NPD Cores off Kvitøya, 2015

By Atle Mørk

June 2018

Content

Enclosures

Photos on the front page:

Uppermost, a faint view of the ice covered **Kvitøya** photographed from the northernmost core locality

Below, the drillship ***Bucentaur*** used for the core drilling.

Preface and Background

During autumn 2015 NPD drilled 8 cores SE of Kvitøya in the northeasternmost part of the Norwegian Barents Sea. The coring was done from the drillship M/V ***Bucentaur*** (photo on front page) with Seacore/Fugro as operator. Atle Mørk was supervisor onboard and also made a preliminary description of the cores. The cores were then shipped to the core store at Dora, Trondheim, were display cuts were made (responsible Atle Mørk). Samples for fusulinid dating was collected during this process and described by V. Davidov in a separate report. The cores and display-cuts were then transported to NPD core store in Stavanger summer 2016.

First part of 2018 the cores have been described by Atle Mørk. The shale dominated cores were described in Stavanger, while the carbonate and sandstone dominated cores were transported to Trondheim and described at the core-store at Dora.

This report contains detailed core-logs in the scale of 1:200, summary logs in the scale of c. 1:1000, and a short core description. Facies interpretations are presented on the detailed logs.

Summary figures, maps and technical information from the core sites as well as interpreted thicknesses between the different wells were first given by Tore Høy (NPD), and for this report updated by Sondre K. Johansen (NPD), who also made the locality map.

Analyses has not taken place at this time, except for superficial studies of thin-sections from the carbonate well. These thin-section observations have been added to the log with key words and symbols.

Emphasis has been on observations relevant for stratigraphic interpretation, facies subdivision and to locate key beds and phenomena that are relevant for regional correlation and hydrocarbon exploration in the Barents Sea.

Use of this report and core-logs

This report only present a short description of the cores. Main emphasis has been given to the detailed logs presented as appendices. These logs are printed in a scale of 1:200, resulting in a one meter long log for the longest cores. Many details are hard to see on this scale, however the enclosed electronic PDF files will show more details, and the logs or part of the logs can be printed in a more detailed scale.

Summary

The results of the drilling off Kvitøya are presented in a stratigraphical review in Figure 1, and a graphic summary of all cores are given in Figure 2. Technical core data are given in Table 1, and stratigraphical distribution between the cored- wells in Table 2. A Legend to symbols used on these figures and on the detailed core logs are given in Figure 3.

Table 1. Technical core data.

Core no.	Well drill no.	Water depth	Top of core	Base of core	Core length
7934/8-U-1	8	231	12.60	196.05	183.45
7934/9-U-1	1	252	12.10	164.70	152.60
7934/6-U-2	6	319	8.80	200.00	191.20
7934/6-U-1	5	333	3.10	182.30	179.20
7933/4-U-1	7	359	6.60	134.10	127.50
7933/4-U-2	3	252	3.50	15.50	12.00
8034/5-U-1	2	252	44.50	52.00	7.50
7933/4-U-3	4	348	7.70	199.85	192.15

Table 2 Stratigraphic distribution of core-length among the different wells (m).

Stratigraphic unit	7934/ 8-U-1	7934/ 9-U-1	7934/ 6-U-2	7934/ 6-U-1	7933/ 4-U-1	7933/ 4-U-2	8034/ 5-U-1	7933/ 4-U-3	Drilled core
Svenskøya Fm.	7								7
Flatsalen Fm.	99								99
De Geerdalen Fm.	88	152	191	179					610
Tschermakfjellet Fm.					67				67
Botneheia Fm.					60				60
Vikinghøgda Fm.						12		31	43
Kapp Starostin Fm.								57	57
Gipsdalen Group / Ørn Fm.							8	104	112
Retrieved cores									**1055**

Eight stratigraphic units have been cored (Table 2, Figures 1, 2) spanning from Late Carboniferous to Late Triassic age. Stratigraphic nomenclature from Svalbard is used as the drilled localities are within the Svalbard archipelago and far away from the Barents Shelf nomenclature established in the southern part of the Barents Sea. Due to uncertainty of correlation within the Gipsdalen Group the Barents Sea nomenclature is added for this unit.

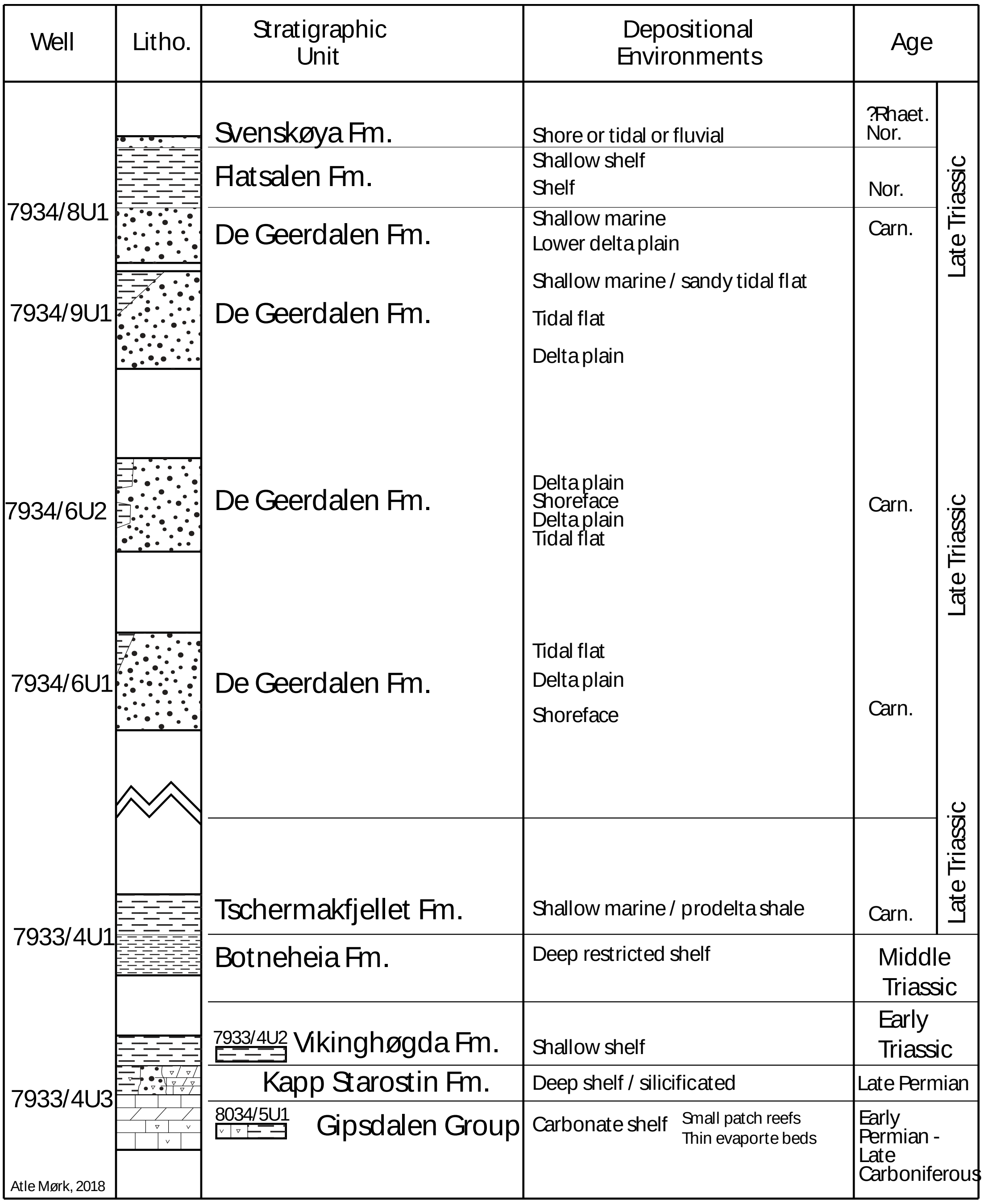

Figure 1. Stratigraphic summary of the drilled cores off Kvitøya.

