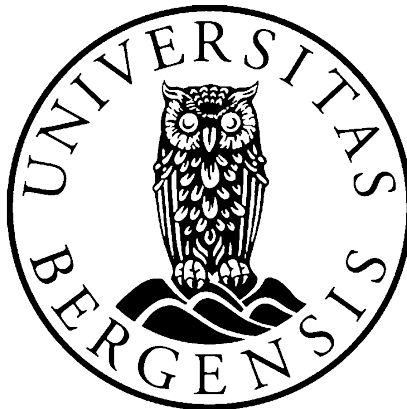# Late Triassic (Carnian) Palynology of the Northern Barents Sea (Sentralbanken High)

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Abstract

This study is part of a broader palynological investigation of late Middle to Late Triassic, where the main aim is to improve the biostratigraphic resolution by applying palynology. The low abundance of macrofossils (e.g. ammonites) in Svalbard and the Barents area, coupled with the long duration of the Late Triassic Epoch results in very low biostratigraphic resolution. This makes palynology an important tool for resolving the stratigraphy and dating the successions.

In this study, 31 palynological samples were analysed from core 7533/3-U-7 drilled through the Snadd Formation on the Sentralbanken High, northern Barents Sea. Four assemblages were recognized, all of which were assigned a mid to late Carnian age. Palynofacies analysis was integrated with sedimentological facies, and the depostional environment was interpreted to represent a delta plain. Eight additional samples from Blåfjellet (Hopen), from the De Geerdalen Formation, were also incorporated into this study at a later stage. Two assemblages were recognized from these samples, where the lowermost assemblage was assigned a mid to late Carnian age and the uppermost a possible latest Carnian age. The logged section on Blåfjellet was also interpreted to represent a delta plain setting, with a possible shallow marine interval in the upper and lower parts of the logged section. This interpretation was based on the sedimentological log; no major changes were recorded in the palynofacies. Also, marine indicators, such as acritarchs, were absent in all the samples from Hopen. The palynofacies and the palynological assemblages recorded in the samples from Hopen closely resembled those from core 7533/3-U-7, i.e. palynofacies dominated by wood particles and palynological assemblage dominated by terrestrial taxa. Abundant fern spores, such as *Leschikisporis, Concavisporites*, *Deltoidospora*, *Dyctyophyllidites* and *Duplexisporites* were recorded in the samples from core 7533/3-U-7 and Hopen. This indicates humid warm conditions during the time of deposition (Abbink et al., 2004). The terrestrial taxa, palynofacies results and sedimentological facies recorded in this study reflects the paralic nature of the Upper Triassic (Carnian) Barents Shelf (Riis et al., 2008).

Acknowledgments

Contents

1. Introduction

This study concerns the palynostratigraphy of the Upper Triassic successions on the Barents Shelf. The Late Triassic spans a period of 35.7 Ma, whereas Middle and Early Triassic have durations of 10.1 and 5.1 Ma respectively. Based on the Boreal Ammonoid Zonation from western North America (Ogg, 2012), the stages in the Late Triassic epoch have an average resolution of approximately 2.23 Ma. In comparison, the Middle and Early Triassic stages have average resolutions of approximately 0.92 Ma and 0.46 Ma respectively. However, due to the lack of ammonite zonations in the arctic area the average resolution is much lower. Based on the palynological assemblages proposed by Hochuli et al. (1989) the average resolution of the Late Triassic stages is 5.95 Ma (divided on six zones), whereas using the assemblages of Vigran et al. (2014) the average resolution is calculated to 8.9Ma (divided on four zones). Continued biostratigraphic work of Upper Triassic successions is therefore important to improve dating and thereby the resolution of these stages.

In general, ammonites and conodonts provide the best biostratigraphic subdivision of the Triassic successions in the Barents Shelf, however, their use is limited by their rare occurrence (Hochuli et al., 1989). This is particularly the case for the Upper Triassic successions. In addition, these fossils are facies-dependent, and may be completely absent in some parts of the sequence. Palynomorphs are also affected by facies, as well as preservation and other factors, but have many advantages compared to ammonites and conodonts: Palynomorphs spread in large numbers; they were well represented throughout the studied succession. Also, palynomorphs spread over vast areas, and are the only fossil group that can be correlated between marine and terrestrial environments. Another advantage is the organic nature of palynomorphs, which makes them very stable and enhances preservation (Traverse, 2007).

Rich palynomorph taxa in Upper Triassic successions is also shown in previous palynological studies worldwide, such as Bonis et al. (2009), Kavary (1972), Blendinger (1988), Fisher (1979), Klaus (1960), Lund (1977), Van der Eem (1983), Roghi (2004), Cirilli (2010) Roghi et al. (2010), Kürschner and Herngreen (2010), among others. Due to the high abundance and rapid evolution of palynomorphs, palynology may provide a higher resolution for biostratigraphic subdivision for the Upper Triassic successions (Hochuli et al., 1989).

1.1 Aim of Study

The main aim of this study is to date the shallow stratigraphic core 7533/3-U-7 using palynology. Also, the palaeoenvironment represented by the core is interpreted by integrating palynofacies and sedimentological analyses. The core was drilled through the Snadd Formation in the Sentralbanken High in the Northern Barents Sea, southeast of the island Hopen (fig. 1). Upper Triassic strata are subcropping close to the sea floor in this region, which combined with the availability of high quality seismic makes the Sentralbanken High suitable for Upper Triassic research in the Barents Sea (Riis et al., 2008).

This study constitutes a part of a broader palynostratigraphic research of the upper Middle to Upper Triassic of the Barents Shelf and Svalbard, currently being undertaken at the University of Bergen. Thus the goal is to contribute to improve the biostratigraphic resolution of the Upper Triassic Barents Shelf.

Additional samples from the southern parts of Blåfjellet, located in the northern parts of Hopen (fig. 1), along with a sedimentological log were added to this study at a later stage. The purpose was to enable a correlation between the samples from the De Geerdalen Formation on Hopen and the Sentralbanken core, or to see a larger change in the palynological assemblages. A correlation of core 7533/3-U-7 with published sections from the Barents Shelf and Svalbard (including these results from Hopen) is presented herein.
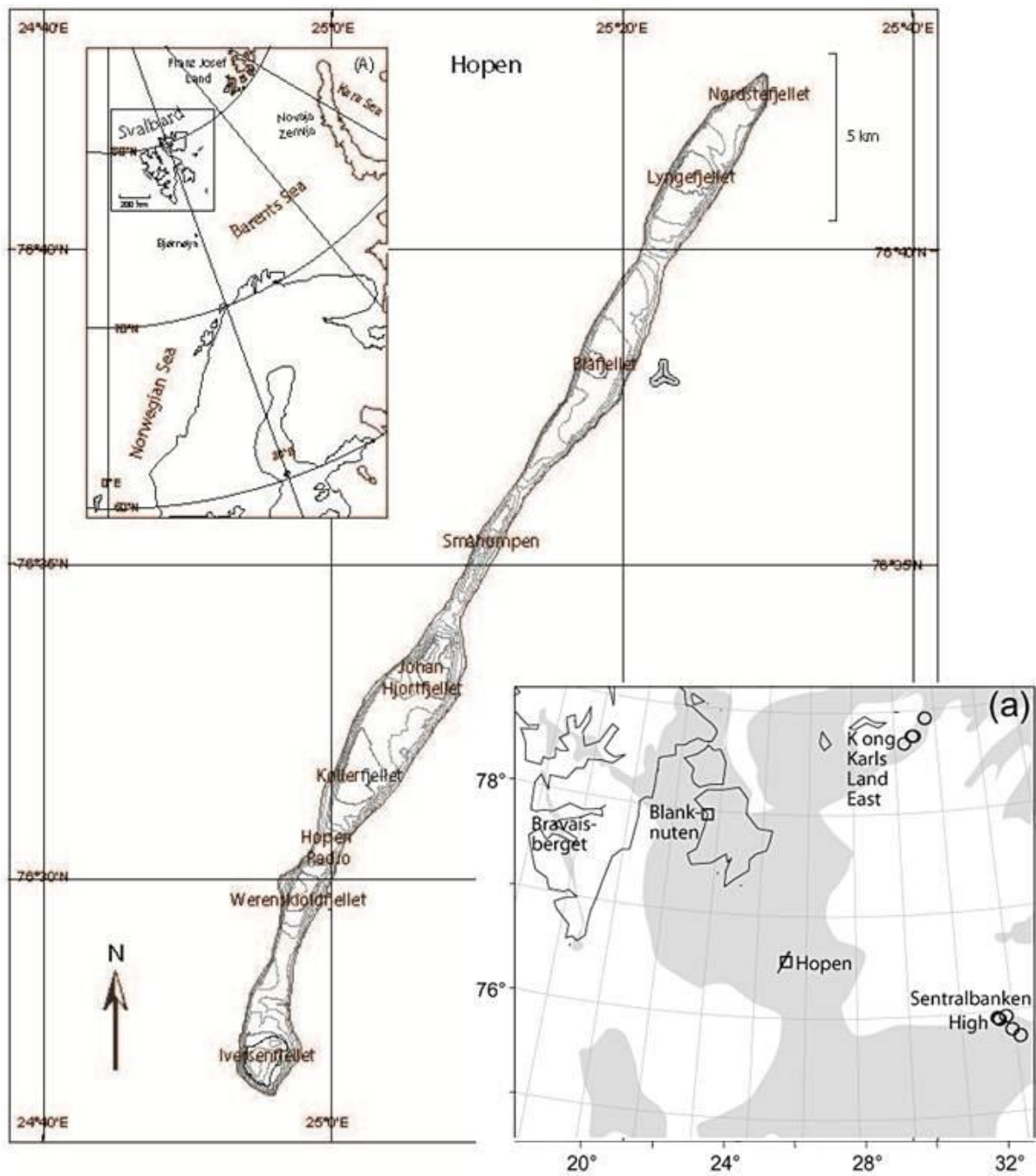
Figure 1: Map over Hopen. The location of Blåfjellet is marked with the triangle. Figure (a) shows the location of the Sentralbanken High relative to Hopen (modified from Riis et al. (2008) and Paterson and Mangerud (submitted))

1.2 Palynological Background

Palynology is the study of acid resistant, organic walled microfossils, collectively termed palynomorphs (Traverse, 2007). This includes the study of various microscopic organisms such as reproductive plant cells (as pollen and spores) and whole organisms (e.g algae). Spores resemble the reproductive particles of lower vascular plants (as ferns and mosses), while pollen originate from seed plants (as gymnosperms and angiosperms) (Traverse, 2007). Palynomorphs are usually in the size-range from 5 to 500 microns (μm), most commonly 20-90 μm. An important property of palynomorphs is that they have a resistant wall that survives the processing techniques, where two main types of walls can be distinguished (Traverse, 2007): Chitin wall is a long-chain polymer that closely resembles cellulose, and is most common for spores and fungi. The other wall-type is called sporopollenin, which is common for pollen, acritarchs and certain spores. Chitin and sporopollenin also plays different parts in the microfossil grains: Chitin is like a coating, while sporopollenin comprises the whole outer wall of the grain. Both sporopollenin and chitin are highly resistant materials and survives transport, diagenesis and processing. By definition, palynomorphs are resistant to both hydrochloric (HCl) and hydrofluoric (HF) acid, as used in standard palynomorphs extraction techniques (Traverse, 2007). However, palynomorphs are affected by oxidation, and will be destroyed by strong oxidation.

Facies will also affect palynomorphs, but they will almost always be present in a sedimentary rock to some extent. Also, palynomorphs have a rapid evolution that makes them very useful for biostratigraphy, and increase the potential for a high resolution biostratigraphic zonation (Traverse, 2007). The study of palynology is mainly used for relative age dating and for interpretation of the palaeoenvironment and depositional environment.

Spores are usually characterised by a monolete or trilete mark, known as a laesura. This is a "scar" that is related to the form the grains possessed when they were expelled from the plant (Traverse, 2007). *Deltoidospora*, *Calamospora*, *Conbaculatisporites* and *Dictyophyllidites* (Appendix I, II and III, Plate I and II) are among the trilete spores that were typical elements in this study. The monolete spores common in this study includes *Apiculatisporis*, *Aratrisporites* and *Leschikisporis* (Plate VI). Pollen grains are usually characterised by an opening (sulcus) and/or by the saccus. *Triadispora* and *Striatoabieites* are two bisaccate

pollen genera that were typically recorded in this study (Plate IX and X), along with *Chasmatosporites* and *Cycadopites* (Plate VII) which were among the common monosulcate pollen. It is important to note that different spores and pollen are not necessarily reflecting different plant species. They are solely distinguished based on a morphological nomenclature. Different palynomorphs can therefore originate from the same plant, but be recognized as different genera or species (Traverse, 2007).

1.3 Previous Palynological Work

There have been numerous studies on the palynostratigraphy of the Triassic period. Important work includes the western Dolomites in Italy, where Van der Eem (1983) recognized seven palynological phases from the Upper Anisian to Middle Carnian, calibrated with ammonite zonations. The Late Ladinian and Carnian in the south-eastern Dolomites was studied by Blendinger (1988). Based on 50 samples Blendinger (1988) identified 60 different miospore taxa and compared the assemblages with the established phases to Van der Eem (1983). Important biostratigraphic work on the Triassic has also been done in Austria. E.g. five assemblage zones, over the Triassic-Jurassic boundary, were recognised from the Eiberg Basin by Bonis et al. (2009). In their study, Bonis et al. (2009) described a rapid change in the assemblages, with a general increase in the diversity of pollen and spores.

The Upper Triassic, specifically Carnian, was studied by Roghi (2004) in northern Italy (southern Alps). He recognized three palynological assemblages and calibrated these with ammonites and conodonts. Later, the Raibler Schichten and Lunz area (also in Austria) was studied by Roghi et al. (2010). Three associations were recognized and dated, mainly within the Carnian.

Palynological work in southern Scandinavia and northwest Germany was done by Lund (1977), who identified six assemblage zones along with three sub-zones from the Rhaetian to Lower Liassic (the lower part of the Lower Jurassic period).

Previous palynological work in Arctic Canada includes Felix (1975), Suneby and Hills (1988) and Fisher (1979). The entire Triassic period, from late Induan (Griesbachian) to Rhaetian, was studied by Fisher (1979), who established nine assemblages.

Palynological studies of the Triassic stratigraphy in more related areas have also been undertaken by some authors, e.g. the papers from Smith (1974), Smith et al. (1975), Bjærke (1977), Bjærke and Manum (1977), Hochuli et al. (1989), Hochuli and Vigran (2010), Ask (2013), Vigran et al. (1998), Vigran et al. (2014) and Paterson and Mangerud (submitted) were especially relevant for this study since they concerns the Barents Shelf and Hopen. As this study was in an almost complete stage when the paper Vigran et al. (2014) was published, the use of this work was rather limited. Smith (1974) collected material for approximately 100 samples from the Kapp Toscana Formation (fig. 2) on Hopen, but many of the samples proved to be unproductive. The productive samples were taken from the lower parts of Iversenfjellet

(fig. 1) and from Braastadskaret (northern parts of the island) (Smith, 1974). In comparison, the Hopen samples provided for this study is taken from Blåfjellet from the lower part of the De Geerdalen Formation, located south of Braastadskaret (fig. 1). Later, Smith (1982) had to change their interpretation of a Rhaetian to Norian age for the Flatsalen Formation (fig. 2), due to ammonite finds in the same formation (Korcinskaja, 1980).

The lack of palynological work in nearby areas at the time, led Bjærke and Manum (1977) to compare their results with assemblages from distant areas such as north-western Europe, Britain and the Arctic Canada. The great distances and the resulting palaeoclimatic and palaeoenvironmental differences makes this kind of long distance correlation uncertain, and both plants as well as their quantitative composition might be very different (Bjærke and Manum, 1977).

Later, sixteen assemblage zones, covering the entire Upper to Lower Triassic successions, were established by Hochuli et al. (1989). It is important to note that Hochuli et al. (1989) based a lot of their work on cuttings and therefore used the first down-hole occurrences and not the first stratigraphic occurrence of the recorded taxa. Their work was followed by Vigran et al. (1998). Based on material from shallow stratigraphic cores they established eight assemblage zones for the Lower and Middle Triassic in the Svalis dome. Six of the assemblage zones were calibrated with established ammonite zones, and Vigran et al. (1998) compared their assemblages with the work of Hochuli et al. (1989). Only the uppermost assemblage (Svalis-8) was from the Snadd formation. All the other assemblages recorded by Vigran et al. (1998) were from formations older than the Snadd formation (as Steinkobbe Fm., Klappmyss Fm. and Havert Fm.), and are thus older than the scope of this study.

The Upper Triassic to Lower Jurassic biofacies on Spitsbergen were studied by Nagy et al. (2011), mainly based on foraminifera, but also including palynomorphs. Triassic climate variations based on palynomorphs was studied by Hochuli and Vigran (2010). They focused on the major floral changes from the late Early Triassic (late Smithian) to the Late Triassic (Rhaetian) and interpreted these to represent climatic changes.

2. Geological Setting: The Triassic Period, with focus on the Snadd Formation

The Barents Shelf is located in the north-western part of the Eurasian plate, with correlative exposures on the Svalbard Archipelago located in the north-western corner of the shelf (Mørk et al., 1999). The western Barents area can be divided into three geological provinces: a platform area north of 74^0N, a east-west trending basin area between 74^0N and the coast of Norway, and a continental margin to the west (Faleide et al., 1984). According to Worsley (2008) five main processes, taking place between the Devonian and Neogene, led to the development of the western Barents Shelf successions and these geological provinces. An important influence on the deposition in the Barents Sea was the continuing northwards movement of the area and the resulting climatic changes. For more information about the pre- and post-Triassic development of the Barents Shelf the reader is referred to Worsley (2008).

During the Triassic the Barents Sea was part of an epicontinental seaway, within a large embayment on the northern coast of Pangea (Glørstad-Clark et al., 2010). Sediments derived from the Baltic Shield from the south and from the recently uplifted Uralian Mountains and Novaya Zemlya from the east gradually filled the Barents Shelf, transforming it from a deeper shelf area to an extensive paralic platform (Riis et al., 2008). The Barents Shelf transformed from a deep shelf in the Anisian to a shallow shelf in the Ladinian (fig. 3) (Riis et al., 2008). The final infilling of the Barents Sea, with massive delta plains and channel deposits, took place during the Carnian (Riis et al., 2008). The western Barents Shelf was tectonically relatively quiet during the Triassic, but Glørstad-Clark et al. (2010) concluded that the development of accommodation space throughout the period was controlled by tectonic activity, mainly related to the development of the Uralian mountains and the North Atlantic rift system.
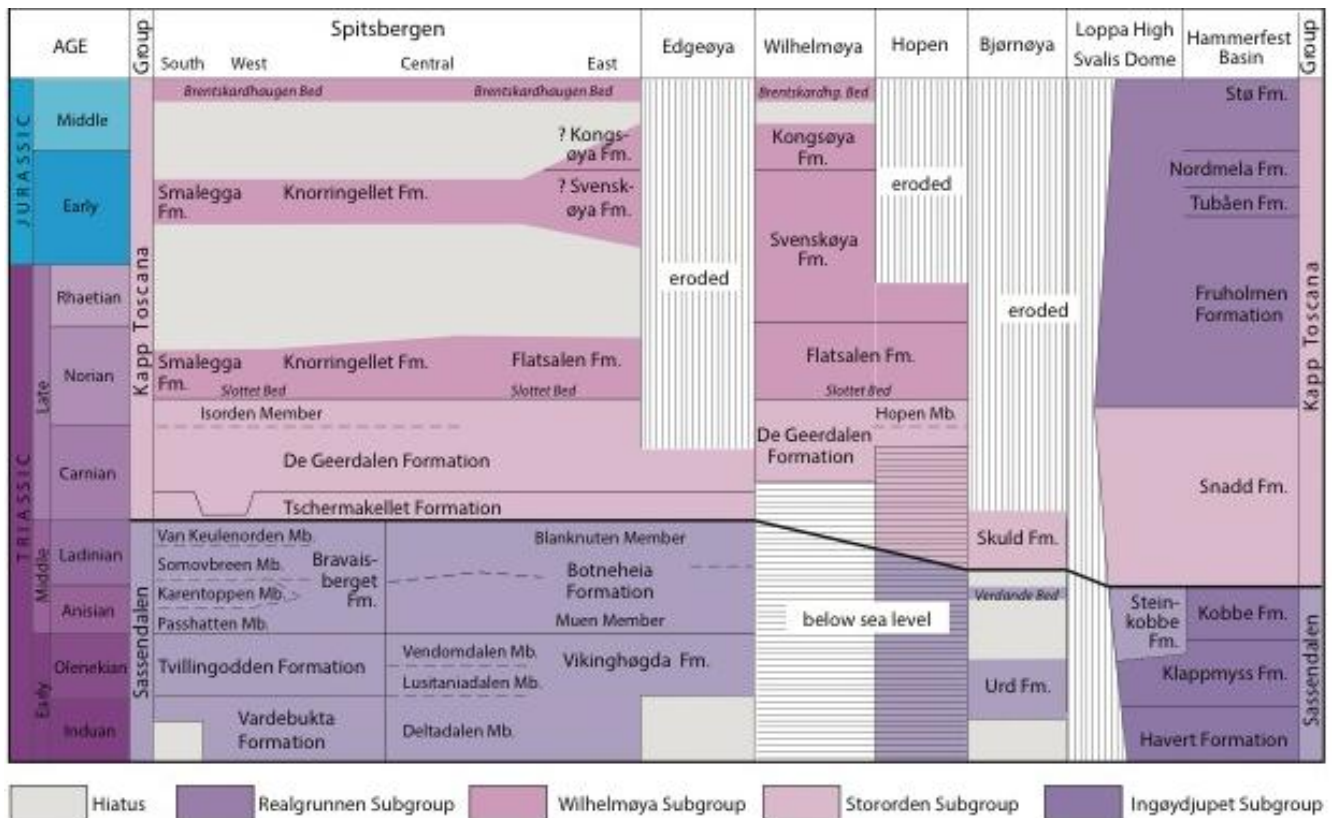
Fig. 2: Lithostratigraphic subdivision of the Triassic to Middle Jurassic successions of Svalbard and the Barents Shelf (from Mørk et al. (2013))

The Triassic successions on Svalbard comprises two groups: the Sassendalen Group and the Kapp Toscana Group (fig. 2), and equivalents to the successions comprising these groups can be found throughout the Barents Shelf (Mørk et al., 1999).

