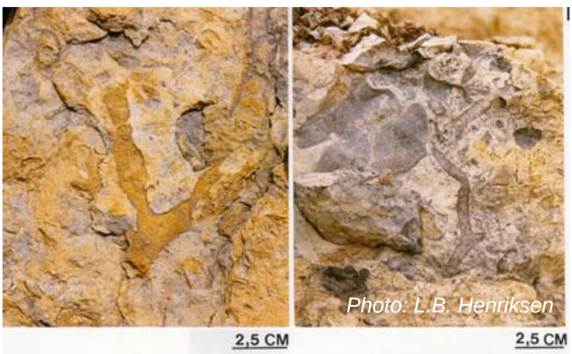
Bryozoan carbonate packstone bed



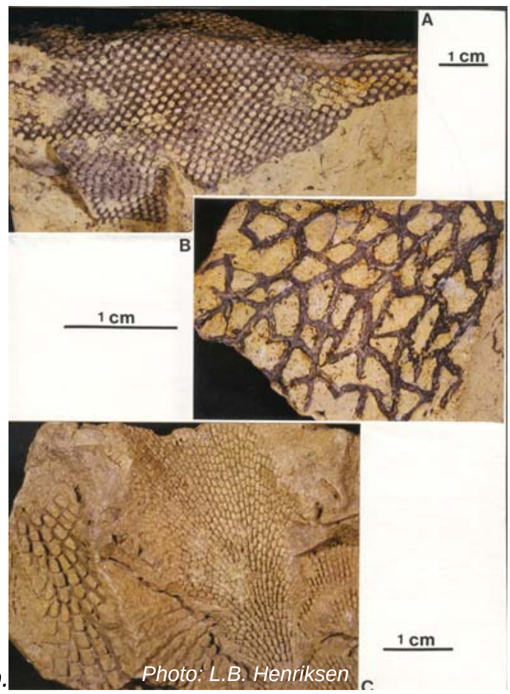
Thin section microphotograph, spiculite. Notice the numerous cross section of the individual spicules



Thin section microphotograph, siliceous sponge-bryozoan carbonate



Ramose and fenestrate bryozoan fragments within carbonate packstones



Bryozoans in Kapp Starostin Fm, (A) Reteporidra grandis, (B) Ramipora hochstetteri, (C) Polypora sp.

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