The stratigraphic summary in Figure 1 also gives a broad chronostratigraphic interpretation, mainly based on lithological correlation with Svalbard, however for the Gipsdalen Group biostratigraphic dating of fusulinids by Davidov (2016) is used.

Figure 2. (next page) Summary of the cores drilled off Kvitøya (this figure is also printed in A3 format as an enclosure).

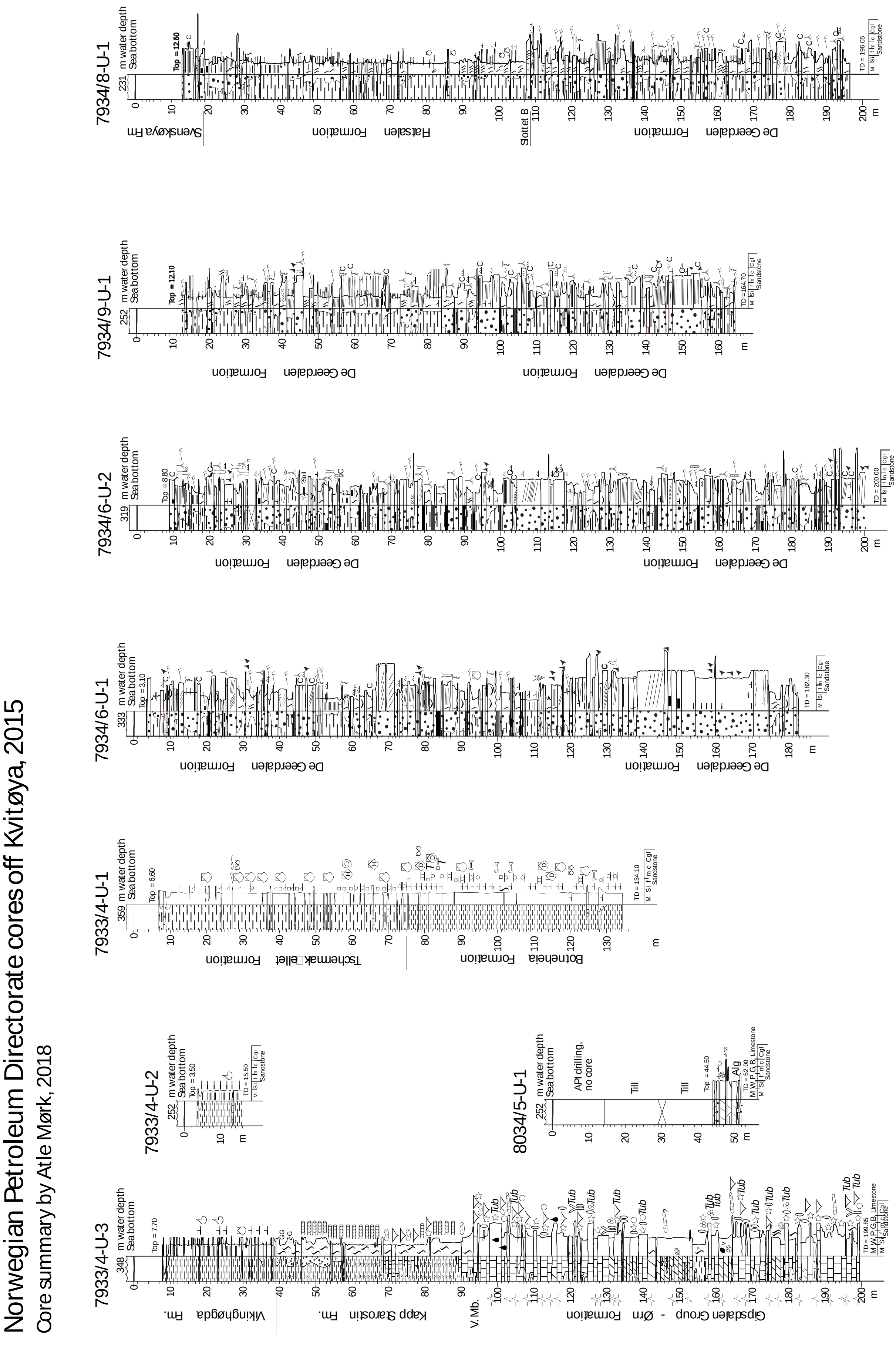
Norwegian Petroleum Directorate cores off Kvitøya, 2015
Core summary by Atle Mørk, 2018
7933/4-U-3
7933/4-U-2
8034/5-U-1
7933/4-U-1
7934/6-U-1
7934/6-U-2
7934/9-U-1
7934/8-U-1
m water depth
Sea bottom
Vikinghøgda Fm.
Kapp Starostin Fm.
Gipsdalen Group - Ørn Formation
Tschermakfjellet Formation
Botneheia Formation
De Geerdalen Formation
Flatsalen Formation
Svenskøya Fm
Slottet B
API drilling, no core
Till

Figure 3. Legend to figures and enclosures presenting core data.

The Gipsdalen Group / Ørn Formation (Late Carboniferous – Early Permian) is drilled in core 7933/4-U-3 where the lowermost 104 m are assigned to this unit. It consists of fossil-rich wackestones, packstones and grainstones, mainly of limestone, but with minor amounts of dolomite. Thin beds of gypsum are present in the lower part of the core, and patchy silicification of fossils and locally of the core are present. The enigmatic fossil *Palaeoaplysina*, which are reef-building on Svalbard and in the Barents Sea have sporadic occurrences. The short core 8034/5-U-1 is also referred to this unit. The unit represent a carbonate shelf.

Residual oil was present in grainstones in the uppermost part of the unit.

Kapp Starostin Formation (Late Permian) is drilled in core 7933/4-U-3 where the entire formation is 57 m thick. The formation mainly consists of silicified mudstone and dolomite locally with fossils. The unit is thoroughly burrowed, mainly by *Zoophycos*. The brachiopod rich Vøringen Member form the base of the formation. Brachiopods are dominating fossil in the formation, but silica sponges also occur. The unit represent a deep shelf with cold water fauna.

Vikinghøgda Formation (Early Triassic) form the uppermost 31 m of core 7933/4-U-3. It consists of laminated mudstone almost devoid of fossils or bioturbation; a feature well known from the lower part of the same unit on Svalbard. Only a few bivalves are present. The 12 m long core 7933/4-U-2 is also assigned to this unit. The unit represent marine environments below normal wave base.

Botneheia Formation (Late Middle Triassic, Ladinian) forms the lower part of core 7933/4-U-1 where the uppermost 60 m of the formation is cored. The core consists of dark mudstone with phosphate nodules and bivalve shells (*Daonella*) as well as bone fragments probably from ichthyosaurs. Uppermost a thin interval has abundant *Tasmanites,* similar to the core off Kong Karls Land (Riis et al. 2008, Vigran et al. 2008). The mudstone is rich in calcite cement. The unit is deposited on deep shelf with restricted circulation.

Tschermakfjellet Formation (early-Late Triassic, early Carnian) forms the upper part of core 7933/4-U-1 where 67 m of the formation is cored. There is a gradual transition from the underlying unit over a few metres. The core consists of grey laminated shale with abundant flat bivalves (*Halobia*) and abundant siderite nodules and thin beds. The core represent prodelta shale, shallowing from the underlying Botneheia Formation.

De Geerdalen Formation (Late Triassic) is penetrated in core 7934/6-U-1 (179 m), 7934/6-U-2 (191 m), 7934/9-U-1 (152 m) and 7934/8-U-1 (88 m) all together 610 m. Lack of base of the unit, and uncertainty of thickness between the cores make it uncertain how thick the unit are in this area. The cores are dominated by sandstones, with minor amounts of shale and thin coal beds, often with underlying roots and podsol. The unit is deposited in shallow marine, shoreface and delta plain environments.