The Lower and Middle Triassic successions comprise the Sassendalen Group (fig. 2). This group can be divided into three units based on the depositional environment: a lowermost unit comprising marine to coastal sediments, a middle unit with coarsening upwards sandstones and a upper unit with organic rich shales and sandstones (Mørk et al., 1999). As non-sileceous fine-grained deposits dominate the entire Sassendalen Group, it is often referred to as the "Early Triassic silica gap" (Worsley, 2008). Shallow marine sedimentation with synchronous stratigraphic boundaries dominate the Lower Triassic deposits, while deeper marine prodelta shales dominated the deposition during the Middle Triassic (Mørk et al., 1999).

The sand-rich Upper Triassic successions comprise the lower part of the Kapp Toscana Group, which extends upwards to the middle Jurassic (fig. 2) (Mørk et al., 1999). In the Barents Shelf, the deposition of the Kapp Toscana Group was initiated in Early Ladinian represented by the Snadd Formation, while the deposition of the De Geerdalen Formation was initiated in the Carnian in the Svalbard Archipelago: thus the transition between the Sassendalen and the Kapp Toscana Group is time-transgressive due to the progradation from the southeast (Riis et al., 2008). By the mid Carnian the paralic deposits, associated with large delta plains and channels, covered the entire area from the eastern Barents Sea to the Svalbard Archipelago (fig. 3) (Riis et al., 2008). Also, a regional transgression divides the Snadd Formation in an upper and lower interval (Klausen et al., 2013).

Based on seismic interpretation, Glørstad-Clark et al. (2010) divided the Triassic successions into five seismic sequences. These sequences were bounded by maximum flooding surfaces, which could be traced regionally over large areas. Lack of evidence of a source area from the north or northwest, as suggested earlier, led Glørstad-Clark et al. (2010) to support the interpretation of Riis et al. (2008) of a major progradation from the east and southeast. Also, Klausen et al. (2013) stated that the sediment supply from the southeast must have been high in order to permit progradation in a depositional system with such high rates of subsidence.

A regional transgression in the Norian led to a renewed connection between Tethys and the Boreal ocean, and the sediment supply from the southeast waned (Worsley, 2008). Shallow marine and coastal environments developed over the entire Barents Shelf, and both the subsidence and sedimentation rates decreased due to this transgression (Worsley, 2008).
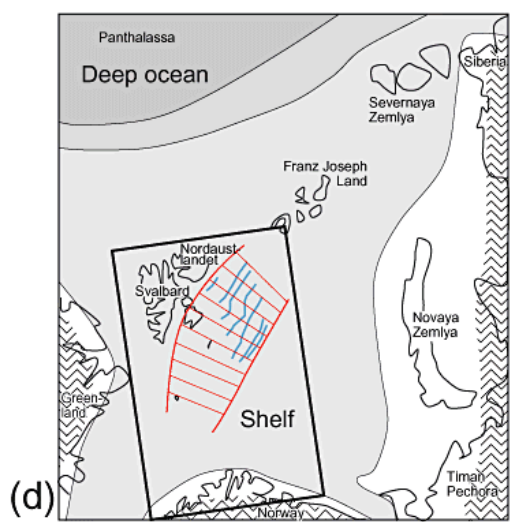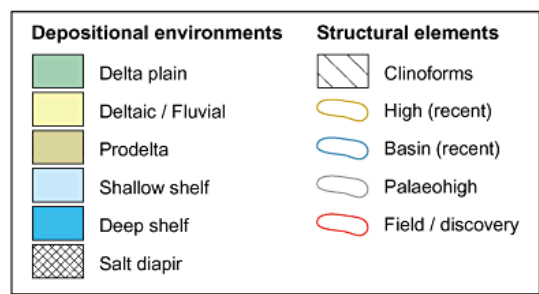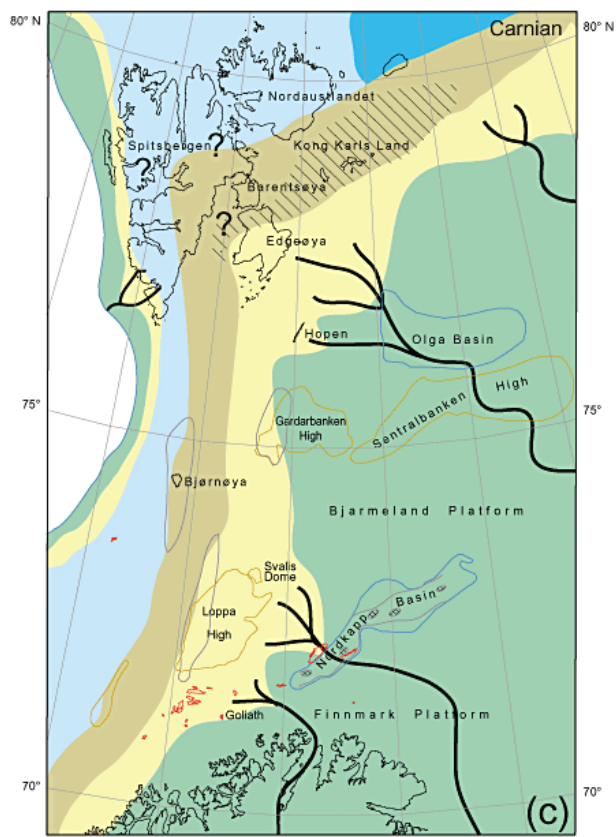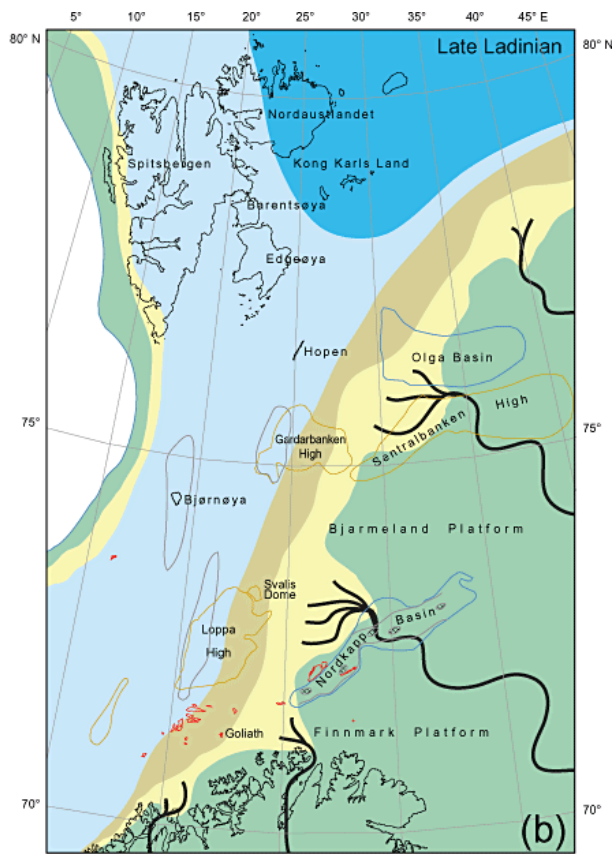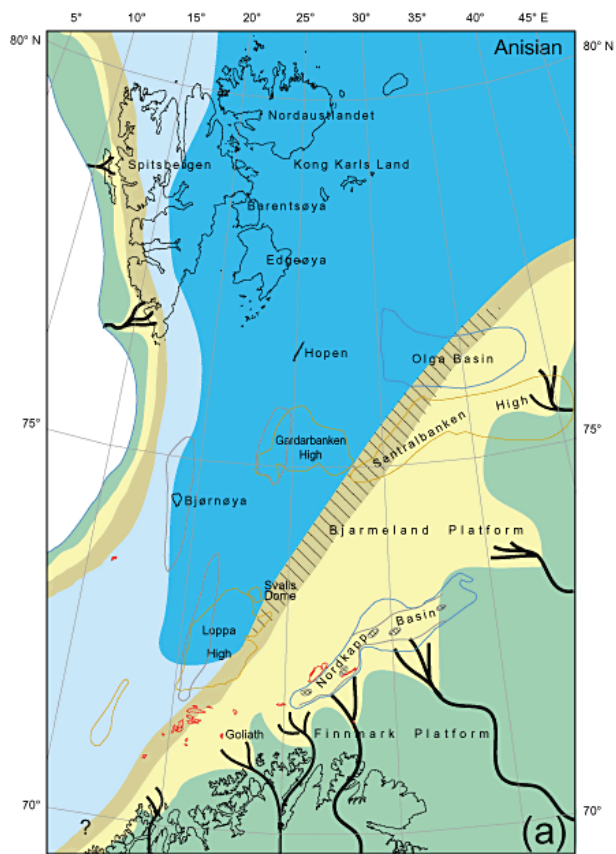
Figure 3: Evolution of the Barents Shelf, from (a) Anisian to (b) Late Ladinian to (c) Carnian, illustrating an extensive progradation from south-east and the development of delta plain and prodelta environment over the entire Barents Shelf. The position of Sentralbanken and Hopen is also shown (from Riis et al. (2008))

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3. Materials and Methods

3.1 Collection of Material

Core 7533/3-U-7 is a 200.31 m long shallow stratigraphic core drilled into the Sentralbanken High. The numbers 7533 in the core name refers to the latitudinal (75^0) and longitudinal (33^0) position of the core (fig. 1). The Sentralbanken core was drilled in 1998 by SINTEF Petroleum Research, contracted by the Norwegian Petroleum Directorate (NPD) (Riis et al., 2008). Seventeen samples were processed by SINTEF Petroleum Research, and Applied Petroleum Technology (APTEC) made thirteen additional palynological preparations from rock samples collected during the core-description/logging (table 3). Some differences were observed between the two sets of palynological samples, especially regarding the un-oxidized samples. Despite large diversity in preservation, none of the samples from the core were barren and complete counts were done for every sample.

A total of eight samples from the De Geerdalen Formation on Hopen were added to this study, where three of these were marked as barren. No counts or palynofacies estimates were done for the barren samples, but the few identifiable palynomorphs in these samples were recorded as present in the range chart. Pictures of the some of the different taxa recorded in this study are included in Appendix IV. Pictures of the same species were included in the plates, in order to see the preservational variations within a species.

3.2 Palynological Preparation

The samples were processed using standard palynological preparation techniques. The process starts with crushing the rock in order to increase the reaction surface during the subsequent steps (fig. 4). Hydrochloric acid (HCl) is then added to remove the carbonates in the rock sample. Methanol is often included in this step to reduce gas production during the reaction (dissolution). The next step is to neutralize the sample, so that the hydrochloric acid do not intervene with the further processes. Hydrofluoric acid (HF) is then added to the solution to remove any silicates from the sample. The solution is also neutralized after this process, which is especially important since hydrofluoric acid is highly dangerous. After this the sample is put in an ultrasonic bath. The purpose is to make the sieving easier, and prevent that organic matter clog the sieve. Additional treatments are oxidation (by using nitric acid (HNO_3)) to remove the undesired organic matter, and centrifuging to remove heavy minerals. Non-oxidized samples were also provided for the palynofacies analysis. Staining of the palynomorphs is sometimes done to make the observation of taxa easier, but this was not done for the samples provided for this study.
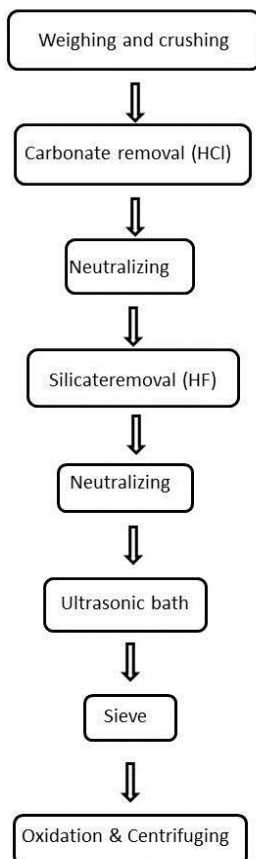

Figure 4: simplified illustration of the step-by-step preparation process (based on Wood et al. (1996))

3.3 Microscopy and Palynological Analyses

The most extensive work for this study was the palynological analysis, especially the identification of all the taxa needed for dating and palaeoenvironmental analysis. Triassic palynofloras are very rich and an extensive number of taxa were identified (Appendix I, II and III). 200 specimens were counted in every sample, except for three of the eight samples from Hopen that turned out to be almost completely barren. Spores, pollen, acritarchs and algae were included in the counts. Species recognized outside the counts were identified and marked with a plus sign in the range chart. This was especially important regarding the observation of acritarchs, since they were normally very scarce in the samples. For the identification of different taxa the papers from Bjærke and Manum (1977) and Scheuring (1974) was of particular relevance. Due to the fact that a lot of the original descriptions are in german, the paper from Jansonius and Hills (1976) was also of particular importance. The paper by Bonis et al. (2009) was also useful for this study. The papers from Klaus (1960) and Scheuring (1978) also included high quality plates, where the plates provided by Scheuring (1978) was especially useful for the pollen.

The preservation in the studied samples was variable, but identification on genus level (often species level) was generally possible. All the palynological results are presented in range charts, created in Stratabugs, in order to give a visual display of the recorded data (Appendix II and III). Since acritarchs were included in both the counts and the palynofacies estimates, their presence was listed in two separate columns in the range charts.

For the palynofacies analysis, the relative proportions of the different material were determined by visual estimations, which is a standard method for palynofacies. This method has the advantage of being faster than a normal count and would provide a sufficient overview of the relative proportions of the organic matter present. Ten fields of view were estimated per sample and the average was calculated. The material was divided in two main groups, amorphous organic material (AOM) and structured material (Tyson, 1995).

A Zeiss Axioplan transmitted light microscope was used for the counts and the palynofacies. The pictures were taken with a Zeiss-Axio imager.A2 Axio Cam ERc 5s. A microscope with UV-fluorescence was not available for this study, so a distinction between true amorphous matter and degraded structureless phytoclasts could not be made based on fluorescence. In

some cases it was possible to observe whether the amorphous organic matter was derived from a larger, structured particle, or if the organic matter consists of fragments of disjointed material which was collected in a structureless organic aggregate (real amorphous organic matter) (Tyson, 1995). This distinction is not always obvious, so in most cases the presumably structureless material was recorded to be of the phytoclast group because of the general high abundance of phytoclasts. A distinction between pollen and spores were not made for the palynofacies, since their relative abundances were available in the palynomorphs counts.

As noted above, two separate batches of samples collected at different times were included for core 7533/3-U-7. These seem to have some different characteristics, particularly in particle size, although the preparation method applied was supposed to be identical. The new samples have generally a lot of fine-grained, fragmented material, especially in the un-oxidized slides. One explanation to this, based on the information available, is that the laboratory used different sieve sizes for the two batches.

3.4 Palynofacies

Combaz first introduced the term palynofacies in 1964. He defined palynofacies as the total amount of acid-resistant organic matter recovered by standard palynological processing techniques using HCl and HF (cited from Batten (1996)). Since then there have been many modifications to this definition. E.g. Tyson (1995) defined palynofacies as the specific assemblage of palynological organic matter that reflects a specific depositional environment. There are many processes, such as climate and changes in sea level, which affect the preservation of the sedimentary organic matter during fossilisation. These factors are collectively termed taphonomy. The preservation is largely dependent on the amount of sporopollenin and chitin in the wall, but grain size and oxidation are also important factors (Batten, 1996).

Several schemes for classification of the palynofacies have been suggested. E.g. Bujak et al. (1977) divided the palynologiacl matter into four main groups: Phyrogen (non-woody material), Halogen (woody material), Melanogen (opaque material) and Amorphogen (structureless material). For this study a modified scheme from Tyson (1995) was used (table 1). Compared to Bujak et al. (1977), the scheme from Tyson (1995) is much more detailed. However, some simplifications were done on the scheme used for this study. In some cases the "constituent" was not relevant, and the organic matter was only recorded by its "source" (table 1). For example, only "Amorphous (AOM)" and "Amorphous resin" were used in the present study.

For descriptions and further information of the different organic matter the work of Tyson (1995) was mainly used, which made his classification scheme a natural choice for the palynofacies in this study. A brief introduction to some of the different types of organic matter follows below.

Table 1: classification of palynofacies (modified from Tyson (1995))

Category		Source	Constituent
Structured	Zooclasts	Zooplankton	Graptolite debris
			Arthropod debris
	Palynomorphs	Zoomorphs	Scolecodonts
			Tectin foraminiferal linings
			Chitinozoans
		Organic-walledphytoplankton (including meroplankton)	Prasinophyte phycomata
			Chronococcale cyanobacteria
			Chlorococcales: Botryococcales, hydrodictyales
			Dinocysts, Acritarchs, Rhodophyte spores
		Sporomorphs	Miospores: microspores, pollen
			Megaspores
	Phytoclasts	Macrophyte plant debris	Cuticle/epidermal tissue
			Cortex tissue
			Secondary xylem (wood) Gelified wood
			Charcoal Biochemically oxidized wood
		Fungal debris	Hyphae
Structureless	Amorphous (AOM)	Higher plant secretions	Resins
		Flocs Phytoplankton	Organic aggregates Faecal pellets
		Bacteria	Cyanobacteria/Thiobacteria
		Higher plant decomposition products	Humic cell-filling precipitates Humic extracellular precipitates

Cuticles are the outermost waxy covering of epidermal cells of leaves and stems of most plants, which protects the plant and reduces the water loss (Batten, 1996). Cuticles are characterised by the cellular structure, and are often thin pale yellow in colour.

Woody material is recognized by the patterns of thickening (cellular structure), as annular (seen as holes), spiral and repticulate, among others (Tyson, 1995). Wood particles are very common in palynofacies assemblages, but the amount of wood depends largely on how proximal/distal the source is (Batten, 1996).

"Gelified wood" is a term taken from Tyson (1995), described as homogenous and massive phytoclasts, where the cellular structure usually is completely destroyed. The distinction between gelified wood and "normal" wood is caused by diagenetic conditions and the type of the original tissue. Gelified wood is dark, nearly opaque, material, which looks almost like

coal-fragments. Gelified wood has, however, often a brown margin and a different outline than coal, such as usually a ruff margin with concoidal fractures (Tyson, 1995).

Acritarch means "of uncertain origin", but the majority of acritarchs are accepted as marine phytoplankton. Both acritarchs and dinoflagelaltes are usually more common in finer sediments, as with pollen and spores (Tyson, 1995).

Structureless organic material is referred to as amorphous organic matter (AOM). This type of organic matter normally dominate in sediments that accumulated in anoxic marine conditions, especially if the terrestrial input was low (Batten, 1996). The very nature of amorphous material makes it difficult to predict the source of amorphous organic matter. It is, however, stated by Tyson (1995) that carbon isotopic dating have proven that the typical AOM in marine fine-grained sediments have a source from phytoplankton or bacteria.

Fungal tissue consists of fragments of hyphae. Matter from this source is recognized by a thin, branching tabular structure (Tyson, 1995).

4. Results

4.1 Palynological Results

4.1.1 Core 7533/3-U-7

The preservation of the various groups of palynomorphs was variable, which sometimes made the interpretation to species level difficult. Samples with poor preservation includes the samples from 91.56 m, 50.50 m, 41.45 m and 39.26 m. Spores dominated all the samples, where the species *Deltoidospora* spp., *Leschikisporis aduncus*, *Dictyophyllidites mortonii*, *Calamospora tener* and *Apiculatisporis parvispinosus* were the most abundant species (Appendix II). An acme of the monolete spore *Leschikisporis aduncus* in the upper parts of the core was the most significant and characteristic change in the assemblages. Acritarchs were sporadically recorded in low numbers in samples from the lowermost 60 m of the core, and were completely absent up to sample 62.50 m. The four assemblages described below are reflecting changes in the recorded taxa. A complete list of samples is included in table 2.