Flatsalen Formation (Late Triassic, Norian) is totally cored in 7934/8-U-1 (99 m). It has the regionally important bioturbated Slottet Bed at base, while the reminder part of the cores is dominated by dark mudstone. A few bivalve fossils are observed. The unit represent open marine shelf deposits and towards the top marine sandstones represent the regressive top of the formation.

Svenskøya Formation is only penetrated at the top of core 7934/8-U-1 (7 m) and consists of laminated sandstones representing a transition from the underlying marine deposits to overlying probably tidal environments.

Drilling operation and core localities

Before the drilling cruise it was planned to focus on the Triassic succession, however also drill to test the Palaeozoic succession as well as interval interpreted to be Jurassic from the seismic data. The succession of wells (Table 1) reflects this strategy, with the first well correctly located within Late Triassic rocks. Well 2 should penetrate Palaeozoic rocks close to outcrops north of Kvitøya. Both drilling problems because of an overlying till and very fragmented rocks with carbonate and chert nodules wrongly estimated the succession as possibly basement and it was terminated after few meters of rock-drilling (after well 4 it was understood that the well correctly penetrated Carboniferous carbonates). Well 3 only penetrated a short unit of Early Triassic rock. Well 4 was very successful and within the permitted 200 m core-length Carboniferous – Permian and Lower Triassic units were penetrated. Well 5 and 6 continued coring of the Late Triassic, while well 7 penetrated the lowermost Upper Triassic into the Middle Triassic establishing an important reflector at the boundary. The last well 8 was suggested to penetrate Jurassic shale and overlying Cretaceous sandstone, but we recovered the uppermost Upper Triassic succession establishing several important marker horizons in this area. Figure 4 show a map of the different drilled localities.

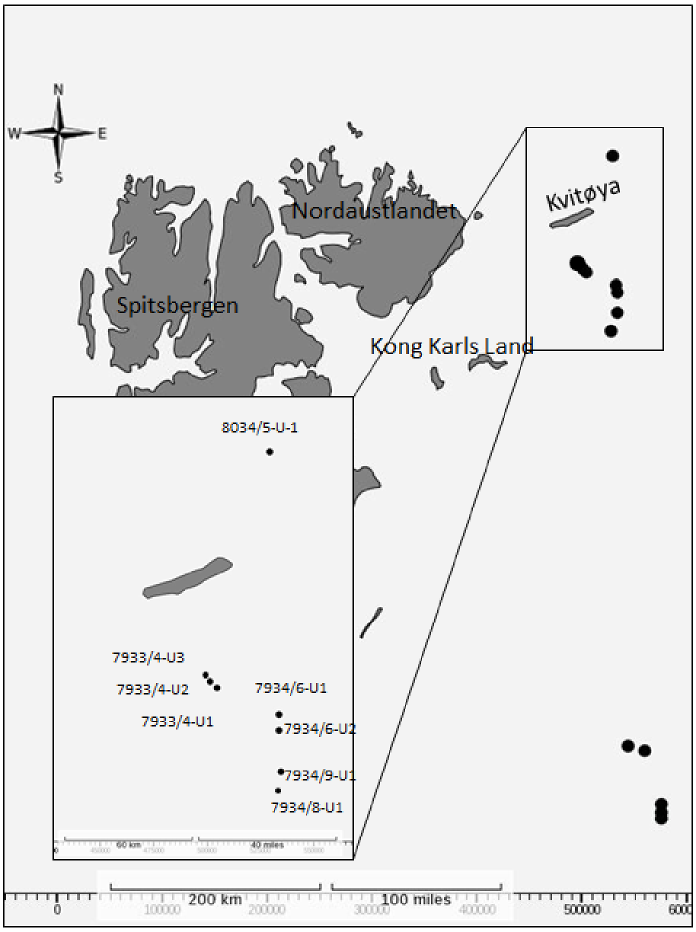

Figure 4. Map showing the coring localities for the 2015 NPD coring cruise (map by Sondre Krogh Johansen).

Core description

The cores will be presented according to the lithostratigraphical units they represent. Here the terminology of the *Lithostratigraphical Lexicon of Svalbard* (Dallmann 1999 ed.) is followed, where the Palaeozoic succession is documented by Dallmann et al. (1999) on Svalbard and Larssen et al. (2002, 2005) in the southern Barents Sea. For the Mesozoic succession, the lithostratigraphy of Mørk et al. (1999a) is followed.

Gipsdalen Group / Ørn Formation

The oldest sediment drilled off Kvitøya can be referred to this unit. The dating of fusulinid foraminifera by Davidov (2016) give ages from Late Gzhelian to Early Sakmarian correlating with the Wordiekammen Formation of the Gipsdalen Group on Svalbard (Dallmann et al. 1999) and its equivalent Ørn Formation in the Barents Sea (Larssen et al. 2002, 2005).

Twenty-five thin-sections have been made from this unit from core 7933/4-U-3 and they are briefly studied. A lithological characterization is given for each thin-section and the main constituents and fossils are plotted on the 1:200 log on the left side of the column. Due to extensive diagenesis it is often hard to see if the rock consists of wackestone, packstone or grainstone, however the most probable lithology is drawn on the log.

Semi-horizontal stylolites are abundant, and often many stylolites occur close above each other. They are most abundant in the pure limestones. The smooth surface of the display cuts often make it difficult to see if there is carbonate or siliciclastic grains. Part of the unit is dolomitized, and there fossils are often hard to recognise.

Dominating fossil group throughout the unit is echinoderm debris. In part of the section fusulinid foraminifera may be rock forming, but they mainly occur spread in the sediment. The enigmatic fossil *Tubiphytes* may be very abundant in some part of the unit, but mostly fragmented. Brachiopods, mostly parts of productids, occur in minor amounts throughout the succession. Large part of the fossil grains are heavily micritized by alga, and this show that deposition clearly took place within the photic zone. Some places algal structure and maze are clearly seen in the thin-sections.

Minor fossil contributions are by bryozoans and non fusulinid foraminifera. Possible trilobite shell fragments may be present as undulating extinction shell fragments are observed in the thin-sections.

Palaeoaplysina is a fossil that have changed biologic classification many times, but it is at present regarded as a sponge. It occurs several places throughout the core and at 103 m it forms a small patch-reef. At 165 m it occur silicified and is easy to recognize (this fossil is not recognised in the thin-section report by an English consultant). Reefs of *Palaeoaplysina* occurs in Carboniferous – Permian beds on Spitsbergen (Dallmann et al. 1999) and Bjørnøya (Stemmerik et al. 1994, Worsley et al. 2001, Mørk et al. 2014) as well as it occurs in cores in the Finnmark East East (Bugge et al. 1995). Most of the occurrences it this unit is quite hard to recognise due to recrystallization. *Palaeoaplysina* reefs are known to produce hydrocarbons in the Timan Pechora Basin and it is also reported to contain hydrocarbons in the Sverdrup Basin. The oil show in the upper part of this unit is in beds that contain *Palaeoaplysina*.

Several thin beds of gypsum/anhydrite occurs in the lower 30 m of the core. Further up small caves are filled by gypsum. From ca 170 m and up to 105 m chert is present in varying amount. Nodules, a few cm in diameter, may have an outer rim of chert and an internal fill by gypsum. Similar occurrences can be seen on Svalbard and in the cores off Finnmark. Above ca 165 m flattened nodules of chert are present. In thin-sections silicified fossils are abundant in the upper part of the unit. Above the gypsum beds in the lower part of the core, fractures and small caves occasionally contain gypsum. This gypsum may have been mobilized at a late stage after deposition, and migrated to fill available caves.

Dolomitization are dominating in the middle part of the unit (between 165 and 135 m), however, without systematic colouring of the core or scanning with element detector it is hard to differentiate between limestone, dolomite and silicified carbonate rocks. Dolomitization may thus have been underestimated on the enclosed 1:200 log.

In the upper part of the unit, just above the reef at 103 m, an interval 6 m thick up to 97 m mainly consists of grainstone with vuggy porosity. This interval yielded oil just after drilling, is brown in colour and even after drying for more than 2 years are oil wet and thus not wetted by water. The oil may have been trapped by the overlying dense limestone and chert in the Kapp Starostin Formation.

The short core 8034/5-U-1 contains dolomite with nodules of chert and gypsum and is thus correlated to the lower part of core 7933/4-U-3 as similar lithologies occur in this core between 165 m and 135 m and it is included in the Gipsdalen Group.

Depositional environments

The whole unit represent carbonate shelf environments, but with a variety of sub-environments.

In the lower part, thin gypsum beds show deposition under restricted environments, possibly short periods of tidal/supratidal conditions. The gypsum beds are, however, interbedded with grainstones with abundant echinoderm debris and brachiopods and bryozoans showing fresh marine conditions. These fossils are heavily micritized showing high algal activity at very shallow depth.

The middle part of the unit is strongly dolomitized, but this part also contain a few gypsum beds and also *Palaeoaplysina* fossils. Fusulinids are very abundant. This part of the succession may represent lagoonal or restricted environments, perhaps also tidal conditions, however shorter intervals with limestones with abundant fossils show alternation with fresh marine conditions.

Above the dolomitized part, limestones dominated by echinoderm fragments as well as brachiopods, a few corals and bryozoans indicate shallow carbonate shelf, but the presence of algae show that deposition took place well within the photic zone.

The uppermost part of the unit is rich in grainstones and also contain thin *Palaeoaplysina* reef or bioherms and represent very shallow shelf environments. It this part of the unit, vuggy porosity are present in the grainstones, and the beds show presence of oil.

Kapp Starostin Formation

This unit forms the middle part of 7933/4-U-3 and is referred to the Kapp Starostin Formation as seen on Svalbard (Dallmann et al. 1999, Blomeier et al. 2013).

At base a bed contains abundant big thick-shelled brachiopods, probably both productids and spiriferids. At Spitsbergen, the Kapp Starostin Formation starts with a transgressive bed rich in these fossils, and the unit is named the Vøringen Member. The transgression above the Vøringen Member must have been quite extensive as the overlying part of the core is dominated by deep shelf sediment with minor limestone. Silica sponges are present and silica spicules occur in several of the thin-sections from this unit.

Macrofossils are rare compared with the underlying units except for some brachiopods (mainly productids) and some bryozoans as well as silica sponges, but the extensive silicification may have obliterated most fossils. Faint fossil structures can be seen in the thin-sections and indicate a more diverse fauna prior to the silicification.

The whole formation is thoroughly bioturbated, mainly by the trace fossil *Zoophycos*. *Chondrites* is also present at many levels. These two ichnogenera are strong indicators of low to dysoxic conditions within the sea bottom sediment as they are regarded as the two ichno-fossil groups that can tolerate the lowest oxygen level (Bromley 1996; Bromley and Ekdale 1984).

At one level in the middle part of the formation (68 m) and close to the top of the unit glauconite is very abundant. This indicate periods of very slow sedimentation rate.

Depositional environments

The Kapp Starostin Formation is totally marine. The brachiopods are mainly productids that are adapted to soft sea bottom. Bryozoans and silica sponges are both cold water indicators. The transition from the warm water carbonate shelf deposits of the Gipsdalen Group to the cold water deposits of the Kapp Starostin Formation is regarded as a response to the closing of the Ural sea-way from the warm Tethys ocean in the south during the final formation of the Pangea supercontinent. In this process a large bight on the northernmost part of Pangea result in a deep shelf facing the Boreal Ocean with cold water faunas.

Silicification is extensive in the formation, except for the basal limestone beds of the Vøringen Member. The silicification obliterate most sedimentary structures and also fossils. The glauconite bed uppermost in the unit show very slow sedimentation rate, however, there is no erosional contact with the overlying unit. Elsewhere on Svalbard and in the Barents Sea lacking dating in the latest Permian and earliest Triassic indicate a period of no or very little sedimentation around the Permian – Triassic boundary (Mørk and Smelror 2001).

Vikinghøgda Formation

The upper part of core 7933/4-U-3 (31 m) and the entire core 7933/4-U-2 (12 m) consist of laminated shale that can be included in the Vikinghøgda Formation of Svalbard (Mørk et al. 1999a,b).

The laminated shale is almost without any sedimentary structures. Some of the siltstone beds are cemented by calcite in core 7933/4-U-3, while the entire core 7933/4-U-2 are heavily cemented by calcite. This differences between the cores suggest that the correlation presented in the summary Figure 4 is probably not correct, and the /4-U-2 core is probably younger than the top of the /4-U-3 core.

The nearest good outcrops of the Vikinghøgda Formation occur at Edgeøya, however, there the earliest Triassic (Induan) is not present and the transgression of the Permian rocks took place in the earliest Olenekian (Vigran et al. 2014). On Edgeøya there is erosional structures on the top Permian (Kapp Starostin Formation), however it is not certain that such structures will be seen in a thin core like that in /4-U-3. No macrofossils that can assist dating is found in any of the two cores of the Vikinghøgda Formation. Palynological investigations may help to investigate whether the lower part of the Triassic succession is preserved in the Kvitøya area or possibly the long hiatus observed at Edgeøya may extend to this area.

The few bivalve fragments are the only evidence of life in the cored Vikinghøgda Formation. Similar situation occur also elsewhere on Svalbard, where the lower Triassic succession lack body fossils and also ichnofossils. This “negative” evidence may indicate that lowermost Triassic sediment (Induan) are cored and that the high responsible for the lack of lowermost Triassic sediment on Edgeøya do not extends further northeast towards Kvitøya.

Depositional environments

The laminated shale, and total lack of sedimentary structures, but presence of few bivalve shells all suggest deposition in a shelf area.

Botneheia Formation

The upper part the Botneheia Formation are drilled in the lower part of core 7933/4-U-1 where it is 60 m thick, but the base is not drilled. The formation consists of dark grey laminated mudstone. Phosphate nodules occur thorough the core, but is most abundant in the upper 25 m. Most of the phosphate nodules are a few centimetre in diameter, but thin phosphatic beds also occurs. Small nodules of pyrite are present, most common in the upper part. The core is cemented by calcite.

Abundant flat shelled bivalves have straight ribs and they can be referred to the genus *Daonella*. At several levels coquina of bivalve shells are present, and some few beds uppermost in the formation contain very small, mm-sized, bivalves. Between 81 and 83 m *Tasmanites* alga are very abundant. Bone fragments, probably from ichthyosaurs, occur at four levels in the core. Some phosphate nodules uppermost in the core resemble silica-sponges like those seen in the Kapp Starostin Formation. Bioturbation is not observed in the formation, except for some phosphate nodules that may resemble the ichnogenera *Thalassionides*.

The dark shale of this core is very similar to the Botneheia Formation as it is seen in eastern Spitsbergen and Edgeøya. The upper part of the Botneheia Formation is calcite cemented and rich in flat bivalves (*Daonella*) and is defined as the Blanknuten Member with its type section at Edgeøya (Mørk et al. 1999; Krajewski 2008). A resent master thesis (Bakke 2017) describe *Daonella* from the Blanknuten Member at eastern and central Spitsbergen, and she also verified the identified of the *Daonella* fossils in this core. This fossil date the unit as Late Middle Triassic (Ladinian). Flattened phosphate nodules at Edgeøya has been interpreted as trace fossils infillings of *Thalassionides* traces by Mørk and Bromley (2008).