Table 2: samples from core 7533/3-U-7. Additional samples marked with "2013"

	Depth in metres	Kerogen slide	Year processed
#30	2.05	K	
#29	5.80	K	2013
#28	16.23	K	
#27	21.60	K	
#26	27.80B	K	2013
#25	27.80A	K	2013
#24	29.30	K	2013
#23	30.47	K	
#22	39.26	K	2013
#21	39.89	K	2013
#20	41.45	K	
#19	50.50	K	2013
#18	53.41	K	
#17	54.00	K	
#16	62.50	K	
#15	72.06	K	
#14	77.10	K	
#13	87.50	K	2013
#12	91.56	K	
#11	94.40	K	
#10	113.94	K	
#9	141.71	K	
#8	151.75	K	2013
#7	157.48	K	
#6	164.60	K	2013
#5	164.70	K	
#4	169.90	K	2013
#3	175.95	K	2013
#2	187.60	K	2013
#1	200.31	K	

Assemblage 1

This assemblage was recorded from the two lowermost samples (200.31 m and 187.60 m).
The diversity was high in both samples and the preservation was moderate. *Dictyophyllidites mortonii, Deltoidospora* spp.*, Calamospora tener, Leschikisporis aduncus* and *Apiculatisporis parvispinosus* dominate this assemblage, where *Leschikisporis aduncus* was very common.
Chasmatosporites hians and *C*. *apertus* dominated the monosulcate pollen, but *Cycadopites* spp. was also common. *Triadispora* spp. *T. sulcata, T. suspecta* and *Striatoabieites* spp. were also recorded, but in low numbers.

Assemblage 2

This assemblage was recorded in samples between 175.95 m and 157.48 m. The diversity was relatively high in this assemblage, which was characterised by a high abundance of the bisaccate pollen group *Triadispora*, which is also more diverse than Assemblage 1. Species such as *Triadispora bella, T. boelchii, T. sulcata* and *T. suspecta* were recorded in Assemblage 2. This assemblage was, however, still dominated by *Dictyophyllidites mortonii, Deltoidospora* spp.*, Calamospora tener, Leschikisporis aduncus* and *Apiculatisporis parvispinosus*, and *Chasmatosporites* and *Cycadopites* spp. dominated the monosulcate pollen. The total number of the *Triadispora* group was variable, but remained relatively high up to 157.48 m (a total of five samples). *Aratrisporites* and *Kraeuselisporites* groups were generally present. The striate pollen *Striatoabieites* was recorded in sample 164.70 m. The monosulcate pollen *Eucommiidites microgranulatus* was recorded in sample 164.60 m, along with the trilete spore *Camarozonosporites rudis*.

Assemblage 3

This assemblage was recorded between 151.75 m and 72.06 m, a total of seven samples. The preservation was variable, but generally moderate to poor. A relatively high diversity was also recorded in the samples in this assemblage. Assemblage 3 differs from Assemblage 2 by rare or absent *Triadispora*. *Dictyophyllidites mortonii, Deltoidospora* spp.*, Calamospora tener, Leschikisporis aduncus* and *Apiculatisporis parvispinosus* dominate this assemblage, and *Cycadopites* spp. and *Chasmatosporites* dominated the pollen. Sample 151.75 m yielded the highest distribution and diversity of acritarchs of all the samples; with species such as *Veryhachium* spp., *Leiofusa cf. jurassica* and *Micrhystridium* spp. Striate pollen, as *Schizaeoisporites worsleyi, Striatoabieites* spp. and *Steevesipollenites* spp,, were also recorded in some of the samples in Assemblage 3.Other species recorded to various extents in this assemblage include *Protodiploxypinis verrucata*, *Schizaeoisporites worsleyi*, *Zebrasporites interscriptus, Thomsonisporites toralis*, *Limatulisporites limatulus, Tetrasaccus, Camarozonosporites rudis* and representatives of the group *Aratrisporites*. The group *Kraeuselisporites* was relatively common in two samples (113.94 m and 94.40 m) but was rare or absent in the other samples. *Camarozonosporites rudis* was common in sample 91.56 m, but usually rare to absent in the other samples. A slight increase in the number of *Triadispora* was recorded in the two uppermost samples in this unit (77.10 m and 72.06 m), but remained relatively rare.

Assemblage 4

Assemblage 4 is the uppermost assemblage in core 7533/3-U-7, recorded in samples from 62.50 m to 2.05 m. The samples in Assemblage 4 were generally well preserved, especially the samples from 30.47 m and 29.30 m. Assemblage 4 differs from Assemblage 1 to 3 by rapid changes in the taxa: an alternating dominance of *Leschikisporis aduncus*, *Apiculatisporis parvispinosus* and representatives of the group *Aratrisporites* (only recorded in one sample) characterise this assemblage. Thus, Assemblage 4 is defined by abundance peaks in the recorded number of monolete spores. *Dictyophyllidites mortonii, Deltoidospora* spp.*, Calamospora tener, Apiculatisporis parvispinosus* and *Leschikisporis aduncus* were the most prominent species in this assemblage. *Cycadopites* spp. and *Chasmatosporites* were common and dominated the pollen.

Leschikisporis aduncus dominated the assemblage in the first five samples (up to 39.89 m). The genus *Triadispora* remains rare to absent. This "sub-assemblage" was generally very homogenous, e.g. low diversity in species. Pollen was generally rare in this assemblage, though an increase in striate pollen was recorded in sample 62.50 m. The freshwater algae *Botryococcus* spp. was also relatively common in this sample.

A change in the assemblage was recorded in sample 39.89 m, marked by a huge drop in *Leschikisporis aduncus*. Bisaccates were still few, but *Triadispora* and *Protodiploxypinus* were recorded in low numbers. An increase in the diversity was also recorded, and species such as *Thomsonisporites toralis, Camarozonosporites laevigatus, C. rudis, Kraeuseligporites* spp.*, Cingulizonates* spp. *Rogalskaisporites cicatricosus* and *Aratrisporties* were recorded in low numbers in some of the samples. This assemblage was only recorded in two samples (39.89 m and 39.26 m).

A change was recorded in the assemblage from 30.47 m, marked by a "new" abundance peak of *Leschikisporis aduncus*. The diversity remained relatively high and the abundance of bisaccate pollen increased. *Triadispora* was more diverse, and *Striatoabieites* and *Protodiploxypinus* were recorded. Although an increase in bisaccate pollen was recorded, *Triadispora* remained relatively rare. The diversity remained high in this assemblage, and species such as *Rogalskaisporites cicatricosus, Anapiculatisporites spiniger* and *Steevesipollenites* were recorded.

Another huge drop in *Leschikisporis aduncus* was recorded in sample 27.80 m, where *Apiculatisporis parvispinosus* dominates. Very few bisaccates were recorded. *Schizaeoisporites worsle*yi was recorded and *Steevesipollenites* spp. was relatively common.

The diversity was relatively high, with species such as *Anapiculatisporites spiniger, Camarozonosporites laevigatus, C. rudis, Conbaculatisporites sp. A, Clathroidites* spp.*, Aratrisporites laevigatus* and *Thomsonisporites toralis*.

A change was recorded in sample 21.60 m marked by common *Camarozonosporites laevigatus* and and *Aratrisporites*. *Deltoidospora* spp.*, Apiculatisporis parvispinosus* and *Leschikisporis aduncus* dominate. The number of *Triadispora* increased, but was still relatively rare. *Protodiploxypinus* was also recorded. Sample 16.23 m was characterised by a high abundance of the *Aratrisporites* group, with species as *Aratrisporites laevigatus, A. macrocavatus and A, scabratus*. Bisaccates were nearly absent in this sample. The diversity in both samples (21.60 m and 16.23 m) was relatively low, but the acritarch *Micrhystridium* was recorded in both of them.

A change was recorded in sample 5.80 m characterised by a drop in abundance and diversity of *Aratrisporites*, and *Apiculatisporis parvispinosus* dominated again. Bisaccate pollen remained nearly absent, and the diversity remained relatively low.

Leschikisporis aduncus dominated again in the uppermost sample in the core (2.05 m). The diversity was still low, including bisaccates which were still few in numbers.

4.1.2. Hopen Section

The preservation in the samples from the De Geerdalen Formation on Hopen was moderate to poor. Also, three of the samples were almost completely barren (table 3). As with the samples from the Sentralbanken core, spores dominate all the samples from Hopen, especially *Deltoidospora* spp., *Leschikisporis aduncus*, *Dictyophyllidites mortonii*, *Calamospora tener* and *Apiculatisporis parvispinosus* (Appendix III). A possible end of a *Leschikisporis aduncus* acme is the most characteristic change in the assemblages from the Hopen material. Acritarchs were not recorded in the studied samples from Hopen herein. However, there have been recorded acritarchs in the lower parts of this section in previous studies (oral communication, Paterson 2014).

Table 3: samples from Hopen (Blåfjellet, south)

Sample	In metres above sea level	Kerogen slide	Barren
#8	132,5	K	x
#7	117	K	
#6	116	K	x
#5	110	K	x
#4	105	K	
#3	84	K	
#2	79	K	
#1	64	K	

Assemblage H1

This assemblage was recorded between 64.00 m and 105.00 m, a total of four samples. The diversity was generally low, with moderate to poor preservation. *Deltoidospora* spp.*, Dictyophyllidites mortonii, Calamospora tener* and *Leschikisporis aduncus* dominate assemblage H1, where *L. aduncus* is very abundant. Thus, this assemblage yields an acme of *Leshikisporis aduncus*. As with the samples from core 7533/3-U-7, *Chasmatosporites hians* and *Cycadopites* spp. dominate the pollen. *Triadispora, Protodiploxypinus* and *Striatoabieites* were present in low numbers. Species such as *Anapiculatisporites spiniger, Conbaculatisporites* spp.*, Duplexisporites problematicus, Punctatisporites fungosus,*

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Thomsonisporites toralis and *Aratrisporites* spp. were also recorded in low numbers. Sample 64.00 m yielded a relatively higher number of *Kraeuselisporites cooksonae.*

The samples from 110.00 m and 116.00 m were almost completely barren, but *Deltoidospora* spp.*, Dictyophyllidites mortonii, Calamospora tener, Leschikisporis aduncus* and *Chasmatosporites hians* were recorded.

Assemblage H2

Compared to assemblage H1 the diversity increases in Assemblage H2, which was only recorded in one sample from 117 m. This assemblage was characterised by a decrease in *Leschikisporis aduncus* and an increase in bisaccate pollen. *Deltoidospora* spp.*, Dictyophyllidites mortonii, Calamospora tener* and *Leschikisporis aduncus* still dominated the assemblage, where *Dictyophyllidites mortonii* was very abundant. *Chasmatosporites hians* and *Cycadopites* spp. still dominated the pollen, but representatives of *Triadispora, Striatoabieites* and *Protodiploxypinus* increase in abundance. *Triadispora* also increase in diversity, with species such as *T. boelchii, T. sulcata* and *T. verrucata*. In addition, the algae *Plaesiodictyon mosellaneum* was relatively common (recorded outside the count). Other species present include *Kraeuselisporites cooksonae, Anapiculatisporites spiniger, Conbaculatisporites* sp. A*, Clathroidites* spp, *Duplexisporites problematicus*, *Aratrisporites laevigatus* and *A. macrocavatus*.

Due to the fact that the overlying sample 132.5 m was barren, it is not possible to determine whether or not the changes recorded in Assemblage H2 are persistent. *Deltoidospora* spp.*, Dictyophyllidites mortonii, Leschikisporis aduncus* and *Chasmatosporites hians* were recorded in this sample.

4.2 Palynofacies Results

4.2.1 Core 7533/3-U-7

The palynofacies results recorded in samples from the Sentralbanken core are included in the range chart (Appendix II).

The samples between 200.31 m and 164.60 m (six samples) were dominated by wood particles. Secondary xylem (wood) and gelified wood alternates to dominate the total organic content (TOC). The lowermost sample (200.31 m) contained acritarchs and the algae *Crassosphaera* spp. (fig. 5). *Crassosphaera* spp. and fungal debris (fig. 5) are present in sample 175.95 m, but acritarchs were not recorded. Acritarchs are present in sample 164.70 m, along with *Botryococcus* spp. (fig. 5), *Crassosphaera* spp., cuticle tissue and fungal debris. There is also a small increase in sporomorphs. Fungal debris and *Crassosphaera* spp. remain present in sample 164.60 m, but acritarchs were not recorded. This sample was, however, among the samples that were prepared after the initial sampling, which contained more fragmented material than the other samples. This makes estimating the relative amounts of organic content somewhat uncertain.

A slight change in the palynofacies was recorded in sample 157.48 m. The total amount of wood, both gelified wood and secondary xylem decreases, and the amount of sporomorphs has increased significantly (27%). Acritarchs, *Botryococcus* spp. and *Crassosphaera* spp. were present, along with some cuticle tissue. The wood content increase again in the overlying sample (151.75 m) (dominated by gelified wood) and the amount of sporomorphs decreases: the palynofacies was again similar to the underlying palynofacies between 200.31 m and 164.60 m. Acritarchs were still present, and fairly common relative to other samples. Cuticle tissue (fig. 6) and *Crassosphaera* spp. are also recorded.

The palynofacies in sample 141.71 m were very similar to the underlying palynofacies (200.31 m – 164.60 m), but acritarchs were not present in any of these samples. The estimated amount of sporomorphs increased in the sample above (113.94 m), where *Crassosphaera* spp. and cuticle tissue were present. The sample was generally dominated by larger clasts of well-preserved woody material. The five overlying samples (up to sample 72.06 m) were still dominated by wood particles, only with variations in estimated amounts of gelified wood and secondary xylem (wood). *Botryococcus* spp. was present in most of them, and *Crassosphaera*

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spp. was present in the uppermost two. A lot of pyrite was present in sample 87.50 m, indicating anoxic conditions (Tyson, 1995).
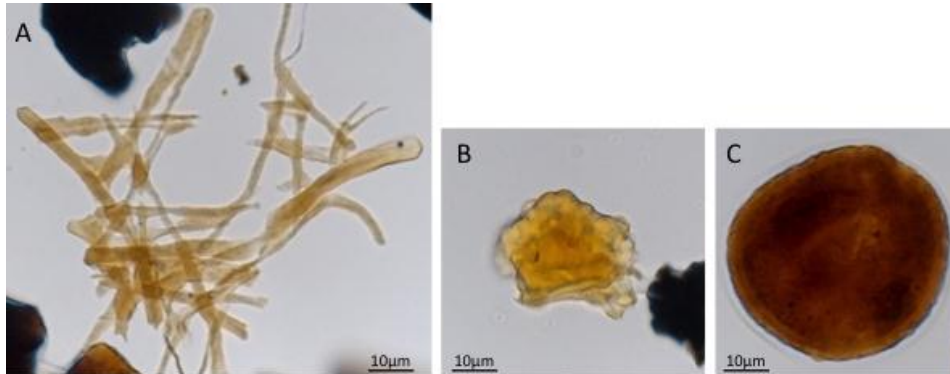

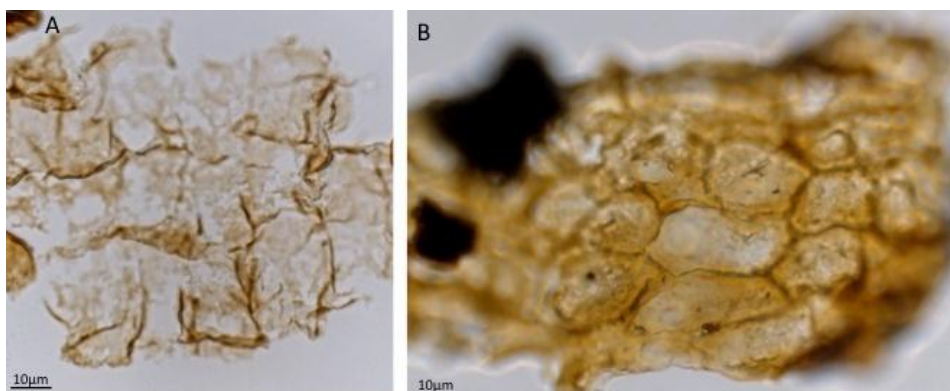Figure 5: (A) Fungal debris, (B) *Botryococcus* spp., (C) *Crassosphaera* spp.

Figure 6: (A) Leaf cuticle and (B) Cortex tissue

A change in the palynofacies was recorded in sample 62.50 m. Wood particles still dominated the TOC, but a relatively high amount of sporomorphs (20 %) was recorded. Cuticle tissue, *Botryococcus* spp., *Crassosphaera* spp. and fungal debris were recorded. Sporomorphs continue to increase in the overlying sample (54.00 m), where they dominate the palynofacies with an estimated amount of 60 %. *Botryococcus* spp. and cuticle tissue were present to a smaller extent. Wood particles dominate again in sample 53.41 m, but the estimated amount of sporomorphs remains relatively high (18 %). Cuticle tissue and *Botryococcus* spp. were present.

A change in the palynofacies was recorded in sample 50.50 m, where wood particles almost completely dominated the sample. This trend continued in the overlying sample (41.45 m),

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with an estimated value of 95 % gelified wood. Only secondary xylem and extremely few sporomorphs were recorded among the gelified wood.

A change was recorded in sample 39.89 m, marked by a huge drop in the estimated amount of gelified wood. Secondary xylem dominated the palynofacies, and both cuticle tissue and sporomorphs increased.

A change in the palynofacies was recorded in sample 30.47 m, marked by a drop in wood content and an increase in sporomorphs. Wood particles still constitute the majority of the TOC, but an estimated amount of 23 % was recorded for the sporomorphs. Cuticle tissue and cortex tissue (fig. 6) were also recorded. In the overlying sample (29.30 m) sporomorphs, especially spores, dominated the palynofacies, with an estimated value of 57 %. Wood particles account for the remaining amount of organic matter, dominated by gelified wood. Acritarchs were not recorded in these samples.

In sample 27.80 m the palynofacies change again. This change was characterised by a drop in sporomorphs to 11 %, and the palynofacies was again dominated by wood material. Wood material completely dominated the two overlying samples (up to 16.23 m), and only smaller amounts of sporomorphs were recorded. *Botryococcus* spp. was recorded in both samples, and the acritarch *Micrhystridium* in sample 21.60 m and 16.23 m.

In sample 5.80 m wood particles still dominated the palynofacies, but the estimated value of sporomorphs increased to 18 %. The amount of sporomorphs remained relatively high in the uppermost sample (2.05 m) from core 7533/3-U-7. In this sample the amount of secondary xylem (wood) and gelified wood was nearly the same in.

4.2.2 Hopen Section

The palynofacies results recorded from the De Geerdalen Formation on Hopen (Blåfjellet) are included in the range chart (Appendix III). Even though un-oxidized samples were provided, the three samples discussed earlier were still barren.

The lowermost sample (64 m) was dominated by secondary xylem (wood), but compared to the samples from the core the estimated amount of sporomorphs was relatively high (19 %). The amount of cuticle tissue was also relatively high. In sample 79 m the amount of sporomorphs increasd (28 %) and the amount decreased again in the overlying sample (17 %). These variations in TOC are not likely to resemble any major changes. The increase and decrease in sporomorphs happens on the expense of gelified wood, so secondary xylem (wood) still dominated the palynofacies in these samples.

A minor change in the palynofacies was recorded in sample 105 m. The amount of sporomorphs increased to 27 %, and continued to increase in the overlying sample (117 m) to 36 %. The amount of cuticle tissue also increased in these samples. Secondary xylem dominated in both samples, so the increase in sporomorphs and cuticle tissue still seems to be at the expense of gelified wood.

The samples from 110 m, 116 m and 132.5 m were almost completely barren, so no estimated values were done for these. Sporomorphs, secondary xylem (wood) and gelified wood were present in all of them.

4.3 Core/log Description

4.3.1 Core 7533/3-U-7

The core was divided into five main units (A-E) on the basis of the facies and the interpreted depositional environment. Seven facies were described for this core (Table 4), with variations in grain size, degree of bioturbation, presence of siderite, organic content, etc.

The facies in Table 4 are listed according to the energetic conditions during deposition, from highest (facies 1) to lowest energy (facies 7). For the description and interpretation of the facies the work of Riis et al. (2008) and Klausen et al. (2013) was of particular relevance. Though cross-bedded to rippled sandstone (facies 2) is a very broad description, it will be sufficient herein since the sedimentology is just a secondary part of this study. The sedimentological log of core 7533/3-U-7, with listed facies and units, is included in this chapter (fig. 10), and a simplified version of the log is included in the range chart (Appendix II).