Abundant *Tasmanites* like the occurrences high up in the formation was also reported from the NPD cores drilled off Kong Karls Land at the same stratigraphic level (Riis et al. 2008, Vigran et al. 2008), and it is abundant in the upper part of the Botneheia Formation at most localities (Vigran et al. 2014).

At present no organic geochemical analyses have taken place, but the Botneheia Formation is known to have very high organic content, especially in the Blanknuten Member, with a mean around 7-8 % and samples as rich as 12 % total organic carbon, and the organic matter is from oil prone kerogen (Mørk and Bjorøy 1984).

Depositional environments

The dark organic rich laminated mudstone without bioturbation have been deposited on a deep restricted shelf. Similar setting occur in the Blanknuten Member of the Botneheia Formation on Svalbard. The lithology with its abundant shelly fauna of *Daonella* is very similar to the development of the Blanknuten Member on Edgeøya, however there abundant *Thalassionides* traces occur in the upper part of the member. Such traces will however be hard to recognise in a thin core. Another differences is that most of the phosphate nodules in the core are round, while they are flattened on Edgeøya. This may indicate deposition in a more basinal setting where less compaction has taken place.

Tschermakfjellet Formation

The lower part the Tschermakfjellet Formation are drilled in the upper part of core 7933/4-U-1 where it is 67 m thick, but the top is not drilled. The formation consists of grey shale with nodules and thin beds of siderite and siderite cemented siltstones. A few beds of very fine grained sandstone show hummocky cross bedding. The mudstone differs from the underlying unit by being non calcareous. Flattened nodules of pyrite is also present as well as a few nodules of phosphate.

Large flat bivalves are abundant, and their curved ribs show that they are of the genus *Halobia* (verified by Nina Bakke who studied them on Svalbard; Bakke 2017). There is also other small bivalves that are not identified, and a few ammonoids. The *Halobia* fossils show that the unit is of earliest Late Triassic (early Carnian) age. This imply that the transition from the Middle to the Late Carnian (Ladinian to Carnian) take place at the formation boundary between the Botneheia Formation and the Tschermakfjellet Formation at 74 meters, similar to the same boundary at Edgeøya and Spitsbergen.

Depositional environments

The grey mudstone with a few hummocky laminated beds are typical of a prodelta environment. The formation is fully marine, but the transition from the underlying dark deep marine shelf mudstone to the grey shales with siderite of the Tschermakfjellet Formation imply a significant shallowing of the basin. A similar regressive development is seen all over Svalbard (Vigran et al. 2014), and in the northern Barents Sea (Lundschien et al. 2014). Regionally a large delta is prograding into the marine basin from south – southeast, and this unit is deposited in front of this progradation (Riis et al. 2008, Lundschien et al. 2014).

De Geerdalen Formation

Sediments from four cores 7934/6-U-1 (179 m), 7934/6-U-2 (191 m), 7934/9-U-1 (152 m) and 7934/8-U-1 (88 m) all together 610 m are assigned to this formation. The formation is, however, significantly thicker as base is not drilled and there is large gaps between the three lowermost cores, while the two uppermost cores may overlap (S.K. Johansen pers. comun. spring 2018).

The unit is dominated by sandstones with minor amounts of shale and also coal and a few podsol horizons. Generally the lithologies are quite similar for all the four cores, although some variations, mainly in the thicknesses and organization of the different lithologies varies throughout the succession.

7934/6-U-1 (179 m) is the lowermost core, and the basal 9 meters consists of bioturbated sandstones probably reflecting shallow marine depositional environment.

Above this, 36 m of coarse sandstone with abundant mud flake conglomerate have coal debris and particles in the upper part which also show low angle cross lamination. This part may represent shore face, and at top there is a 5 meter laminated medium to fine grained sandstones that may represent upper shore face environments.

Then follow a close to 40 m thick interval dominated by fine to coarse grained sandstones with minor shale beds. At one level bivalves are present, and *Teichichnus* trace fossils occur at several levels. A six meter shale unit overly the bivalve fossils and are again overlain by sandstones, possibly a channel. This whole interval, spans from shoreface to tidal channels, interdistributary bay sediment and shallow marine deposits.

The upper part of the core, above ca. 100 m have several coal beds and beds with coal shale, however, between such beds bivalve fossils occur (95 m). Several up to 5 meter thick laminated sandstones may represent shoreface. This whole interval represent delta plain to shallow marine deposits including shoreface deposits and coal marsh.

7934/6-U-2 (191 m) is follows with a gap above /6-U-1. The sedimentological pattern from the underlying core continue, with abundant thin coal seams, however never as thick as one meter. Roots are abundant, and often occur below the coals. Vertical burrows are also common. These can be filled by coarser sand than the surrounding sediment, and several places roots grow inside the burrows. Low angle cross bedding are present at several levels and above 118 m a 14 m thick sandstone may represent shoreface. The whole core represent delta plain and tidal flat environment.

7934/9-U-1 (152 m) is follows with a gap, and the same sediment type are present as in the underlying core. From base up to 83 m the facies with thin coal beds, roots and interbedded shale and sandstones of delta plain environment continue. Several paleosol horizons occur below coal beds.

A transition occur at 83 m and a ca 20 m unit with tidal flat sediment is dominated by shale with minor sands. It is overlain by possibly lagoonal sediment with thin shallow channels.

The upper part of the core is shale dominated and may represent a transition from a tidal flat to shallow marine environments.

7934/8-U-1 (88 m) may overlap with the underlying core, however it is a long distance between the cores that may explain the facies differences. The lower 88 m is included in the De Geerdalen Formation, however this core has a quit higher proportion of shale than seen below in the formation. Coal are only present close to the base of the core. Syneresis cracks are abundant. The sandstones are mostly less than on metre thick. No body fossils are observed but bioturbation is abundant. The sediment may represent lower delta plain, grading to shallow marine in the upper part.

Depositional environments

Comments on depositional environments are given in the description of the individual cores, but the entire formation represent shallow marine to delta plain deposits. While the lower three cores show abundant thin coal beds and often with underlying roots, a transition take place around 83 m of /9-U-1 to dominance of shale with minor sandstones. This may indicate a marine transgression, although still within very shallow water.

Similar facies are well known from Svalbard (Mørk et al. 1982; Lord et al. 2017) where deltaic sedimentation interfinger with shallow marine sediment. Similar facies is also interpreted for major parts of the Barents Sea in the De Geerdalen Formation, and its equivalent in the southern Barents Sea the Snadd Formation (Lundschien et al. 2014).

No equivalent of the Isfjorden Member (Mørk et al. 1999a) seems to be present in these cores. The Isfjorden Member have red shales and podsol horizons as well as thin coal beds (Lord et al. 2017; Haugen 2016). Although coal beds and podsol horizons are present in the middle part of the formation, no reddened shales are observed and the upper part of the formation represent a marine and not continental setting.

The sandstones are mineralogical immature, feldspar rich, as reported by Mørk et al. (1982) and from cores of the same formation drilled below Longyearbyen by Mørk, M.B.E. (1999), however no thin sections or analytical work on these sandstone have been done at present.

Flatsalen Formation

Flatsalen Formation is fully cored in 7934/8-U-1 where it is 99 m thick. At base a slightly more than 1 meter thick bed of calcite cemented sandstone is thoroughly burrowed, and vertical *Skolithos* traces are abundant in the upper part. This bed is very similar to the Slottet Bed as it occurs at Hopen (Mørk et al. 2013; Lord et al. 2014a), and regarded as the norteastenmost occurences of this bed which is widely present on Svalbard (Mørk et al. 1999a).

Above the Slottet Bed the unit is dominated by dark mudstone with bivalve shells and thin sandstone beds. Minor coarsening upward sequences consist of increasing silt-very fine-grained sand in the mudstone. Bioturbation is extensive in the lower 20 m, but also in the more silty parts throughout the unit. Siltstone beds in the lower part of the formation is calcite cemented.

The middle part of the formation show several thin siderite beds or nodules. A silty-sandy interval ca 30 m below top of the formation are heavily bioturbated and trace fossils like *Teichichnus* and *Chondrites* are recognised.

The upper 15 m form a coarsening up sequence and fine grained and medium grained sandstones, mostly planar laminated dominate. No body fossils are seen in this part of the unit, but several beds are bioturbated.

Depositional environments

The Flatsalen Formation is fully cored and have a thicker development (99 m) than seen elsewhere on Svalbard (62 m in the type section on Hopen; Lord et al. 2014a). The characteristic Slottet Bed are here as elsewhere regarded as a transgressive bed, and dated as early Norian on Hopen (Pchelina 1972; Lord et al. 2014a; Paterson in press, DOI 2016).

The bivalves found in the formation is not identified, but similar bivalves are also present on Hopen (Mørk et al. 2013; Lord et al. 2014a). The Flatsalen Formation in this cores like on Hopen is deposited on open shelf environments following the basal transgression resulting in the Slottet Bed. The uppermost part show a regressive development probably shallowing up to delta plain setting. Similar development also occur on Hopen.

Svenskøya Formation

The uppermost 7 m of core 7934/8-U-1 show a transition to a white medium grained sandstone in a similar development as seen on Hopen (Lord et al. in press) and this sandstone can be included in the Svenskøya Formation. No body fossils are found in this unit and bioturbation is also lacking, however coal debris is common on the surfaces on the laminated sandstone beds.

Depositional environments

The Flatsalen Formation occur in a similar setting as on Hopen were also only the basal part of the unit is preserved. The renewed description of the Svenskøya Formation is given by Lord et al. (in press) where this white sandstone is shown to have a wide distribution on eastern Svalbard on Hopen, Wilhelmøya and Kong Karls Land, and herby also extended towards Kvitøya.

The short cored interval may display shore face sediment but tidal or fluvial setting can not be excluded.

Regional correlations and implications

The plan for the drilling cruise was to concentrate on the Triassic succession, but also drill Palaeozoic rocks as well as some Jurassic formations. The localities were planned from estimating seismic reflectors from areas long distance to the south. This plan is also reflected in the sequence of drilled localities (Table 1), and partly on wrong field conclusions made before any analyses were done and a good overview of the stratigraphical distribution could be made.

Drilling plan and results

Well number one (7934/9-U-1) was planned to drill Jurassic rocks and the correct stratigraphy was not understood before the neighbouring wells were also drilled. Well number 2 (8034/4-U-3) is the northernmost well and should penetrate outcropping Palaeozoic rocks. It really did, but drilling problems and highly diagentic altered rocks led to the wrong conclusion that this might be basement rocks. After drilling of core 7933/4-U-3 it was clear that also 8034/4-U-3 penetrated Gipsdalen Group carbonates. Well 3 (7933/4-U-2) was drilled into laminated calcareous shale, but was terminated early to allow drilling of a more promising locality (well 4 - 7933/4-U-3) that penetrated lower Triassic and down into Palaeozoic rocks. The easy to determine cherty rocks with *Zoophycos* clearly showed that Kapp Starostin Formation was drilled and the underlying formation contained abundant fusulinids, *Palaeoaplysina* and at base gypsum bed verified drilling in the Gipsdalen Group.

Wells 5 and 6 (7934/6-U-1 and 2) both penetrated the Upper Triassic rocks which was easily referred to the De Geerdalen Formation based on lithology and similarities with rocks on Svalbard. Well 7 (7933/4-U-1) drilled the Upper and Middle Triassic formations and lithology as well as the downward change from *Halobia* bivalve to *Daonella* bivalve showed that the Tschermakfjellet Formation and the boundary to the Botneheia Formation, the last with its abundant phosphate nodules, were cored.

The last well, number 8 (7934/8-U-1) was planned to drill the Jurassic formations Svenskøya and Kongsøya and perhaps the shale of the Janusfjellet Subgroup and possibly the Cretaceous Helvetiafjellet Formation at top. Correctly a similar sequence of sandstone and shales were cored, however the retrieved cores turned out to be a major sequence older than expected. The lowermost part of the core was the top of the De Geerdalen Formation, with the overlying shales of the Flatsalen Formation with a thin recovered core of the Svenskøya Formation on top.

The stratigraphic drilling result was excellent and several sequence boundaries were penetrated and dated:

- Coring of the Gipsdalen Group as the oldest unit, that penetrating down to gypsum beds. Presence of *Plaeoaplysina* bioherms, and oil show in the upper part of the unit.
- Penetrating the Kapp Starostin Formation, both base and top cored.

- Coring the lowermost part of the Triassic Vikinghøgda Formation. This make it possible to date the lower shale unit to see if the hiatus on Edgeøya also continues to this locality.
- Coring the Tschermakfjellet Formation down into the Botneheia Formation, dating the important Middle to Upper Triassic boundary; a major sequence boundary. Dating both formations with bivalves. Permitting organic geochemical investigation of the Botneheia Formation source rocks.
- Four wells drilled as much as 610 m of the De Geerdalen Formation, but including undrilled base and distances between the cores, this show a thick basinal development in this area.
- Coring the whole Flatsalen Formation with its regional marker horizon and sequence boundary, the Slottet Bed, in a northern locality that is thicker than seen any other places.
- At top, the drilled succession of a few meters of the Svenskøya Formation tie the whole succession together.

Regional implications

The Gipsdalen Group / Ørn Formation as cored off Kvitøya show that the carbonate province of Svalbard continues to the East. The fusulinid dating (Davidov 2016) show that the unit is of latest Carboniferous and earliest Permian age. On Spitsbergen (Dallmann et al. 1999) and Bjørnøya (Worsley et al. 2001) as well as in the Barents Sea (Larssen et al. 2002, 2005; Bugge et al. 1995) *Paleoaplysina* reefs also occur at the carboniferous – Permian boundary. The occurrence of this fossil also close to Kvitøya show that this is a regional phenomenon. This establish a huge carbonate shelf all over the Barents Sea area.

Kapp Starostin Formation is fully drilled close to Kvitøya. The major sequence boundary, below the Vøringen Member is clearly of regional extent, and can be followed on Svalbard down to Bjørnøya and in the Barents Sea. The basinal sediment with chert and *Zoophycos* trace fossils is similar to that of Spitsbergen, however there local fossiliferous shoals occur. It also contrast the development on Bjørnøya (Worsley et al. 2001) which is clearly a shallow carbonate bank deposits compared with the muddy cherts of this unit off Kvitøya.

Vikinghøgda Formation is the lowermost Triassic unit on Svalbard, and the base of the formation is a major sequence boundary all over the Arctic (Mørk and Smelror 2001). At Edgeøya, one of the closest land exposures of the formation the lower stage of the Triassic (Induan) is missing. Paleontological dating of the sediment in the lower part of the Vikinghøgda Formation in the core is needed to evaluate whether there is a major hiatus also at this locality, or if it is more continuous sedimentation as seen on central and western Spitsbergen (Mørk et al. 1999a). The total lack of bioturbation and sparse macrofauna only consisting of some bivalves is typical for the lowermost part of the formation on Spitsbergen, and it may indicate more continuous sedimentation than on Edgeøya.

Botneheia Formation off Kvitøya show the typical dark organic rich rocks with abundant phosphate nodules. The *Daonella* bivalves are of Ladinian age and the abundant calcite cement is typical for the upper member of the formation which is the Blanknuten Member.

The occurrence is quite similar to the development of the Blanknuten Member on Edgeøya and eastern Spitsbergen. The unit also correlate with the upper part of the Steinkobbe Formation as it is defined on the Svalis Dome central in the Barents Sea by Mørk and Elvebakk (1999). The formation is very organic rich elsewhere (Mørk and Bjorøy 1984) and the organic content of the unit should be analysed.