Table 4: List of facies, ordered in decreasing energetic conditions

Figure	Facies	Description	Interpretation
7	1	Intraformational conglomerate	Channel
7	2	Cross-bedded to rippled sandstone	Channel
8	3	Muddy sandstone	Floodplain, overbank deposits
8	4	Mudstone with sandstone lamina and/or lenses	Floodplain, interdistributary bay
8	5	Mudstone (usually bioturbated or with high organic content)	Floodplain, interdistributary bay
9	6	Structureless, pale yellow clay	Palaeosol
9	7	Coal	Mire
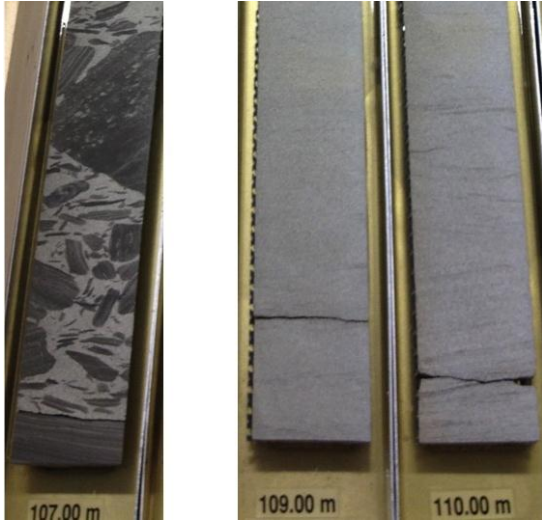
Figure 7: The two channel facies: Intraformational conglomerate (to the left) and cross-bedded to rippled sandstone (to the right)
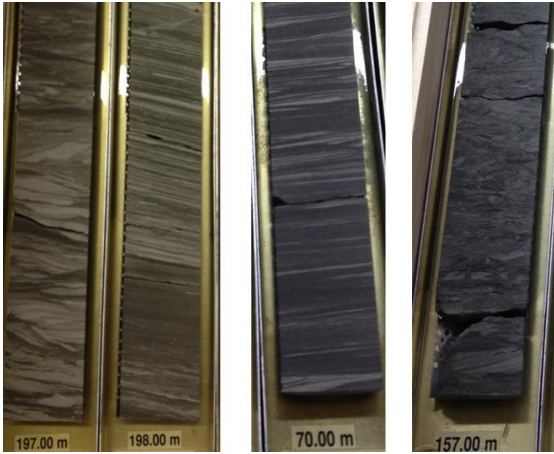
Figure 8: the three floodplain facies: Muddy sandstone (to the left), mudstone with sandstone lamina (in the middle) and bioturbated mudstone (to the right)

Figure 9: Palaeosol (facies 6) to the left and coal (facies 7) to the right

Unit A is the deepest unit between 200 m and 185.60 m (fig. 10). This unit was characterised by a very high mud-content, and consisted of alternating heterolithic beds of sandstone with mud flaser (facies 3: muddy sandstone) and mudstone with sandstone lamina and lenses with a very low sand content (facies 4). Bioturbation was generally present. Coal-fragments and organic rich mudstone were also recorded in this unit, along with an organic rich, partly coalified, mudstone.

Unit B was recorded between 185.60 m and 148.00 m (fig. 10). The transition to this unit is easily recognised by the appearance of siderite nodules and siderite cementation in a muddy sandstone, overlying a sharp contact. Unit B contains alternating beds of facies 1, 3 and 4. Soft sediment deformation is present between 172.00 m and 175.00 m. This unit was also generally highly bioturbated, especially in the upper parts of the unit (between 161 m and 152 m), and some places the primary sedimentary structures were completely destroyed. Burrows were also present in this unit, but mainly constrained to the more fine-grained muddy parts of the unit.

Unit C was recorded between 148.0 m and 112.20 m (fig. 10). The transition to this unit is marked by a prominent erosional contact and a large increase in grain size. Unit C only contained beds of facies 2 and 3. This unit consist largely of generally thick beds of fine to medium grained sands. The uppermost 12 meters of sandstone-beds contain a lot of fine-grained siderite. The mud-content was generally very low in this unit; facies 4 was only sporadically recorded in relatively thin beds.

Unit D was recorded between 112.20 m and 62.20 m (fig. 10). This unit showed a more rapid change in facies than the underlying units, and comprised some fining upwards sequences, e.g between 106 m and 101 m: intraformational conglomerate (facies 1) gradually passes to a mudstone with sandstone lamina and lenses (facies 4). Alternating beds of facies 1, 2, 3, 4, and 5 were present in this unit, which contained a much smaller amount of sand than the underlying unit C. Facies 1, 2, 3 and 4 alternate, with varying extent, up to 95.00 m. The boundaries are usually sharp, and appear about every 20-40 cm. A bed of calcite-cemented sandstone was also recorded in this succession. From 95.00 m a 33 m thick succession comprising facies 4 continued to the top of this unit. Bioturbation was generally lacking in this unit, but soft sediment deformation was sporadically present in the thick uppermost bed

of facies 4. Burrows were recorded between 63.00 and 62.60 m, and roots were present in the uppermost 10 cm of this unit (62.50 m).

Unit E is the uppermost unit of the core, recorded between 62.20 m and 01.63 m (fig. 10). This unit was even more chaotic than the underlying unit D, containing several, rapidly alternating facies. This unit containd rapidly shifting beds of facies 2, 3, 4, 5, 6 and 7, i.e. every facies listed in table 2, except for intraformational conglomerate (facies 1). The degree of bioturbation was generally high, but variable. Burrows appear frequently, especially in the finer grained, mud-rich parts of the unit. Roots and coal-fragments also appear often in this unit. Siderite nodules were sporadically recorded in facies 2. The organic content was usually high in facies 5.
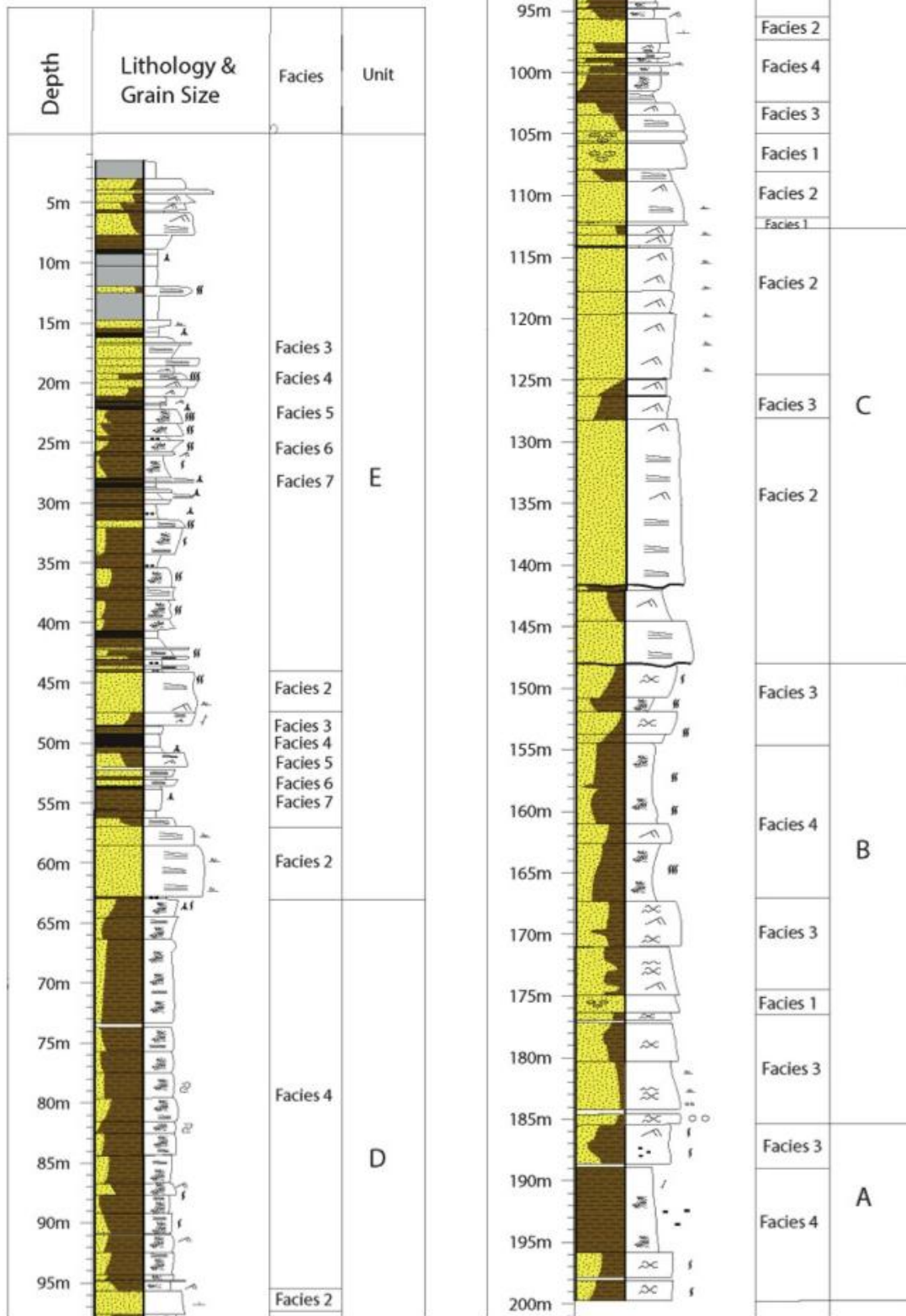
Fig. 10: log of core 7533/3-U-7. Because of the great length of the core, the log had to be broken up and simplified. Logged in scale 1:100

4.3.2 Hopen Section

Since no further descriptions were provided along with the log, no detailed observations can be described. However, the section contains several coarsening upwards units with relatively thick intervals of finer sediments overlain by thinner beds of rippled sandstone (both wave and current ripples) (fig. 11). Hummocky bedding is also recorded in two layers. Roots are present in some intervals, along with a generally low degree of bioturbation and siderite nodules in one layer.
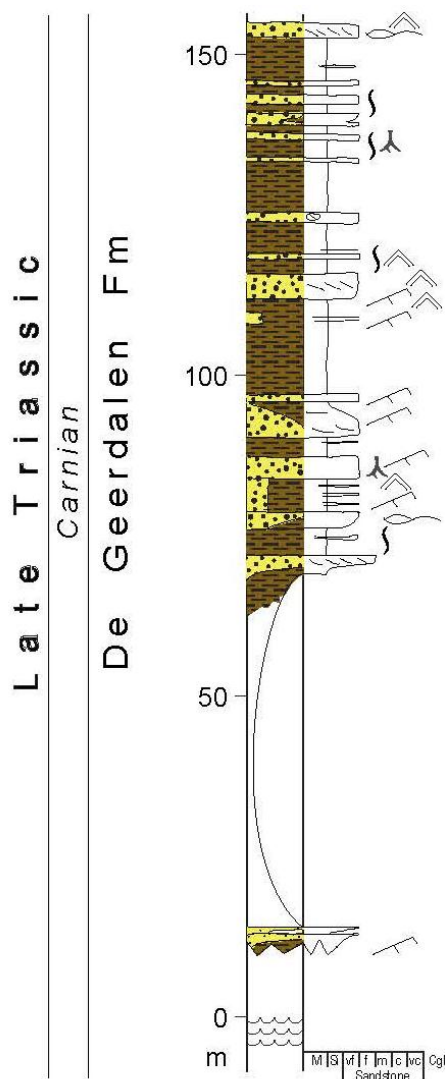
Fig. 11: Log of the De Geerdalen Fm. Blåfjellet, south (Hopen). Modified from Terje Solbakk, Bjørn Anders Lundschien, Mike Charnock (2011)

5. Discussion

5.1 Discussion of the Palynological Results

As described in chapter 4.1 the most characteristic feature in the assemblages recognized from the Snadd Formation in core 7533/3-U-7 and the De Geerdalen Formation on Hopen was the acme of *Leschikisporis aduncus*. This acme was recorded in Assemblage 4 from the Sentralbanken core and Assemblage H1 from Hopen. Similar acmes have been described by several authors from the Barents Sea area and Hopen, including Vigran et al. (2014), Hochuli and Vigran (2010), Paterson and Mangerud (submitted), Ask (2013), Nagy et al. (2011), Hochuli et al. (1989) (Assemblage D and E) and Bjærke and Manum (1977). Most of these were interpreted to be of Carnian age. The changes recorded in Assemblage 4 fluctuate and appear inconsistent, and the mainly quantitative variations are not believed to reflect any major change in the palynofloral assemblages. Thus, the assemblages recorded from the entire interval are regarded as one overall assemblage, only reflecting smaller changes in the depositional environment.

A schematic correlation of previous palynological work from this region is included (table 5 and 6). Below is a comparison with the recorded assemblages from the present study with all the relevant published literature. The range charts are also included in this chapter (fig. 12 and 13). See Appendix II for a complete range chart of core 7533/3-U-7.

Table 5: Correlation of previous palynological work

Stage/age	Hochuli et al. (1989)	Paterson and Mangerud (submitted)	Vigran et al. (2014)	Vigran et al. (1998)	This study
Rhaetian	A	*Rogalskaisporites ambientis*	*Ricciisporites tuberculatus*		
Norian	B_1	*Limbosporites lundbladii - Quadraeculina anellaeformis*	*Limbosporites lundbladii*		
	B_2	*Rhaetogonyaulax rhaetica*			
		Classopollis torosus			
Carnian	C	*Protodiploxypinus spp.*	*Rhaetogonyaulax spp.*		?H2
	D E	*Leschikisporis aduncus*	*Aulisporites astigmosus*		A1 - A4 & H1
	F				
Ladinian	G		*Echinitosporites iliacoides*		
	H				
	I			Svalis-8	

The assemblages recorded from the two studied sections can be correlated with the Carnian assemblages of Hochuli et al. (1989). The gymnosperm pollen *Aulisporites astigmosus* is believed to have its earliest occurrences in the Early Carnian Assemblage F (Hochuli et al., 1989). This assemblage was also calibrated with an ammonite dating (*Stolleites tenuis* zone) from the lower part of the Tschermakfjellet Formation (Hochuli et al., 1989), which indicates that an age older than Early Carnian is unlikely for the Sentralbanken core and makes the age interpretation more reliable. Other important species recorded in the present study from the Sentralbanken core include *Camarozonosporites rudis, Triadispora verrucata, Chasmatosporites* spp., *Schizaeoisporites worsleyi, Striatoabieites balmei, Thomsonisporites toralis,Ovalipollis ovalis,* and *Kraeuselisporites cooksonae* (fig. 12). Of these species *Camarozonosporites rudis, Triadispora verrucata, Chasmatosporites* spp., *Thomsonisporites toralis,Ovalipollis ovalis* and *Kraeuselisporites cooksonae* were recorded in the samples from Hopen (fig. 13). All these have also been recorded in Carnian successions in the Barents Sea by Hochuli et al. (1989) and Vigran et al. (2014). The First Appearance Datum (FAD) of *Camarozonosporites rudis* and *Ovalipollis ovalis* was also recorded in the Carnian (Assemblage zone II) by Cirilli (2010).

Fig. 12: Modified range chart of core 7533/3-U-7

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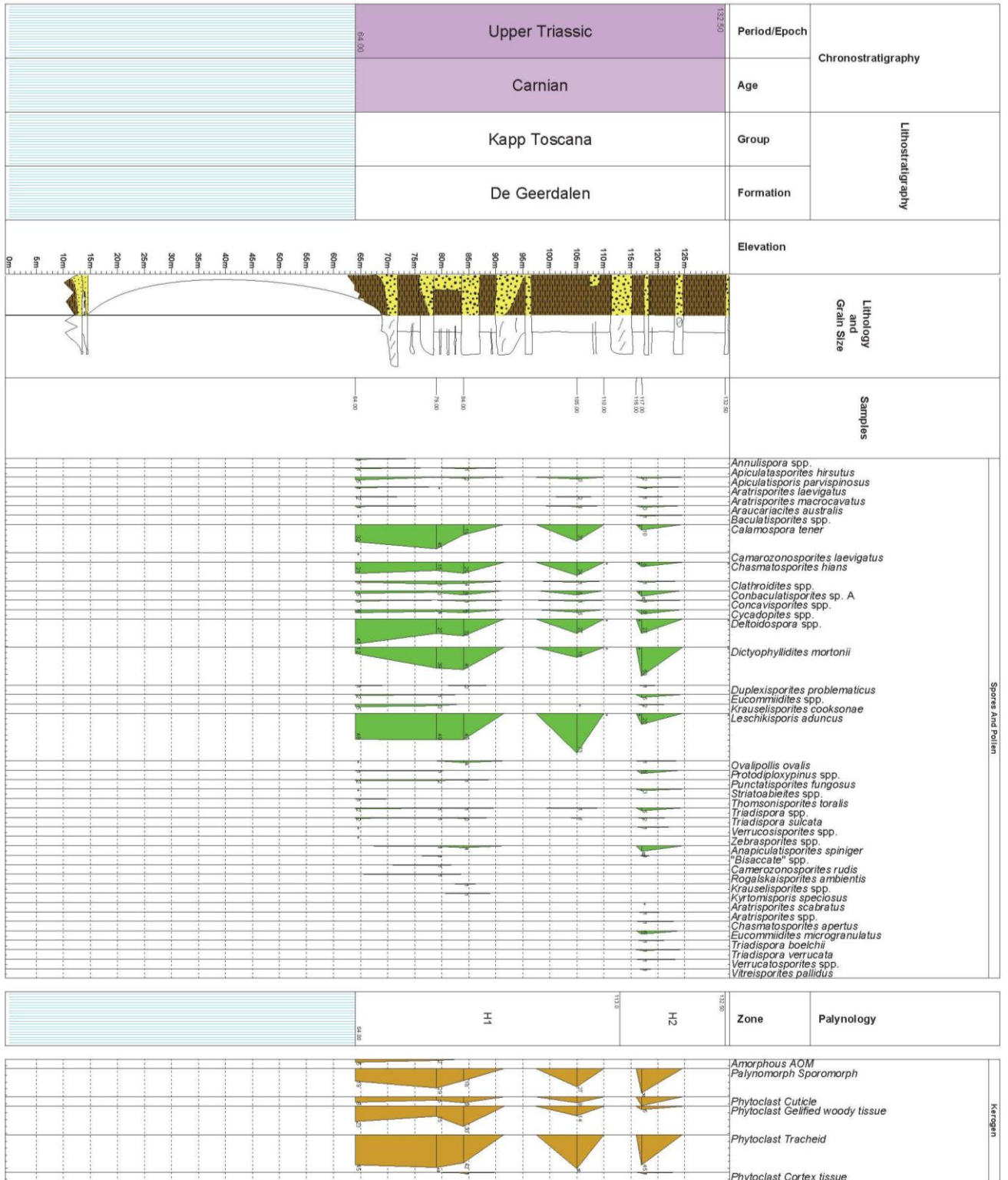
Fig. 13: Range chart of Hopen (Blåfjellet, south)

A total of four assemblages (C – F) were described from the Carnian in the Barents Sea area by Hochuli et al. (1989). Their youngest Carnian assemblage (Assemblage C) is characterised by the first down-hole occurrence of *Pseudozonalasporites summus, Schizaeoisporites worsleyi, Semiretrisporites sp. 1, Striatoabieites balmei, Succinctisporites grandior, Thomsonisporites toralis* and *Triadispora verrucata* (Hochuli et al., 1989). *Schizaeoisporites worsleyi, Striatoabieites balmei, Thomsonisporites toralis* and *Triadispora verrucata* were also recorded in this study, indicating a pre-Norian age. Assemblage C is characterised by a dominance of conifer pollen, especially *Protodiploxypinus*, while spores decrease in number and diversity. A dominance of conifer pollen was, however, not recorded in this study, suggesting that the recorded assemblages predates Assemblage C of Hochuli et al. (1989). The exception might be the uppermost assemblage from Hopen (Assemblage H2), which may correlate with Assemblage C (see discussion below).

The middle Carnian Assemblage D and E of Hochuli et al. (1989) is characterised by the first down-hole appearance of *Aulisporites astigmosus, Duplicisporites granulatus, Ilinites chitinoides, Infernopollenites sulcatus, Kraeuselisporites cooksonae, Kuglerina meieri, Triadispora plicata* and *Uvaesporites gadensis*. Amongst these species, only *Aulisporites astigmosus* and *Kraeuselisporites cooksonae* were recorded in the samples from the Sentralbanken core, and only *Kraeuselisporites cooksonae* were recorded from Hopen. Assemblage D is, as also is the case for Assemblage C, dominated by conifer pollen like *Triadispora, Brachysaccus* and *Ovalipollis* (Hochuli et al., 1989). This is in contrast to the present study where spores largely dominate all the samples. However, *Leschikisporis aduncus* was described as one of the common spores in assemblage D (Hochuli et al., 1989). Common *Leschikisporis aduncus*, along with the presence of *Aulisporites astigmosus* and *Kraeuselisporites cooksonae*, correlates with this study (*Aulisporites astigmosus* was not recorded in the samples from Hopen). It is important to note that Hochuli et al. (1989) did not include their quantitative data.

A down-hole decrease in the number of *Protodiploxypinus* was recorded by Hochuli et al. (1989) in their assemblage D. It is therefore interesting to note that low numbers of *Protodiploxypinus* was recorded throughout core 7533/3-U-7, with a slight increase upwards in the succession. This could indicate that the core represents a stratigraphically older interval compared to Assemblage D. Assemblage E differs from assemblage D only by a decrease in the number of *Ovalipollis*, while *Triadispora* and *Leschikisporis* dominate the assemblage

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(Hochuli et al., 1989). Although a dominance of *Triadispora* was not recorded in this study, the group appear more common in the lower parts of the core (assemblage 2) and *L. aduncus* is common to abundant in most samples from the Sentralbanken core and from Hopen. The similarities with Assemblage D and E to (Hochuli et al., 1989) suggests a middle Carnian for the described Assemblages 1 - 4 from core 7533/3-U-7 and Assemblage H1 described from Hopen (table 5).

Assemblage F of Hochuli et al. (1989) is characterised by the first down-hole appearance of *Angustisulcites klausii, Discisporites psilatus, Podosporites amicus, Sellaspora rugoverrucata, Triplexisporites playfordii* and *Voltziaceaesporites heteromorphous*. None of these species were recorded in the present study (fig. 12 and 13). This strongly supports that the recorded assemblages in the present study post-dates their Assemblage F. In addition, the youngest occurrences of *Echinitosporites iliacoides* and *Retisulcites perforates* occur in the Late Ladinian assemblage G of Hochuli et al. (1989): neither of which were recorded in any of the assemblages in this study (fig. 12 and 13). This strengthens the interpretation of an age younger than the Late Ladinian.

According to Hochuli et al. (1989) the Norian assemblage B-2 mainly contains the same species also present in their Rhaetian assemblages. The presence of the following species is, however, not recorded in the Rhaetian by Hochuli et al. (1989): *Leschikisporis aduncus, Protodiploxypinus gracilis, Striatoabieites aytugii, Triadispora* spp. and *Plaesiodictyon mosellanum* (green algae), all of which are recorded in samples from core 7533/3-U-7 and Hopen (fig. 12 and 13). Other characteristic of Assemblage B2 was the presence of the dinoflagellate cysts *Heibergella asymmetrica, H. salebrosacea* and *Rhaetogonyaulax arctica* (Hochuli et al., 1989). None of these marine dinoflagellate species was recorded from the Hopen samples nor from the core, which indicates that the sections studied herein predate the distinct Norian transgression.

As discussed above, the abundance peak of the monolete spore *Leschikisporis aduncus* is the most prominent trend in the assemblages from the Sentralbanken core and Hopen (fig. 12 and 13). A similar abundance peak was also described by Hochuli and Vigran (2010). Based on the assemblages described by Hochuli et al. (1989), five floral phases (11 to 15) were described for the Carnian (fig. 14) by Hochuli and Vigran (2010). The earliest Carnian phase (11) is dominated by non-taeniate bisaccates, including common specimens of *Brachysaccus* and representatives of *Triadispora* and

Angustisulcites (Hochuli and Vigran, 2010). This might be correlated with the slight increase of *Triadispora* recorded in Assemblage 2 in the lower parts of the Sentralbanken core (fig. 12). Trilete and monolete spores increase in number in the upper part of "Floral Phase 11", and continue to increase in phase 12 (middle Carnian) where monolete spores, such as *Leschikisporis*, dominates (fig. 14) (Hochuli and Vigran, 2010). "Floral Phase 12" may thus be correlated with the *Leschikisporis aduncus* acme recorded in the upper parts of the core (assemblage 4) and Assemblage 1 from Hopen. During the middle Carnian (phase 13 and 14) smooth trilete spores continue to increase, along with non-taeniate bisaccate pollen (Hochuli and Vigran, 2010). The similarities with floral phase 12 of Hochuli and Vigran (2010) suggest a mid Carnian age for core 75533/3-U-7 and the Hopen Assemblage H1 .

Assemblage G, F, E and D of Hochuli et al. (1989) were all included in the "*Aulisporites astigmosus* Composite Assemblage Zone" of Vigran et al. (2014). This assemblage is distinguished based on the first occurrence of *Aulisporites astigmosus*, which was recorded in low numbers in the Sentralbanken core. An increase of smooth trilete spores, including *Deltoidospora* and *Calamospora*, along with abundance peaks of *Leschikisporis aduncus* was also described as characteristic for the "*Aulisporites astigmosus* assemblage" (Vigran et al., 2014). This correlates with the recorded assemblages 1 to 4 from core 7533/3-U-7 and assemblage H1 from Hopen (see table 5 and fig. 12 and 13). The "*Aulisporites astigmosus* Assemblage" was assigned an Early to mid Carnian age (Vigran et al., 2014). Also, they considered a possible earliest Carnian assemblage zone based on the co-occurrence of *Echinitosporites iliacoides* and *Aulisporites astigmosus*. In their study a preliminary analysis of core 7533/3-U-7 was included. Without quantitative data, they assigned an early Carnian age for the Sentralbanken core (Vigran et al., 2014). However, for the present study of core 7533/3-U-7, thirteen additional samples were provided to improve the resolution and, quantitative data was gathered (complete counts were done for all the samples). Quantitative analysis has enabled a more precise age dating for the Sentralbanken core. The similarities with the "*Aulisporites astigmosus* assemblage" and the lack of *Echinitosporites iliacoides* strengthens the argument for a middle Carnian age for Assemblage 1-4 and Assemblage H1 recorded in this study.
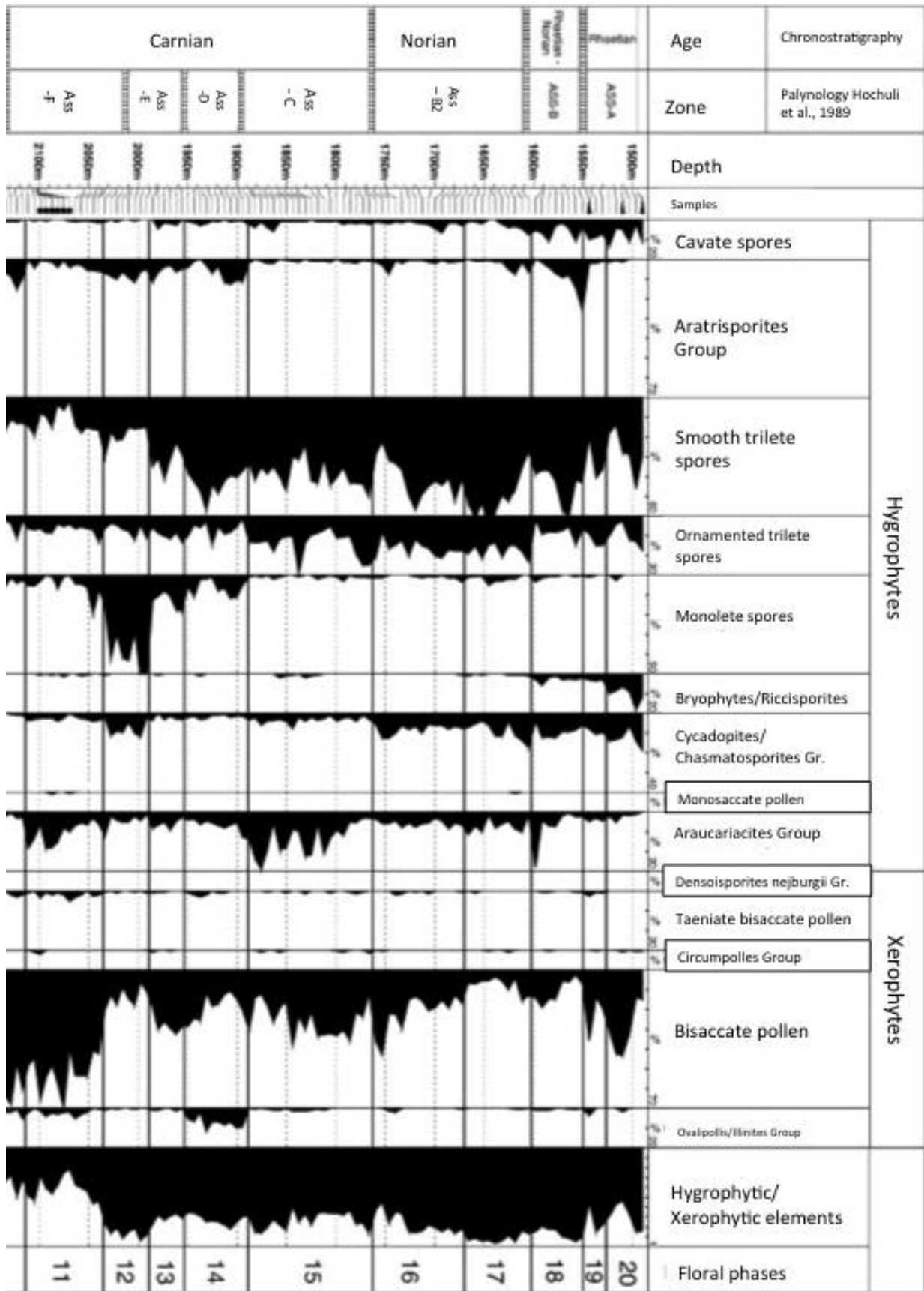
Fig. 14: The relative proporitons of different taxa and groups during the late Triassic (modified from Hochuli and Vigran (2010))

The discussion above mainly dealt with previous regional palynological studies from the Barents Sea area. Below follows a discussion comparing the assemblages recorded in this study with previous palynological studies from Hopen.

Six palynological assemblages, ranging from mid-late Carnian to late Rhaetian age, were described by Paterson and Mangerud (submitted) for the successions on Hopen. Their study comprised the full succession, including the De Geerdalen, Flatsalen and Svenskøya Formation. Their two oldest assemblages were of particular relevance for this study: the *Leschikisporis aduncus* assemblage and the *Protodiploxypinus* spp. assemblage (table 5). In addition to a dominance of the monolete spore *L. aduncus*, the "*Leschikisporis aduncus* assemblage*" is characterised by common *Apiculatasporites hirsutus, A. lativerrucosus, Apiculatisporis parvispinosus, Aratrisporites fischer* and *A. scabratus* (Paterson and Mangerud, submitted). With the exception of *Aratrisporites fischer*, all these species were recorded in the present study. Other species recorded in their *Leschikisporis aduncus* assemblage include *Camarozonosporites rudis, Conbaculatisporites* spp.*, Dictyophyllidites mortonii, Duplexisporites problematicus, Kraeuselisporites cooksonae, Zebrasporites interscriptus, Araucariacites australis, Chasmatosporites* spp.*, Cycadopites* spp.*, Eucommiidites* spp.*, Ovalipollis Ovalis* and *Triadispora verrucata*, all of which were recorded in this study (fig. 12 and 13). They also recorded *Aulisporites astigmosus* which were present in the Sentralbanken core. Based on correlations with assemblage D and E of Hochuli et al. (1989), Floral Phase 12 of Hochuli and Vigran (2010) and the *Aulisporites astigmosus* Zone of Vigran et al. (2014), Paterson and Mangerud (submitted) interpreted the *Leschikisporis aduncus* assemblage to be of mid-late Carnian age.

Table 6: Comparison of the "*Leschikisporis aduncus* assemblage" and "*Protodiploxypinus* spp. Assemblage" with previous studies from Hopen (Paterson and Mangerud, submitted)

Lithostratigraphy	* Smith et al. 1975	* Bjærke & Manum 1977	Ask 2013	Paterson and Mangerud (submitted)
Svenskøya Formation	'P. crenulatus - L. lundbladii'	/////	/////	Rogalskaisporites ambientis
			L-3	Q. anellaeformis - L. lundbladii
Flatsalen Fm.	'R. rhaetica'	'R. rhaetica'	/////	Rhaetogonyaulax rhaetica
Slottet Bed		'forams & microplankton'		Classopollis torosus
Hopen Mbr.	'Kyrtomisporis speciosus'	'P. radiatus - S. worsleyi'	L-2b	Protodiploxypinus spp.
			L-2a	
De Geerdalen Formation	/////	/////		
	'Equisetosporites chinleana'	'Leschikisporis aduncus'	L-1	Leschikisporis aduncus
SEA LEVEL				

A high abundance of gymnosperm pollen characterise the "*Protodiploxypinus* spp. Assemblage" of Paterson and Mangerud (submitted), which was assigned a latest Carnian age. This assemblage is characterised by a high abundance of *Protodiploxypinus* spp., in addition to presence of *Araucariacites australis, Aulisporites astigmosus, Chasmatosporites* spp., *Cycadopites* spp., *Eucommiidites* spp., *Illinites chitinoides, Ovalipollis ovalis, Triadispora verrucata* and *Vesicaspora fuscus* (Paterson and Mangerud, submitted). Of these taxa *Protodiploxypinus* spp., *Araucariacites australis, Chasmatosporites* spp., *Cycadopites* spp., *Eucommiidites* spp., *Ovalipollis ovalis* and *Triadispora verrucata* were also recorded in Assemblage H2 (fig. 13), supporting a correlation with their "*Protodiploxypinus* spp. Assemblage". The freshwater algae *Plaesiodictyon mosellanum* was also recorded relatively common in sample 117 m (but outside the count), a feature also described in the "*Protodiploxypinus* spp. Assemblage". This suggests a latest Carnian for Assemblage H2. However, the fact that this is based on one sample makes it uncertain whether this is the base of the dominance of conifer pollen or just represents a variation within the previously recorded assemblage (H1). In addition to Hochuli et al. (1989) and Paterson and Mangerud

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(submitted), an abundance peak of *Protodiploxypinus* was also described in the upper part of the "*Aulisporites astigmosus* Composite Assemblage Zone" of Vigran et al. (2014). High abundance of the genus *Protodiploxypinus* was also recorded in "Phase 15" of Hochuli and Vigran (2010) (fig. 14), which was assigned a late Carnian age. A common occurrence of *Araucariacites* and *Chasmatosporites* was also described in this phase of Hochuli and Vigran (2010), which was also recorded in assemblage H2 of the present study.

Previous palynological work on Hopen includes Smith (1974) and Bjærke and Manum (1977). Based on the recorded presence of species such as *Camarozonosporites rudis*, *Kraeuselisporites cooksonae*, *Duplexisporites* sp., *Aratrisporites* spp., *Ovalipollis ovalis*, *Paracirculina* sp. and *Duplicisporites* sp, Smith (1974) suggested a general Late Triassic age, possibly Carnian, for the Iversenfjellet Formation (now De Geerdalen Fm.). With the exception of *Paracirculina* sp. and *Duplicisporites* sp., all of these species were recorded in various numbers in the assemblages in the present study (fig. 12 and 13). However, based on the recorded presence of *Granuloperculatipollis, Eucommidites, Chasmatosporites* and *Riciisporites*, along with the absence of typical Carnian taxa such as *Camerosporites*, *Duplicisporites* and *Echinitosporites*, Smith et al. (1975) did not rule out a post-Carnian age for the entire Iversenfjellet Formation. However, a post-Carnian age for the De Geerdalen Formation is, based on present knowledge, rejected. The assemblages in the present study may thus correlate with the assemblage recorded by Smith (1974) from the De Geerdalen Formation. A similar correlation was suggested by Paterson and Mangerud (submitted) for their "*Leschikisporis aduncus* assemblage" (Table 6).

An acme of *Leschikisporis aduncus* was reported by Bjærke and Manum (1977) in a sample taken from a coal layer from the De Geerdalen Formation on Iversenfjellet (Hopen). Another sample from a shale layer in the same horizon also gave a high number of *L. aduncus*, but also yielded a higher diversity with species such as *Colpectopollis ellipsoideus*, C. *Laricoidites* and *Psophosphaera spp.*, none of which were recorded in this study. Due to the fact that no species with stratigraphic significance were present in either of these samples, Bjærke and Manum (1977) could not determine whether these samples were of Norian or Rhaetian age, but argue that they found no palynological evidence for Norian or Hettangian (earliest Jurassic) strata. A Rhaetian age for the De Geerdalen Formation is now dismissed, however, the *Leschikisporis aduncus* acme recorded by Bjærke and Manum (1977) may correlate with

the abundance peaks of monolete spores recorded in this study. Similar correlations was also proposed by Paterson and Mangerud (submitted) (table 6).

Palynological correlations over long distances are limited by climatic and environmental factors; assemblages from the Boreal realm can be very different from the assemblages from Germanic and Alpine realms (Hochuli et al., 1989). Differences in relative abundances seem to be one feature, i.e. the Boreal realm differs from the Germanic and Alpine realm having a high abundance and diversity of spores, which is probably related to climatic factors (Hochuli et al., 1989). However, some similarities are observed between the present study area and distant areas.

Leschikisporis aduncus was recorded in the "*Aulisporites astigmosus* assemblage" (ass. B) of Roghi et al. (2010) based upon studies in the Tethyan Realm. *Calamospora lunzensis, Kraeuselisporites cooksonae, Distalanulasporites punctus, Leschikisporis aduncus, Tigrisporites halleinis, Duplexisporites sp. 1 Aulisporites astigmosus* and *Aratrisporites* spp. were among the recorded taxa that characterised this assemblage. Abundant *Leschikisporis aduncus* was also recorded in the *Lagenella martini* assemblage (ass. C) of Roghi et al. (2010). The recorded abundances were, however, only a semiquantitative record. These assemblages were correlated with the "*Aulisporites-Aratrisporites* acme" recorded in the upper Conzen Formation and lower Tor Formation, which Roghi (2004) assigned to the Julian/Tuvalian boundary (see Ogg (2012)). This was calibrated with the ammonite sub-zone *Neoprotrachyceras* of late Julian age, recorded from the lower part of the Tor Formation (Roghi, 2004), making the age interpretation more reliable. The recorded assemblage, including the presence of *Kraeuselisporites cooksonae, Leschikisporis aduncus, Aulisporites astigmosus* (only recorded in samples from the Sentralbanken core) and *Aratrisporites* spp., and the age assignment of Roghi et al. (2010) correlates well with the recorded assemblages and age interpretations in this study.

In the Canadian Arctic Archipelago, which at the time was situated at the approximately same paleolatitude as Svalbard, Fisher (1979) reported the first occurrence of the following species as indicative of an Carnian age: *Bhardwajispora sp., Camarozonosporites rudis, Camerosporites pseudoverrucatus, C. secatus, Chordasporites sp., Cordaitina minor, Cuneatisporites radialis, Duplicisporites granulatus, Fossapollenites densus, Pseudenzonalasporites summusm Spirisporites spirabilis* and *Zebrasporites corneolus.* Except for *Camarozonosporites rudis*, none of these species were recorded in this study. However,

other taxa present in the Carnian assemblage of Fisher (1979) includes *Striatoabieites aytugii*, *Kraeuselisporites cooksonae*, different species of *Triadispora, Protodiploxypinus gracilis, Stereisporites* spp*., Carnisporites spiniger* (synonymous to *Anapiculatisporites spiniger*), *Ovalipollis ovalis* and *Kyrtomisporis laevigatus*, all of which were recorded in this study (fig. 12 and 13), suggesting a correlation with core 7533/3-U-7 and the De Geerdalen Formation on Hopen.

In order to strengthen the age interpretation of the assemblages presented herein, observations of important missing taxa can be applied and used as negative evidence. The absence of dinoflagellate cysts, such as *Rhaetogonyaulax rhaetica, R. arctica, Heibergella asymmetrica, H. salebrosacea*, strongly suggests a pre-Norian age. These are recorded in the Flatsalen Formation on Hopen (fig. 2), which is stratigraphically overlying the De Geerdalen Formation, and dated as Early Norian based on ammonites (Korcinskaja, 1980). In addition, based on magnetostratigraphic data, Lord et al. (in press) interpreted the entire De Geerdalen Formation on Hopen to be of Carnian age. The FAD of the ammonite *Daxatina canadensis* was described as a primary marker for the base of the Carnian (Mietto et al., 2008), and Vigran et al. (2014) reports a regular occurrence of *Echinitosporites iliacoides* slightly above strata calibrated with this ammonite zone. The absence of *E. iliacoides* in this study therefore indicates an age younger than Early Carnian. *Daxatina canadensis* is also recorded on Bjørnøya in beds assigned a latest Ladinian age (Mørk et al., 1990).

Based on the discussions above the most likely age for core 7533/3-U-7 is middle to late Carnian. The section from the De Geerdalen Formation on Hopen is also assigned a middle to late Carnian age, with a possible latest Carnian age for the uppermost recorded assemblage (H2). These conclusions are reached based on correlations with previous palynological studies from this region and includes the presence of the *Leschikisporis aduncus* acme, along with the recorded presence of *Aulisporites astigmosus*, *Camarozonosporites rudis*, *Triadispora verrucata*, *Schizaeoisporites worsleyi*, *Striatoabieites balmei*, *Thomsonisporites toralis,* and *Kraeuselisporites cooksonae*, along with negative evidence, including no observations of important Ladinian nor Norian taxa.

5.2 Depositional Environment and Palaeo-environment

The core was divided into five main units, A-E, on the basis of the changing trends in deposition. The distinction between the different units, the interpretation of the depositional environment and palaeoenvironment will be discussed in this chapter.