Tschermakfjellet Formation are drilled in the same well as the Botneheia Formation. The boundary between these two formations in the core is similar to the boundary as exposed on Edgeøya and on Spitsbergen. At the boundary it is a marked transition from dark mudstone to grey shale. The abundant phosphate nodules in the Botneheia Formation is strongly reduced, however, a few larger and of a lighter grey colour phosphate nodules still occur in the lowermost beds. Siderite nodules and thin beds occur from the base of the Tschermakfjellet Formation in the core just as on the land exposed on Svalbard. The change from the flat bivalve *Daonella* to *Halobia* also take place at the boundary.

The formational transition correspond to a major transgression at the Ladinian –Carnian boundary and is synchronous all over Svalbard (Mørk and Smelror 2001) and also in the NPD cores drilled off Kong Karls Land where the transitional beds are radiometric dated (Xu et al. 2014). This correlation cannot be followed southwards in the Barents Sea as the prodelta grey sediment that are lithological similar to the Tschermakfjellet Formation is there dated as starting earlier, it is within the Ladinian (Vigran et al. 1998; Lundschien et al. 2014). This imply that the lower part of the Snadd Formation in the Barents Sea is lithological similar to the Tschermakfjellet Formation although it correlate with the upper part of the Botneheia and Steinkobbe Formation (Worsley et al. 1988; Mørk and Elvebakk 1999; Vigran et al. 1998; Lundschien et al. 2014).

De Geerdalen Formation is cored in four wells, where the three lowermost in the succession have stratigraphic gap between the wells, while the uppermost one may overlap with the next uppermost core (S.K. Johansen pers. comun. 2018). The accumulative thickness of 610 m, where base is not cored and there is uncertainties on the length of gap between the cores show that there is a substantial sinking of the depositional basin during sedimentation as most of the core represent sedimentation close to sea level (delta plain and shallow marine environments). At Hopen, the De Geerdalen Formation is estimated as 650 m thick based on data from the Hopen 2 well (Lord et al. 2014a), while it is considerable thinner with a maximum thickness of 350 m on Spitsbergen (Vigran et al. 2014).

In the Barents Sea a minimum of 4 sequences are mapped on seismic record (Riis et al. 2008; Lundschien et al. 2014), but from the cored data it is hard to see if these sequences can be followed northwards to Kvitøya. Close comparisons of seismic data and the core data may show whether these sequences can be recognised also in this area.

Extensive channelling has been recognised on Edgeøya and eastern Spitsbergen (Lord et al. 2017) and on Hopen (Lord et al. 2014b) and similar channel belts as seen on Hopen are also recognised in the correlative Snadd Formation in the southern Barents Sea (Klausen and Mørk 2014), and most probably the channels recognised close to Kvitøya (see the

Enclosures) follow the same pattern. The delta plain to shallow marine depositional environments thus seems to extend all over the Barents Sea and further north than Kvitøya.

Flatsalen Formation is fully cored off Kvitøya, and the 99 m thickness here is the largest thickness observed for this unit. The base marked by the Slotted Bed is a regional marker that can be followed over large areas of Svalbard (Mørk et al. 1999a) and also into the Barents Sea where it is recognised on Sentralbanken (Lundschien et al. 1014). Correlation with the Fruholmen Formation of the southern Barents Sea (Worsley et al. 1988) can be done on chronostratigraphic evidences, but direct lithological correlation is more dubious.

The facies of the Flatsalen Formation off Kvitøya is similar to that of the same formation on Hopen, both representation open shelf sedimentation. Although the basal Slottet Bed can be correlated over large part of Svalbard the overlying lithology on Spitsbergen is more proximal and represent shallow marine environments.

Svenskøya Formation is only represented with the uppermost 7 metres of the cores. The development off Kvitøya is very similar to that seen on Hopen, indicating that the Svenskøya Formation has an extensive development in the northeastern Svalbard islands and this part of the Barents Sea.

Regional Sequence boundaries

Five sequence boundaries are recognised in the drilled cores:

5 Base Svenskøya Formation (*Rhaetian*)
4 Slottet Bed at base Flatsalen Formation (*Early Norian*)
3 Base Tschermakfjellet Formation (*base Ladinian*)
2 Base Vikinghøgda Formation (*base Triassic*)
1 Vøringen Member at base Kapp Starostin Formation (*Artinskian*?)

In addition a major sequence boundary should be present at base of the Botneheia Formation (*base Anisian*).

All these sequence boundaries from the near Kvitøya area is also recognised on Svalbard and can be followed throughout the Barents Sea, and also widely in the Arctic areas (Mørk and Smelror (2001).

References

Bakke, N. 2017: The evolution of the Triassic bivalve *Daonella* into *Halobia* in the Botneheia Formation on Svalbard. Master thesis, NTNU, 185 pp.

Blomeier D., Dustira A.M., Forke H. & Scheibner C. 2013: Facies analysis and depositional environments of a storm-dominated, temperate to cold, mixed siliceous-carbonate ramp: the Permian Kapp Starostin Formation in NE Svalbard. Norwegian journal of geology 93, 75-94.

Bromley R.G. 1996: Trace fossils. Biology, taphonomy and applications. 2nd edition. London: Chapman & Hall.

Bromley R.G. & Ekdale A.A. 1984: Chondrites: a trace fossi lindicator of anoxia in sediments. Science 224, 872–874.

Bugge, T., Mangerud, G., Elvebakk, G., Mørk, A., Nilsson, I., Fanavoll, S. & Vigran, J.O. 1995: The Upper Palaeozoic succession the Finnmark Platform, Barents Sea. Norsk Geologisk Tidsskrift, 75, 3-30.

Dallmann W.K. (ed.) 1999: Lithostratigraphic lexicon of Svalbard. Upper Palaeozoic to Quaternary bedrock. Review and recommendations for nomenclature use. Tromsø: Committee on the Stratigraphy of Svalbard / Norwegian Polar Institute. 320 pp.

Dallmann, W., Gjelberg, J., Harland, W., Johannessen, E., Keilen, H., Lønøy, A., Nilsson, I., & Worsley, D. 1999: Upper Palaeozoic lithostratigraphy. Norwegian polar institute. 25-126 in: Dallmann W.K. (ed.): Lithostratigraphic Lexicon of Svalbard. Upper Palaeozoic to Quaternary bedrock. Review and recommendations for nomenclature use. https://data.npolar.no/publication/3946b161-82ae-48c4-93bc-41bc01c754af

Davidov, V. 2016: Foraminiferal and algal biostratigraphic dating of Upper Paleozoic core samples from 7933/4-U-3 well, Barents Sea, Norway. Report 16 pp.

Haugen, T. 2016: A sedimentological study of the De Geerdalen Formation with focus on the Isfjorden Member and palaeosols. (Master thesis NTNU) 1565 pp.

Klausen, T.G. & Mørk, A. 2014: The Upper Triassic paralic deposits of the De Geerdalen Formation on Hopen: Outcrop analog to the subsurface Snadd Formation in the Barents Sea. AAPG Bulletin, 98, 1911-1941. DOI: 10.1306/02191413064

Krajewski, K.P. 2008: The Botneheia Formation (Middle Trias-sic) in Edgeøya and Barentsøya, Svalbard: lithostratigraphy, facies, phosphogenesis, paleoenvironment. Polish polar research 29, 319-364.

Larssen, G.B., Elvebakk, G., Henriksen, L.B., Kristensen, S.-E., Nilsson, I., Samuelsberg, T.J., Svånå, T.A., Stemmerik, L. & Worsley, D. 2002: Upper Palaeozoic lithostratigraphy of the Southern Norwegian Barents Sea. Npd Bulletin 9. http://www.npd.no/Global/Norsk/3-Publikasjoner/NPD-Bulletin/PalaeozoicNomenclature_17.pdf

Larssen, G.B., Elvebakk, G., Henriksen, L.B., Kristensen, S.-E., Nilsson, I., Samuelsberg, T.J., Svånå, T.A., Stemmerik, L. & Worsley, D. 2005: Upper Paleozoic_Southern Barents Sea. NGU Bull. 444.