Unit A is the lowermost unit recorded between 200 m and 185.60 m. This unit has a high mud-content, and consists of layered sand and mud (facies 3 and 4). This is interpreted as interdistributary bay deposits. Interdistributary bays are usually associated with shallow waters, which can be fresh, brackish or marine (Elliott, 1974). The sedimentation in these bays are controlled by flooding from distributaries, mainly by overbank flooding, crevasse splay and avulsion (Elliott, 1974). The coals and organic rich mudstone in this unit indicate terrestrial conditions. Since an interdistributary bay is easily exposed, the frequent coals suggest an interdistributary bay rather than an open marine depositional environment. Marine acritarchs were, however, present in both samples from this unit (samples 200.31 m and 187.60 m, Appendix II), indicating some marine influence. The palynofacies assemblages were dominated by wood particles, which points towards a strong terrestrial dominance and extensive vegetation in or close to the area of deposition.
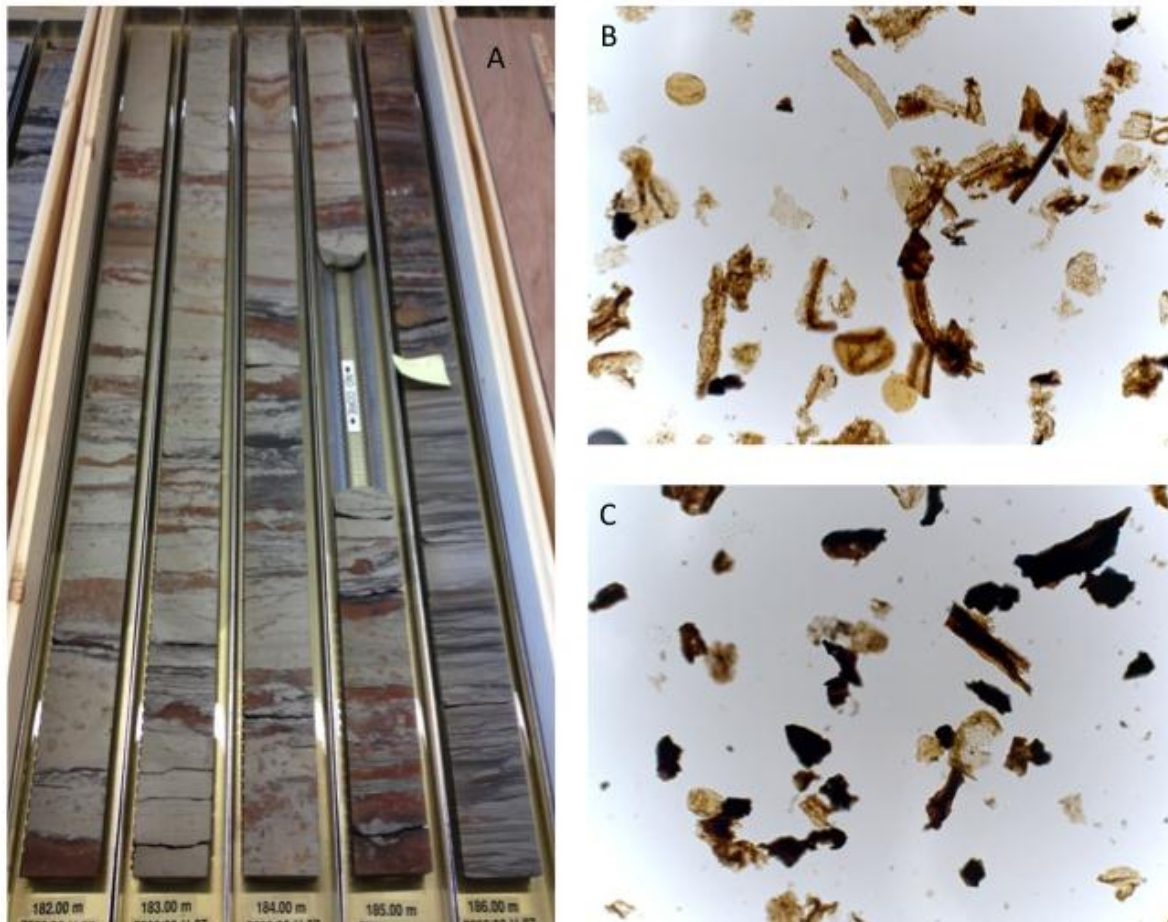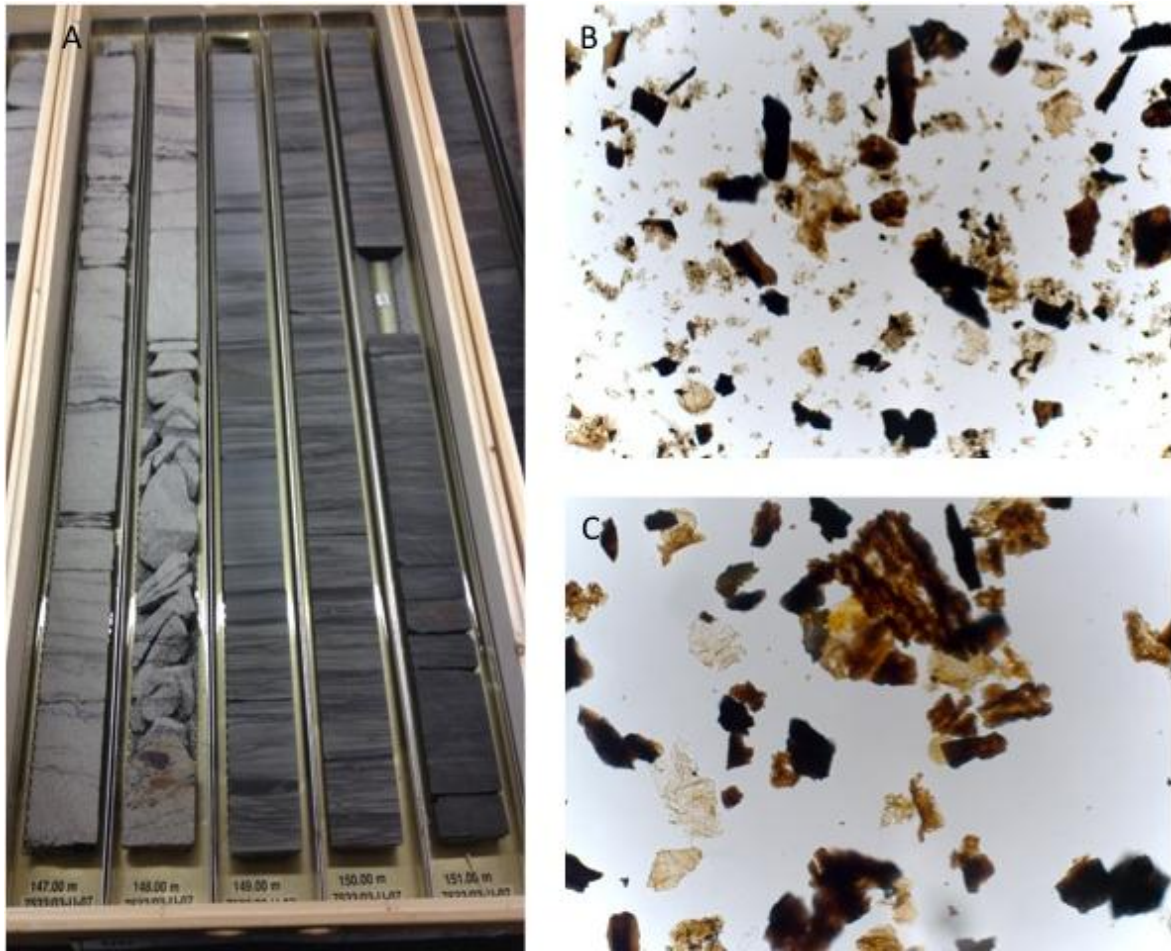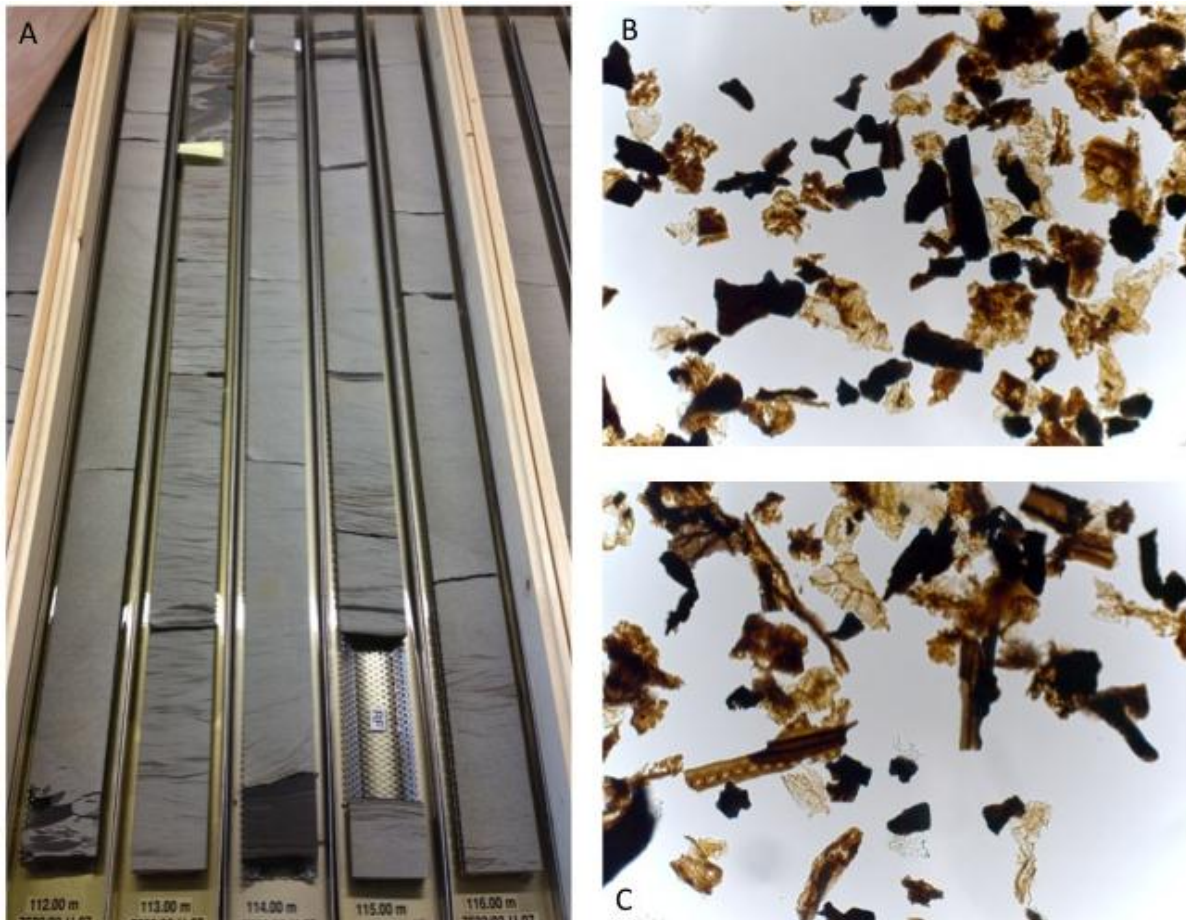
Figure 15: display (A) the transition between Unit A and B, and the palynofacies from the closest samples on either side of the transition (B: 187.60 m, C: 175.95 m). Sample B is dominated by secondary xylem (wood) and has a higher content of sporomorphs. Sample C is dominated by gelified wood. Scale not included.

Unit B is recorded between 185.60 m and 148.00 m. This unit is distinguished from Unit A by a much higher sand-content. The initiation of unit B is easily recognized by an extremely high abundance of siderite clasts in a muddy sandstone (facies 3) (fig. 15). The precipitation of siderite is favoured by reducing conditions in fine-grained sediments, preferably organic-rich, non-marine sedimentary environments (Reading, 1996). Though siderite is mainly associated with freshwater sediments, Postma (1982) did concluded that minor amounts of siderite may form in brackish and marine environments, so the presence of siderite do not necessarily reflect a freshwater palaeo-environment. Facies 3 are interpreted to represent overbank deposits in an alluvial floodplain, where the relative amount of sand indicates how close the channel was. It could be argued that the particular bed that initiates Unit B represents channel fills, a conclusion that was reached by Riis et al. (2008) for a similar bed. However, the upwards increase in mud content for this bed suggests overbank deposits rather than channel fills.

The unusually high siderite content (the amount of siderite is usually much lower in this facies) in the lowermost parts of Unit B, indicates a very restricted access to oxygen and a high organic content. Where the sand content is low (facies 4), the depositional environment is again interpreted as an interdistributary bay. Particularly for the highly bioturbated upper 18 m of this unit, since interdistributary deposits are commonly bioturbated (Huffman Jr et al., 1988). Also, a sporadic presence of burrows was recorded in this interval, which may be assigned to the trace fossil *diplocraterion*. Bioturbation normally indicates unstressed conditions with slow deposition or high faunal biomass (MacEachern et al., 2010), which fits with the interpretation of an interdistributary bay.

A bed of intraformational conglomerate is also recorded in this unit between 176.30 m and 175.70 m. This compolex is often related to migration of the channel and resulting erosion of the mud-rich overbank (Reading, 1996). This facies is thus interpreted as channel fill deposits. The rip-up clasts in facies 1 are generally angular, indicating short transport (maybe none). The presence of the channel-fill deposits (facies 1) followed by mud rich sandstone deposits also strengthens the interpretation that facies 3 are from an alluvial floodplain.

Some places in Unit B, e.g. at 167.30 m, a muddy sandstone (with a very low mud-content) is overlain by a mudstone with a sharp contact, i.e. the deposition of sand abruptly ceases and the deposition is replaced by finer sediments. This may be interpreted to represent abandonment fills from when a channel broke through its original course and left a segment behind that was filled with finer sediments in a low energetic environment. Soft sediment deformation is sporadically present in some mud rich beds between 172.00 m and 175.00 m. Soft sediment deformation was described by Mills (1983) as the interruption of unlithified sediments during or closely after deposition. A number of processes can result in soft-sediment deformation, e.g. water escaping the sediments, though it is always associated with high deposition rates, low permeability and low shear strength (Mills, 1983).

The presence of acritarchs in some samples from this unit, 164.70 m, 157.48 m and 151.75 m (Appendix II), indicates a marine influence. A clear distinction between unit A and B is not recorded in the palynofacies (Appendix II), so the palynofacies still indicates terrestrial conditions. There is, however, a change in the palynofacies in sample 157.48 m, characterised by a significant increase in the amount of sporomorphs. This sample was from a highly bioturbated muddy sandstone.

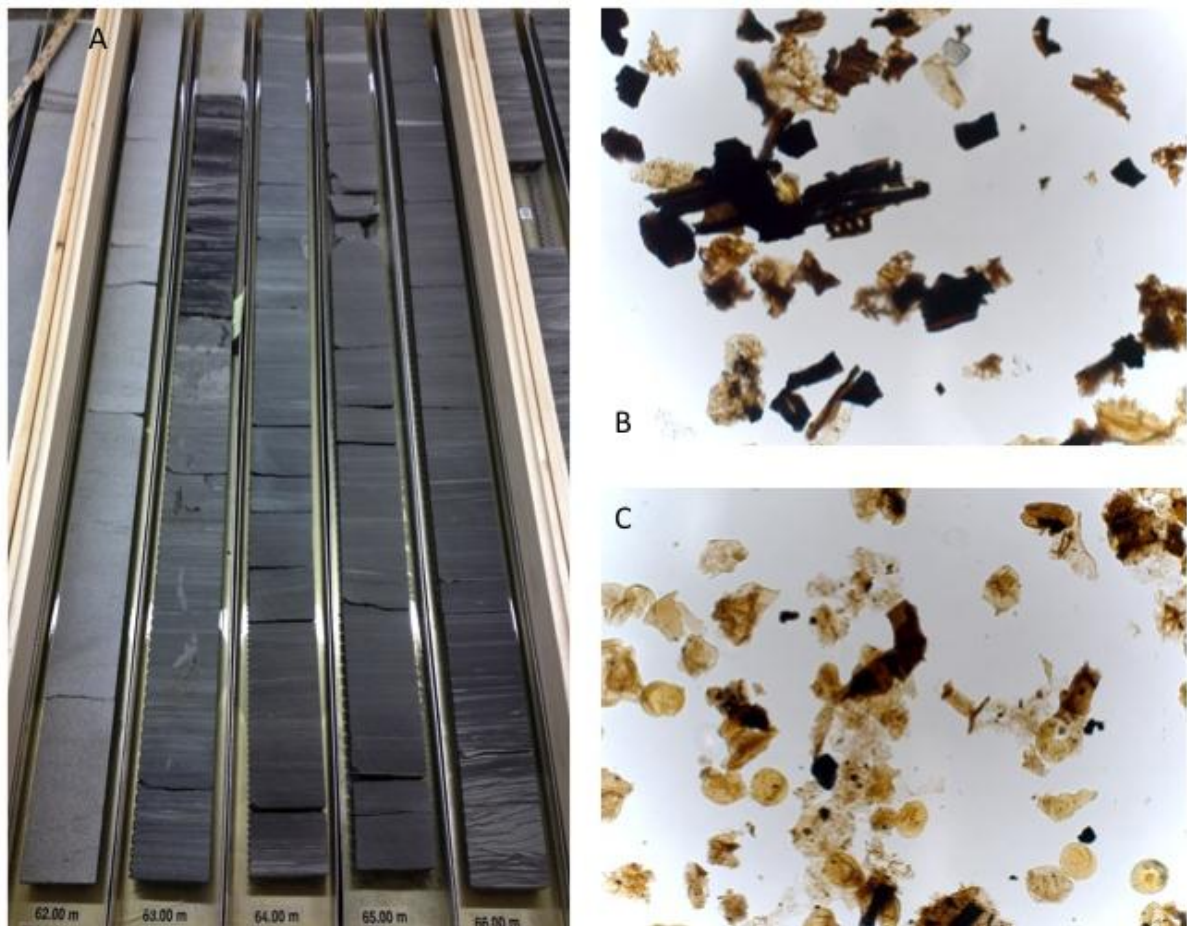Figure 16: display (A) the transition between Unit B and C, and the palynofacies from the closest samples on either side of the transition (B: 151.75 m, C: 141.71 m). Both samples are dominated by gelified wood. Sample B has a lot of fine-grained particles and a higher content of sporomorphs than sample C.

Unit C is recorded between 148.00 m and 112.20 m. The transition between Unit B and C is marked by a prominent erosional contact and a large increase in grain size (fig. 16). A yellow post-it note, which marks the erosional contact, is barely visible in the uppermost part of figure 16. Unit C is mainly dominated by cross-bedded and rippled sandstone (facies 2), and is distinguished from unit B by a very low content of finer sediments (mud). This includes rip-up mud clasts (facies 1), which is completely lacking in this unit. Based on the increase in grain size, the thickness of the sandstone beds, the sedimentary structures and the erosional surfaces, facies 2 is interpreted to represent channel fill deposits. The small, sporadic input of finer sediments (mainly facies 3) is interpreted as overbank floodplain deposits (as above). This is interpreted to never be far away from the channel based on the high sand-content and the relatively thin beds of the fine-grained overbank deposits, since the relative amount of sand indicates how close the channel was. Bioturbation is completely absent in this unit. The lack of acritarchs in all samples from this unit also indicates no or very low marine influence.

The palynofacies are very similar to the recorded palynofacies below this unit: dominated by wood, with a generally small amount of sporomorphs (Appendix II). This strengthens the interpretation of a terrestrial environment. The sample from 113.94 m had a very small amount of fine-grained material; the TOC consisted generally of larger wood particles. This may represent a smaller change in the depositional environment represented by shorter transport.

Figure 17: display (A) the transition between Unit C and D, and the palynofacies from the closest samples on either side of the transition (B: 113.94, C: 94.40 m). There is a very high content of secondary xylem (wood) and gelified wood in both samples. Both samples contained very small amounts of fine-grained matter and the particle were generally well preserved

Unit D is recorded between 112.20 m and 62.50 m. This unit differs from unit C with a high mud content, including rip-up clasts (fig. 17). The facies in this unit alternate frequently, usually with sharp bases, up to 95 m. The rapidly changing facies, along with the fining upwards sequences, indicate a higher degree of channel-migration than the underlying units. From 95.00 m a 33 m thick succession of facies 4 continues to the top of this unit.

Bioturbation is generally lacking, except for the uppermost part (63.00 m – 62.60 m) where burrows and root traces are present (fig. 16). This is interpreted to represent interdistributary bay deposits. The great thickness of these deposits can be explained by the great dimensions of this progradational system, comprising large-scale fluvial channels (Klausen et al., 2013; Riis et al., 2008). The lack of acritarchs in the samples from this unit strengthens the interpretation of a non-marine depositional environment. Except for a lot of pyrite growth in sample 87.50 m the palynofacies are similar to the recorded palynofacies below unit D (Appendix II), e.g. dominated by wood, with a relative small amount of sporomorphs. This also suggests a terrestrial environment.

Figure 18: display (A) the transition between Unit D and E, and the palynofacies from the closest samples on either side of the transition (B: 72.06 m, C: 54.00 m). Sample B is dominated by wood particles (especially gelified wood). Sample C is dominated by well-preserved palynomorphs.

Unit E is the uppermost unit recorded in core 7533/3-U-7, recorded between 62.50 m and 01.63 m. The transition to unit E is marked with a coal layer (fig. 18), followed by rapidly changing facies. Coal layers appear frequent, but are never very thick. Also, the deposits between coal layers are often heavy bioturbated and burrows appear often (some of which are assigned to the trace fossil *diplocraterion*). These deposits are interpreted to be from a marsh with channel and floodplain deposits.

The recorded palynofacies, palynological assemblages and the sedimentological facies are all changing rapidly in this unit, which reflects an unstable, rapidly changing depositional environment. The palynofacies in samples 50.50 m and 41.45 m, where gelified wood particles almost completely dominate the palynofacies, are in agreement with Tyson (1995), who states that the amount of gelified wood is generally high where plant debris is most common, such as coaly layers. Acritarchs were found in the samples 21.60 m and 16.23 m in this unit, indicating a marine influence.