Lord, G.S., Johansen, S.K., Støen, S.J. & Mørk, A. 2017: Facies development of the Upper Triassic succession on Barentsøya, Wilhelmøya and NE Spitsbergen, Svalbard. Norwegian Journal of Geology 97, 33–62. https://dx.doi.org/10.17850/njg97-1-03.

Lord, G.S., Mørk, M.B.E., Mørk, A. & Olaussen, S. in press: Sedimentology and Petrography of the Svenskøya Formation on Hopen, Svalbard: An analogue to sandstone reservoirs in the Realgrunnen Subgroup. Polar Research.

Lord, G.S., Solvi, K.H., Ask, M., Mork, A., Hounslow, M.W. & Paterson, N.W. 2014a: The Hopen Member: A new member of the Triassic De Geerdalen Formation, Svalbard. Norwegian Petroleum Directorate Bulletin, No. 11, pp. 81–96. ISBN 978-82-7257-117-6.

Lord, G.S., Solvi, K.H., Klausen, T.G. & Mørk, A. 2014b: Triassic channel bodies on Hopen, Svalbard: Their facies, stratigraphical significance and spatial distribution. Norwegian Petroleum Directorate Bulletin, No. 11, pp. 41-59. Stavanger 2014, ISBN 978-82-7257-117-6.

Lundschien, B.A., Høy, T. & Mørk, A. 2014: Triassic hydrocarbon potential in the Northern Barents Sea; integrating Svalbard and stratigraphic core data. Norwegian Petroleum Directorate Bulletin, 11, 3–20. ISBN 978-82-7257-117-6.

Mørk A. & Bjorøy M. 1984: Mesozoic source rocks on Sval-bard. Pp. 371-382 IN: Petroleum geology of the North European margin: proceedings of the North European Margin Symposium (NEMS ’83) / ed. A.M. Spencer et al. London: Graham & Trotman.

Mørk, A. & Bromley, R.G. 2008: Ichnology of a marine regressive systems tract: the Middle Triassic of Svalbard. Polar Research 27, 339-359.

Mørk, A., Dallmann, W., Dypvik, H., Johannessen, E., Larssen, G., Nagy, J.,Worsley, D. 1999a: Mesozoic lithostratigraphy [peer-reviewed]. Norwegian polar institute. Lithostratigraphic Lexicon of Svalbard. Upper Palaeozoic to Quaternary bedrock. Review and recommendations for nomenclature use. https://data.npolar.no/publication/cdf4537b-5fd9-4829-bfa1-5d00c0777d2b

Mørk, A. & Elvebakk, G. 1999: Lithological description of subcropping Lower and Middle Triassic rocks from the Svalis Dome, Barents Sea. Polar Research 18 (1), 83-104.

Mørk, A., Elvebakk, G., Forsberg, A.W, Hounslow, M.W., Nakrem, H.A., Vigran, J.O. & Weitschat, W. 1999b: The type section of the Vikinghøgda Formation: a new Lower Triassic unit in central and eastern Svalbard. Polar Research 18, 51-82.

Mørk, A., Gjelberg, J.G. &Worsley, D. 2014: Bjørnøya – an Upper Paleozoic-Triassic window into the Barents Shelf. Geological Society of Norway Geological Guides 2014-1, 49 pp. ISBN: 978-82-92- 39487-8. http://www.geologi.no/geologiskeguider/ Bjornoya_nr_1_2014

Mørk A., Knarud R. & Worsley D. 1982: Depositional and diagenetic environments of the Triassic and Lower Jurassic succession of Svalbard. Pp. 371-398 IN: Arctic geology and geophysics: proceedings of the Third International Symposium on Arctic Geology / ed. A.F. Embry and H.R. Balkwill. (Canadian Society of Petroleum Geologists. Memoir; 8). Calgary.

Mørk A., Lord, G.S., Solvi, K.H. & Dallmann, W.K. 2013: Geological map of Svalbard 1:100 000, sheet G14G Hopen. Norsk Polarinstitutt Temakart No. 50.

Mørk, A. & Smelror, M. 2001: Correlation and Non-correlation of High Order Circum-Arctic Mesozoic Sequences. Polarforschung, 69, 65-72.

Mørk M.B.E. 1999: Compositional variations and provenance of Triassic sandstones from the Barents Shelf. Journal of sedimentary research 69, 690-710.

Paterson, N.W., Mangerud, G-, Cetean, C.G., Mørk, A., Lord, G.S., Klausen, D.GF., Mørkved, P.T. 2016: A multidisciplinary biofacies characterisation of the Late Triassic (late Carnian–Rhaetian) Kapp Toscana Group on Hopen, Arctic Norway. Palaeogeography,Palaeoclimatology, (in press). http://dx.doi.org/10.1016/j.palaeo.2015.10.035

Pčelina, T.M. 1972: K voprosu o vozraste osadočnoj tolšči os Nadeždy (Sval'bard). (On the age of the sedimentary succe of the island of Hopen (Svalbard)). In V.N. Sokolov & Vasilevskaja (eds.): Mezozoiskie otloženija Sval'barda (Mes deposits of Svalbard), NIIGA, Leningrad, 75-81. (In Russian).

Riis F., Lundschien B.A., Høy T. Mørk A. & Mørk M.B. 2008: Evolution of the Triassic shelf in the northern Barents Sea region. Polar research 27, 318-338.

Vigran, J.O., Mangerud, G., Mørk, A., Bugge, T. & Weitschat, W. 1998: Biostratigraphy and sequence stratigraphy of the Lower and Middle Triassic deposits from the Svalis Dome, Central Barents Sea, Norway. Palynology 22, 89-141.

Vigran J.O., Mangerud G., Mørk A., Worsley D. & Hochuli P.A. 2014: Palynology and geology of the Triassic succession of Svalbard and the Barents Sea. (Geological Survey of Norway. Special publications 14). Trondheim. 270 pp.

Vigran, J.O., Mørk, A., Forsberg, A.W., Weiss, H.M. & Weitshcat, W. 2008: *Tasmanites* algae – contributors to the Middle Triassic hydrocarbon source rocks of Svalbard and the Barents Shelf. Polar Research 27, 360-371.

Stemmerik, L., Larson, P.A., Larssen, G.B., Mørk, A. & Simonsen, B.T. 1994: Depositional evolution of Lower Permian Palaeoaplysina build-ups, Kapp Duner Formation, Bjørnøya, Arctic Norway. Sedimentary Geology 92, 161- 174.

Worsley, D., Agdestein, A., Gjelberg, J.G., Kirkemo, K., Mørk, A., Nilsson, I., Olaussen, O., Steel, R.J. & Stemmerik, L. 2001: The geological evolution of Bjørnøya, Arctic Norway: implications for the Barents Shelf. Norwegian Journal of Geology, 81, 195-234.

Worsley, D., Johansen, R. & Kristensen, S.E. 1988: The Mesozoic and Cenozoic succession of Tromsøflaket. Pp. 42-65 in Dalland, A., Worsley, D. & Ofstad, K. (eds.), A lithostratigraphic scheme for the Mesozoic and Cenozoic succession offshore mid- and northern Norway. Norwegian Petroleum Directorate Bulletin, 4.

Xu, G., Hannah, J.L., Stein, H.J., Mørk, A., Vigran, J.O., Bingen, B., Schutt, D.L. &. Lundschien, B.A. 2014: Cause of Upper Triassic climate crisis revealed by Re–Os geochemistry of Boreal black shales. Palaeogeography, Palaeoclimatology, Palaeoecology 395 (2014) 222–232