The depositional environment for core 7533/3-U-7 is interpreted to represent a delta plain. This is based on the interpretations above, mainly deposits from fluvial channels, floodplains and interdistributary bays, along with frequent palaeosol and coals. According to Reading (1996) the lower delta plain environment is characterised by channels and interdistributary deposits as lakes, tidal flats, marshes and swamps. This fits the interpretations presented herein. Also, the lower delta plain is affected by saline water, which do not affect the upper delta plain (Reading, 1996). The sporadic presence of acritarchs (Appendix II) is therefore another indicator of a lower delta plain setting, rather than the upper delta plain. These interpretations reflects the paralic nature of the Carnian Barents Shelf, as described by Riis et al. (2008).

For the logged section from Blåfjellet, the wave ripples and hummocky bedding are typical marine features. However, the current ripples and beds with roots suggests a terrestrial environment; the sandstone beds represent fluvial channel fill deposits and the thicker fine-grained beds are overbank floodplain and interdistributary bay deposits. The palynofacies from Blåfjellet (Appendix III) closely resemble the recorded palynofacies from the core, both sections being largely dominated by wood particles. However, the samples from Hopen yielded a generally high amount of sporomorphs, dominated by terrestrial taxa. The dominating middle parts of the logged section are interpreted to a delta plain environment, similar to the Sentralbanken core. The lower part with hummocky bedding is interpreted as

part of a paralic platform with increased marine influence (relative to the overlying channel and overbank depiosits), maybe shallow marine. Also, Acritarchs were not recorded in any of the samples from Hopen in the present study, but they have been recorded in previous studies (oral communication, Paterson 2014), which attest to some marine influence. The uppermost hummocky bed may indicate increased marine influence, maybe a flooding, however, no samples were provided from this section. A paralic depositional environment with marine influenced deposits was also described for the De Geerdalen Formation on Hopen by Klausen et al. (2013).

Concavisporites spp., *Calamospora* spp., *Cycadopites* spp., *Deltoidospora* spp., *Dyctyophyllidites* spp. and *Duplexisporites problematicus* were among the taxa grouped in the Lowland Sporomorph Ecogroup (SEG) to Abbink et al. (2004), all of which were recorded in samples from core 7533/3-U-7 and Hopen (Appendix II and III). The Lowland SEG is characterised by lowland plains periodically submerged by freshwater and/or swamps (Abbink et al., 2004). This strengthens the interpretation of a delta plain environment for the core and Hopen.

Leschikisporis, Concavisporites, *Deltoidospora*, *Dyctyophyllidites* and *Duplexisporites* are spores from ferns, which prefer shadowy, humid and warm environments (Abbink et al., 2004). Increasing abundance and diversity of fern spores in the Late Triassic was also described by Hochuli and Vigran (2010) (fig. 14). They concluded that a major change in the palynoflora is present within the Carnian, characterised by a change from dryer conditions in the early Carnian (phase 10 and 11) to humid conditions in the mid Carnian and onwards (phases 12 to 20) (Hochuli and Vigran, 2010).

A dominance of terrestrial taxa was also described for the De Geerdalen Formation in Spitsbergen by Nagy et al. (2011). Based on the local absence of foraminifera and the low diversity of taxa, Nagy et al. (2011) interpreted the lower De Geerdalen Formation to be an interdistributary bay to delta front with restricted environmental conditions in shallow marginal marine waters. The middle to upper De Geerdalen Formation was interpreted as delta plain to coastal plain, and were totally dominated by terrestrial palynomorphs, such as *Leshikisporis aduncus*, *Aratrisporites poicabilis* and *Duplexisporites problematicus* (Nagy et al., 2011). Both the total dominance of terrestrial taxa (Appendix II and III) and the delta to coastal plain environment for the middle to upper De Geerdalen Formation can be related to this study for both Hopen (Blåfjellet) and core 7533/3-U-7.

6. Conclusions

Core 7533/3-U-7 is assigned a mid to late Carnian age based on:
- ➤ The presence of *Aulisporites astigmosus*
- ➤ The assemblages correlates with "Assemblage D and E" of Hochuli et al. (1989), "Phase 12" of Hochuli and Vigran (2010), the "*Aulisporites astigmosus* Composite Assemblage Zone" of Vigran et al. (2014) and the "*Leschikisporis aduncus* assemblage" of Paterson and Mangerud (submitted)
- ➤ The absence of *Echinitosporites iliacoides* suggest an age younger than earliest Carnian
- ➤ The absence of dinoflagellate cysts suggests a pre-Norian age
- ➤ No major palynofloral changes were recorded in the palynological assemblages

The De Geerdalen Formation on Hopen is assigned a mid to late Carnian age with a possible latest Carnian uppermost part based on:
- ➤ Assemblage H1 correlates with "Assemblage D and E" of Hochuli et al. (1989), "Phase 12" of Hochuli and Vigran (2010), the "*Aulisporites astigmosus* Composite Assemblage Zone" of Vigran et al. (2014) and the "*Leschikisporis aduncus* assemblage" of Paterson and Mangerud (submitted)
- ➤ Assemblage H2 may correlate with the "*Protodiploxypinus* spp. Assemblage" of Paterson and Mangerud (submitted), Assemblage C of Hochuli et al. (1989), the upper part of the "*Aulisporites astigmosus* Composite Assemblage Zone" of Vigran et al. (2014) and "Floral Phase 15" of Hochuli and Vigran (2010)
- ➤ The absence of *Echinitosporites iliacoides* suggest an age younger than earliest Carnian
- ➤ The absence of dinoflagellate cysts suggests a pre-Norian age

- The terrestrial taxa recorded from core 75533/3-U-7 and Hopen, such as *Concavisporites* spp., *Calamospora* spp., *Cycadopites* spp., *Deltoidospora* spp., *Dyctyophyllidites* spp. and *Duplexisporites problematicus*, indicate a swampy terrestrial environment
- Low numbers of acritarchs recorded in samples from the Sentralbanken core indicates a minor marine influence
- Abundant fern spores, including *Leschikisporis, Concavisporites*, *Deltoidospora*, *Dyctyophyllidites* and *Duplexisporites*, indicate humid and warm conditions for the Sentralbanken core and the De Geerdalen Formation on Hopen, also described by Hochuli and Vigran (2010)

- Based on the sedimentological facies the depositional environment for core 7533/3-U-7 is interpreted to represent a delta plain. This is strengthened by the palynofacies (dominated by wood particles and sporadically occurring marine acritarchs) and the dominance by terrestrial taxa in the palynological assemblages
- Based on the facies, represented by the sedimentological log, and the similarities with the Sentralbanken core, the De Geerdalen Formation on Hopen is interpreted to represent a delta plain. As with the core, this is strengthened by palynofacies dominated by wood particles and the palynological assemblage dominated by terrestrial taxa
- The terrestrial taxa, palynofacies results and sedimentological facies of core 7533/3-U-7 and the De Geerdalen Formation on Hopen (Blåfjellet) reflects the paralic nature of the Carnian Barents Shelf, also documented by Riis et al. (2008)

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Appendix

Appendix I: List of taxa

Spores
Anapiculatisporites spiniger (Leschik 1955) Reinhardt 1962
Annulispora spp.
Annulispora folliculosa (Rogalska, 1954) de Jersey 1959
Apiculatasporites hirsutus Leschik 1955
Apiculatasporites lativerrucosus Leschik 1955
Apiculatisporis parvispinosus (Leschik 1955) Playford & Dettman 1965
Aratrisporites spp.
Aratrisporites laevigatus Bjærke & Manum 1977
Aratrisporites macrocavatus Bjærke & Manum 1977
Aratrisporites scabratus Klaus 1960
Baculatisporites spp.
Calamospora tener (Leschik, 1955) Mädler 1964
Camarozonosporites laevigatus Schulz 1967
Camarozonosporites rudis (Leschik, 1955) Klaus 1960
Cingulizonates spp.
Cingulizonates rhaeticus (Reinhardt 1962) Schulz 1967
Clathroidites spp.
Conbaculatisporites spp.
Conbaculatisporites sp. A *sensu* Paterson & Mangerud (submitted)
Concavisporites spp.
Deltoidospora spp.
Dictyphyllidites mortonii (de Jersey 1959) Playford & Dettman 1965
Duplexisporites problematicus (Couper) Playford & Dettman 1965
Krauselisporites spp.
Kraeuselisporites cooksonae (Klaus 1962) Dettman 1963
Kraeuselisporites dendatus Leschik 1956
Leschikisporis aduncus (Leschik 1955) Potonié 1958
Limatulasporites limatulus (Playford 1965) Helby & Foster 1979
Punctatisporites fungosus Balme 1963
Rogalskaisporites cicatricosus (Rogalska 1954) Danze-Corsin & Laveine 1963
Stereisporites spp. Pflug 1953
Striatella seebergensis Mädler 1964
Thomsonisporites toralis Leschik 1955
Verrucatosporites spp.
Verrucosisporites spp.
Zebrasporites spp.
Zebrasporites *interscriptus* (Thiergart 1949) Klaus 1960

Pollen

Angustisulcites klausii (Freudenthal 1964) Visscher 1966
Aulisporites astigmosus (Leschik 1955) Klaus 1960
Araucariacites australis Cookson 1947
Bisaccate spp.
Chasmatosporites apertus (Rogalska 1954) Nilsson 1958
Chasmatosporites hians Nilsson 1958
Cycadopites spp.
Enzonalasporites spp.
Ephedripites spp.
Eucommiidites spp.
Eucommiidites microgranulatus Scheuring 1970
Lunatisporites spp.
Ovalipollis spp.
Ovalipollis ovalis (Krutsch) Scheuring 1970
Pinuspollenites spp.
Protodiploxypinus spp.
Protodiploxypinus ornatus (Pautsch 1973) Bjærke & Manum 1977
Schizaeoisporites Worsleyi Bjærke & Manum 1977
Steevesipollenites spp.
Striatoabieites spp.
Striatoabieites aytugi (Visscher 1966) Scheuring 1970
Striatoabieites balmei (Klaus 1964) Scheuring 1978
Striate bisaccate informal taxon
Tetrasaccus Pant 1954
Triadispora spp.
Triadispora bella Scheuring 1978
Triadispora boelchii (Scheuring 1970) Scheuring 1978
Triadispora obscura Scheuring 1970
Triadispora sulcata Scheuring 1978
Triadispora suspecta Scheuring 1970
Triadispora verrucata (Schulz 1966) Scheuring 1970
Vitreisporites pallidus (Reissinger 1938) Nilsson 1958

Acritarchs

Acritarch spp. species indet.
Leiofusa cf. jurassica Cookson & Eisenack 1958
Micrhystridium spp.
Veryhachium spp.

Chlorococcales

Botryococcus spp.
Crassosphaera spp.
Plaesiodictyon mosellaneum Willie 1970

Range chart, including palynofacies estimates and simplified core log
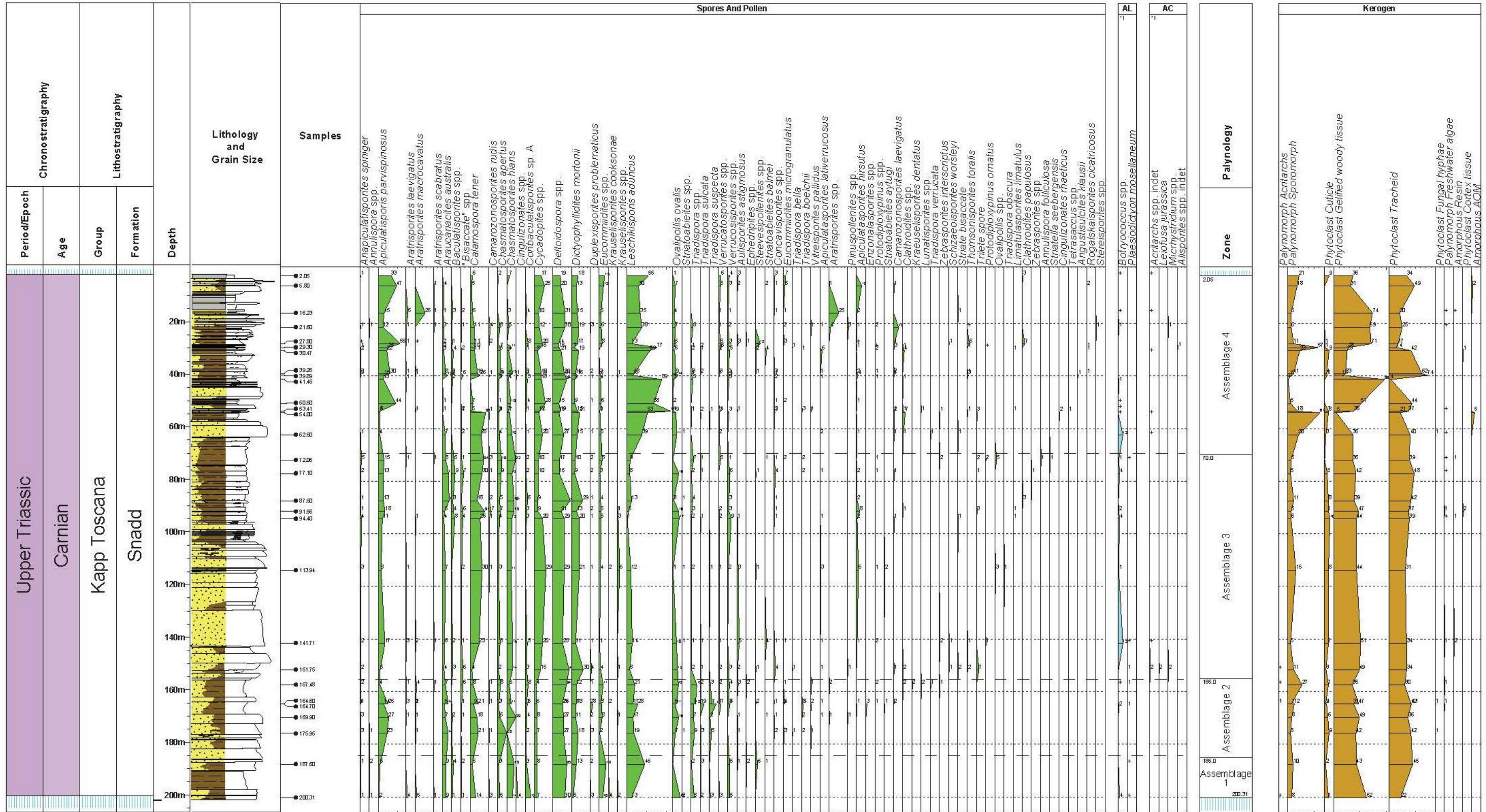
Appendix III: Range chart for Hopen, Blåfjellet (south)

Range chart, including palynofacies estimates and simplified log
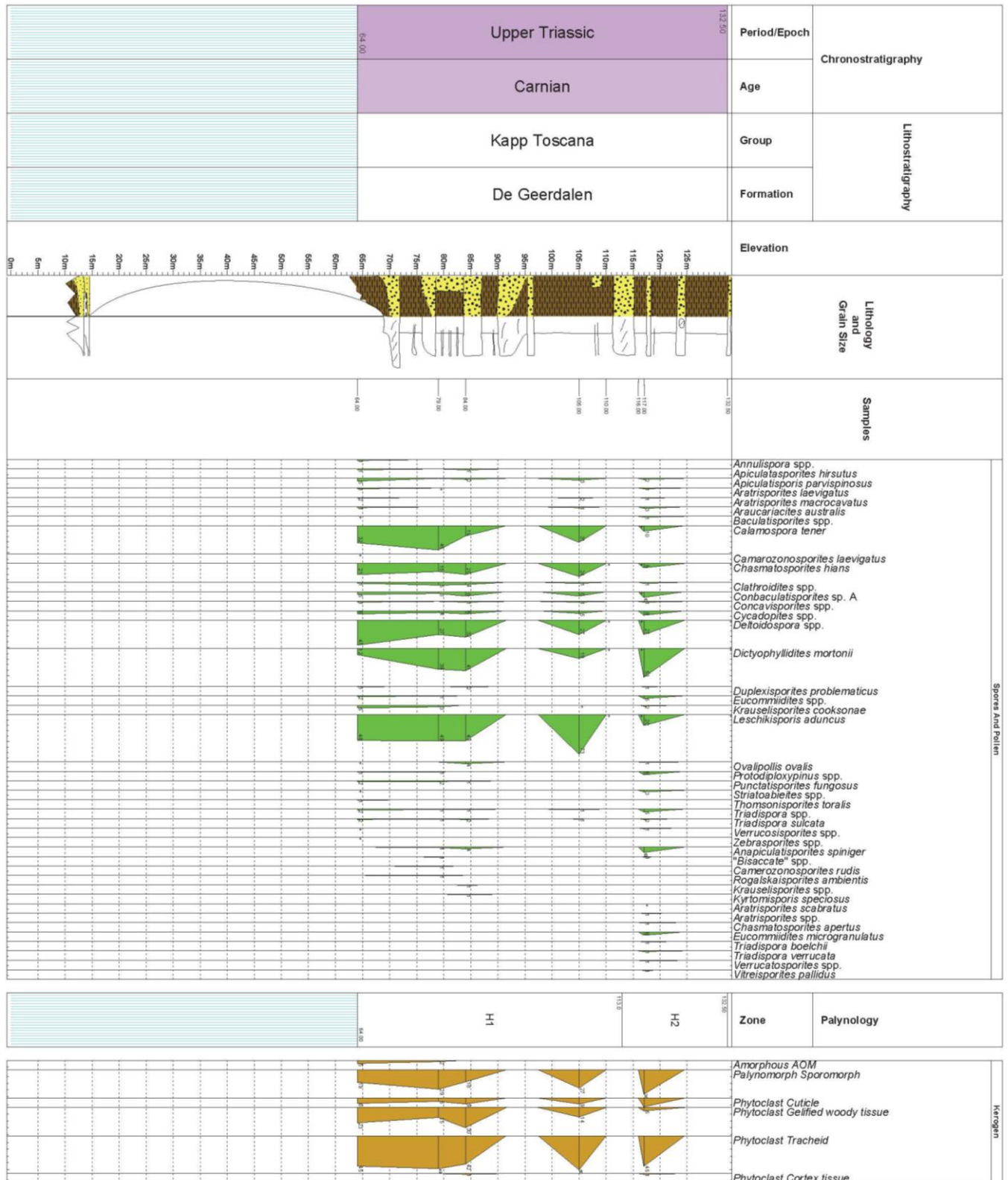
Appendix IV: Plates

Following the species name is the sample number. A, B, C, etc., is given when several samples were provided for the same depth. This is followed by the position of the specimen given by the use of an England Finder. All the samples were put under the microscope with the label to the left. If nothing else is given the sample is from core 7533/3-U-7.

Plate I

Fig. 1: *Deltoidospora* spp. 200.31(A) K33

Fig. 2: *Deltoidospora* spp. 29.30 U40.1

Fig. 3: *Deltoidospora* spp. 16.23(A) E24.3

Fig. 4: *Dictyphyllidites mortonii* 27.80(B) L37.1

Fig. 5: *Dictyphyllidites mortonii* 79(Hopen) O12

Fig. 6: *Dictyphyllidites mortonii* 84(Hopen) T22

Fig. 7: *Calamospora tener* 54.00(A) R43

Fig. 8: *Calamospora tener* 141.71(A)   J19.3

Fig. 9: *Calamospora tener* 157.48(A) V39

Fig. 10: *Punctatisporites fungosus* 84(Hopen) T26.2

Fig. 11: *Punctatisporites fungosus* 27.80(A) Q29.3

Plate I
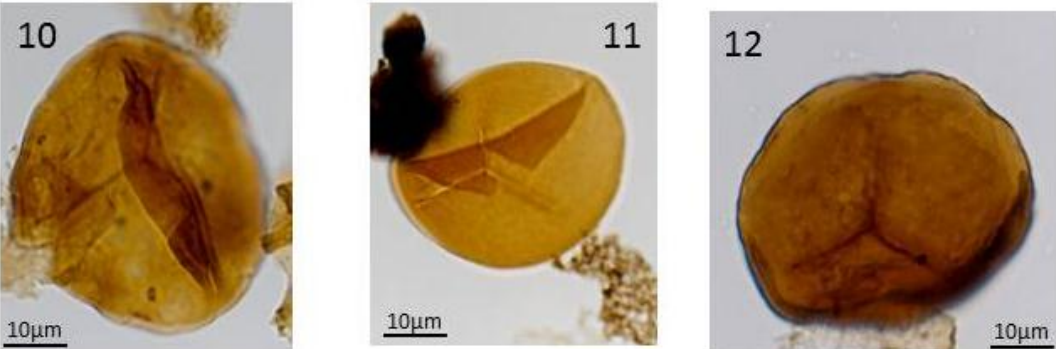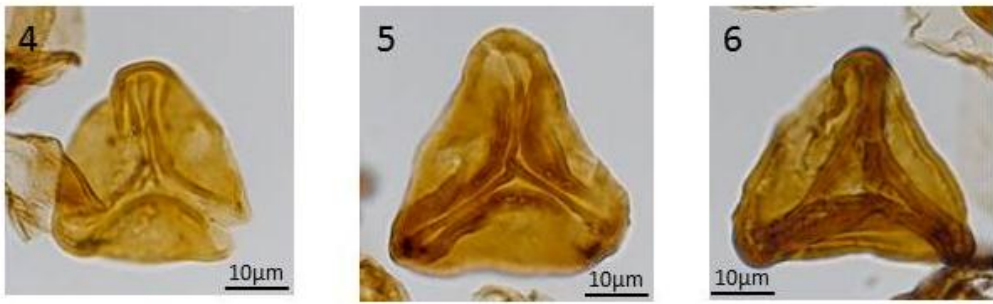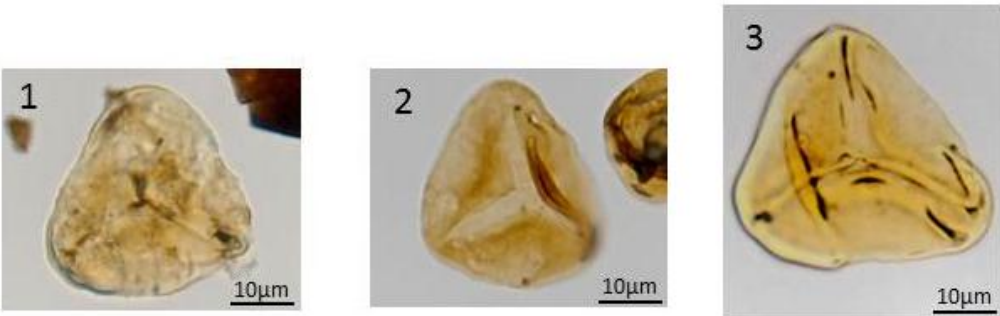
Plate II

Fig. 1: *Clathroidites* spp. 27.80(A) S22.2

Fig. 2: *Clathroidites* spp. 151.75 Q31.4

Fig. 3: *Clathroidites* spp. 79(Hopen) O39 1

Fig. 4: *Conbaculatisporites* sp. A 187.60 E19.1

Fig. 5: *Conbaculatisporites* sp. A 29.30 F24.1

Fig. 6: *Conbaculatisporites* sp. A 157.48(A) Q36

Fig. 7: *Anapiculatisporites spiniger* 105(Hopen) S13.4

Fig. 8: *Anapiculatisporites spiniger* 27.80(A) G26.3

Fig. 9: *Anapiculatisporites spiniger* 84(Hopen) T24.1

Plate II
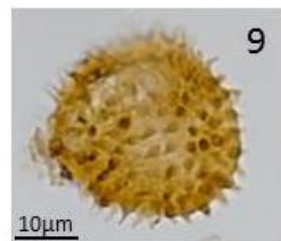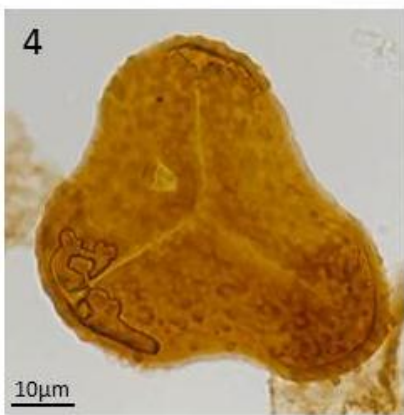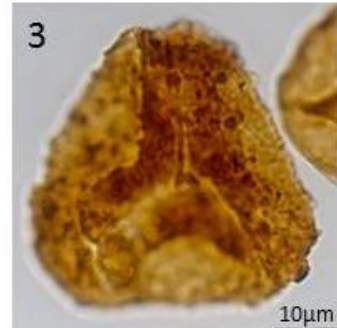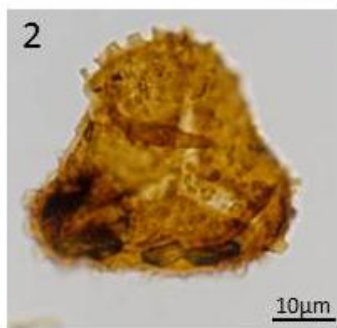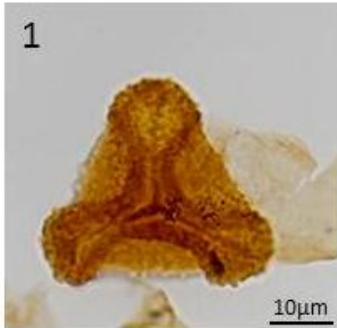
Plate III

Fig. 1: *Camarozonosporites laevigatus* 94.40(B) R38

Fig. 2: *Camarozonosporites laevigatus* 30.47(C) F29

Fig. 3: *Camarozonosporites laevigatus* 29.30 Q43.3-4

Fig. 4: *Zebrasporites interscriotus* 77.10(A) P33.2-4

Fig. 5: *Zebrasporites interscriotus* 54.00(A) P46

Fig. 6: *Zebrasporites interscriotus* 77.10(A) P33.2-4

Fig. 7: *Limatulisporites limatulus* 30.47(C) R40

Fig. 8: *Limatulisporites limatulus* 53.41(A) P23.3

Fig. 9: *Limatulisporites limatulus* 94.40(B) P20.3

Plate III
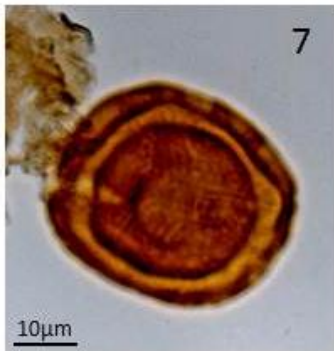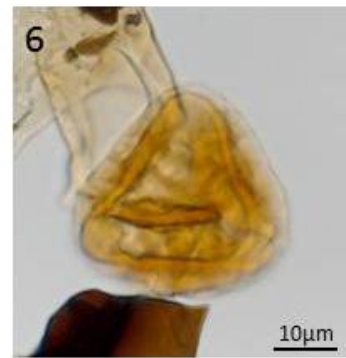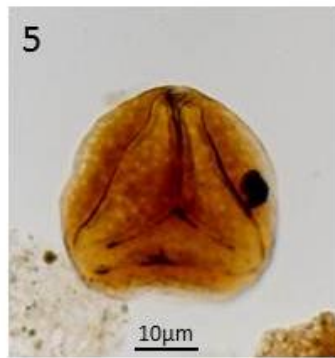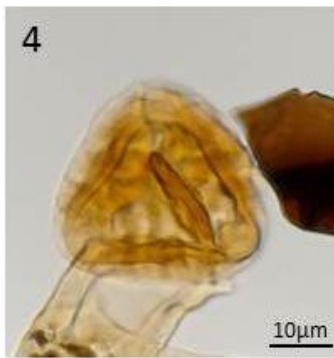
Plate IV

Fig. 1: *Camarozonosporites rudis* 29.30 J41,1

Fig. 2: *Camarozonosporites rudis* 21.60(C) O28

Fig. 3: *Camarozonosporites rudis* 72.06(C) R29 2-4

Fig. 4: *Rogalskaisporites cicatricosus* 30.47(C) Q38 2-4

Fig. 5: *Annulispora folliculosa* 39.89 J27

Fig. 6: *Annulispora folliculosa* 84(Hopen) X31.2

Fig. 7: *Duplexisporites problematicus* 29.30 U36, 1

Fig. 8: *Duplexisporites problematicus* 141.71(D) R27.2

Fig. 9: *Duplexisporites problematicus* 164.70(C) j37.4

Plate IV
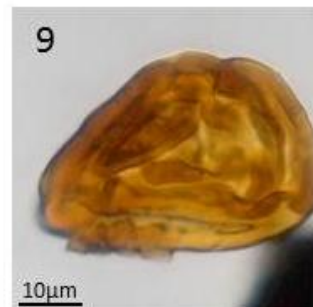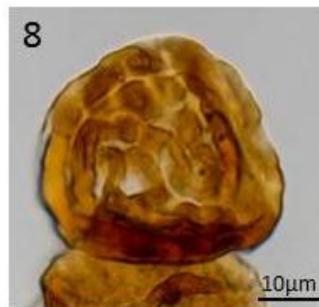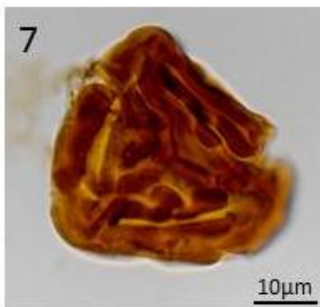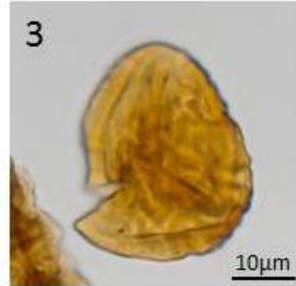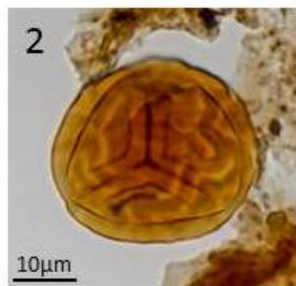
Plate V

Fig. 1: *Thomsonisporites toralis* 151.75 Q39 3-4

Fig. 2: *Thomsonisporites toralis* 29.30 S31.1

Fig. 3: Thomsonisporites toralis 39.26 M42.3-4

Fig. 4: *Limbosporites* spp. 77.10(A) R39 2

Fig. 5: *Cingulizonates* spp. 200.31(A) N30.3

Fig. 6: *Cingulizonates* spp. 200.31(A) U31.4

Fig. 9: *Kraeuselisporites* spp. 141.71(C) H41

Fig. 8: *Kraeuselisporites* spp. 94.40 (B) R36

Fig. 7: *Kraeuselisporites* spp. 21.60(A) V29

Plate V
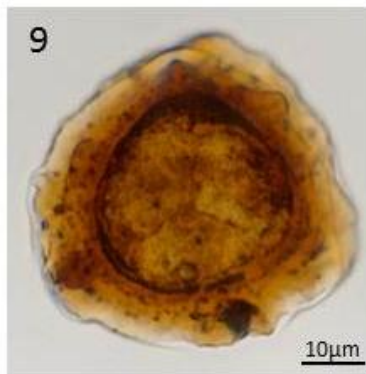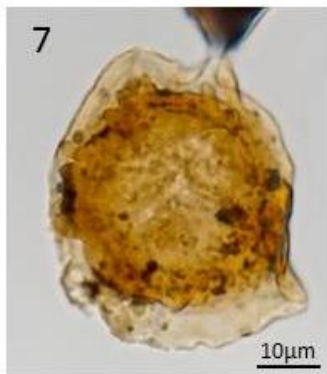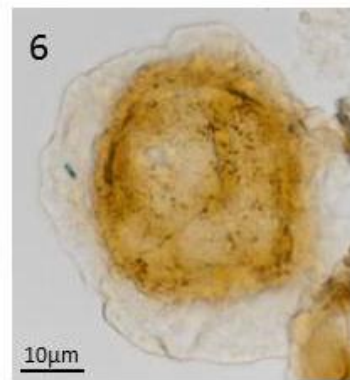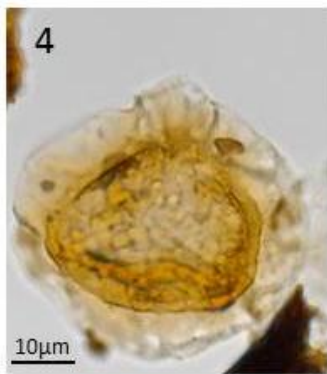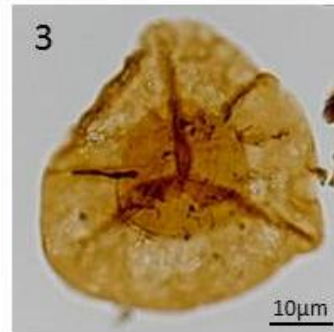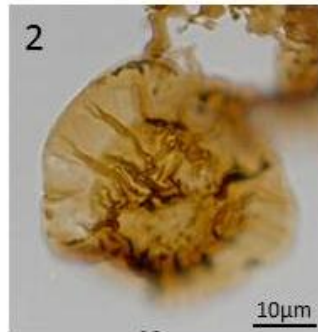
Plate VI

Fig. 1: *Leschikisporis aduncus* 29.30 S31.1

Fig. 2: *Leschikisporis aduncus* 141.71(D) O26.3

Fig. 3: *Leschikisporis aduncus* 105(Hopen) W33

Fig. 4: *Apiculatisporites parvispinosus* 27.80(A) U27.2

Fig. 5: *Apiculatisporites parvispinosus* 29.30 S27

Fig. 6: *Apiculatisporites parvispinosus* 29.30 S47.3

Fig. 7: *Apiculatasporites hirsutus* 29.30 H30

Fig. 8: *Apiculatasporites hirsutus* 29.30 H31

Fig. 9: *Apiculatasporites lativerrucosus* 30.47(C) J31.3

Fig. 10: *Aratrisporites macrocavatus* 94.40(A) S39.1

Fig. 11: *Aratrisporites macrocavatus* 27.80 (B) M39

Fig. 12: *Aratrisporites macrocavatus* 16.23(B) R20

Plate VI
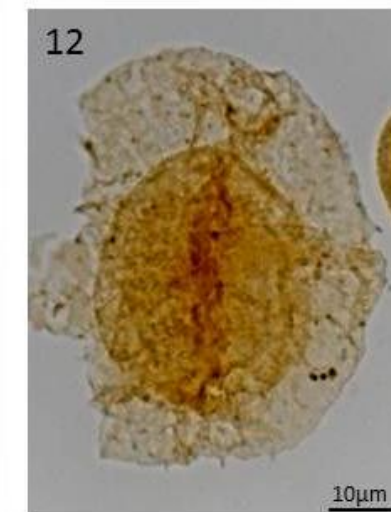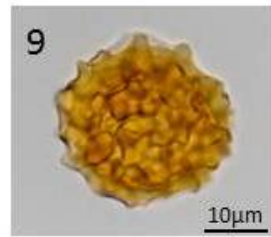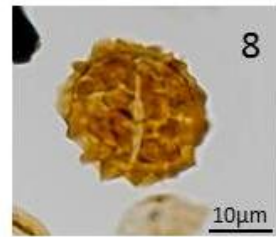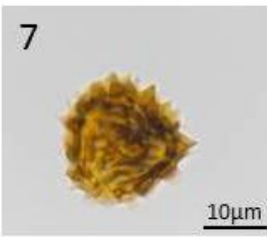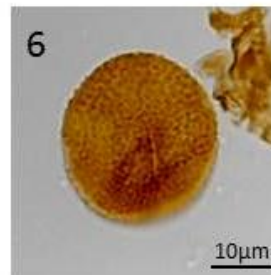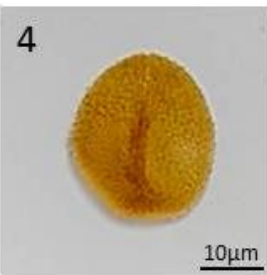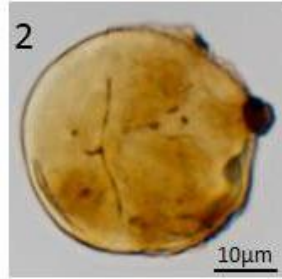
Plate VII

Fig. 1: *Araucariacites australis* 29.30 H33.4

Fig. 2: *Araucariacites australis* 141.71(D) P24.1

Fig. 3: *Steevesipollenites* spp. 27.80(A) Q38.4

Fig. 4: *Steevesipollenites* spp. 27.80(A) Q38.4

Fig. 5: *Steevesipollenites* spp. 27.80(A) X36

Fig. 6: *Steevesipollenites* spp. 27.80(A) S29.3

Fig. 7: *Ephedripites* spp. 27.80(A) K28,2

Fig. 8: *Ephedripites* spp. 27.80(A) Q36.4

Fig. 9: *Schizaeoisporites cf. Worsleyi* 141.71(D) M27.3-4

Fig. 10: *Aulisporites astigmosus* 113.94(B) M39. 3-4

Fig. 11: *Aulisporites astigmosus* 164.70(C) S23.1-2

Plate VII
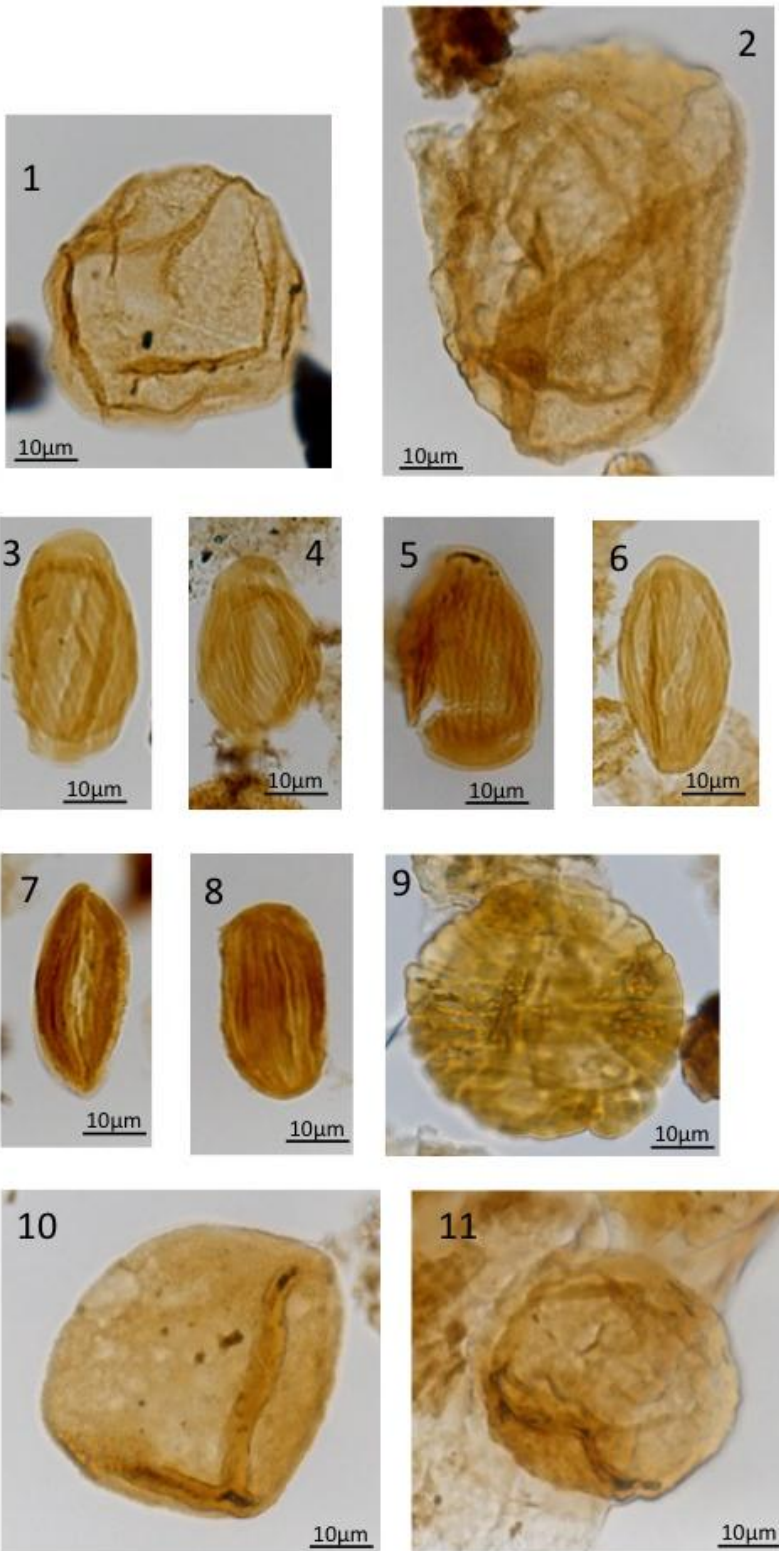
Plate VIII

Fig. 1: *Chasmatosporites apertus* 29.30 R39.4

Fig. 2: *Chasmatosporites apertus* 27.80(A) Q28.3

Fig. 3: *Chasmatosporites cf. apertus* 164.70(C) S26

Fig. 4: *Chasmatosporites hians* 29.30 F36

Fig. 5: *Chasmatosporites hians* 187.60 K17.1

Fig. 6: *Chasmatosporites hians* 50.50 L31

Fig. 7: *Cycadopites* spp. 164.60 U30

Fig. 8: *Cycadopites* spp. 141.71(D) R26.4

Fig. 9: *Cycadopites* spp. 113.94(B) S38.1

Plate VIII
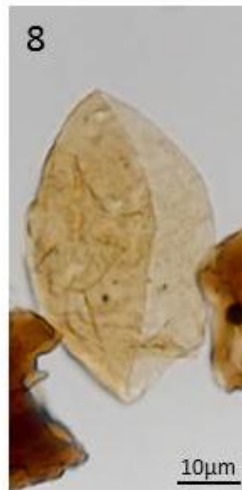
Plate IX

Fig. 1: *Ovalipollis ovalis* 113.94(C) R40.2

Fig. 2: *Ovalipollis ovalis* 105(Hopen) W19.1

Fig. 4: *Protodiploxypinus ornatus* 29.30 R24

Fig. 5: *Protodiploxypinus ornatus* 29.30 V19.2

Fig. 6: *Protodiploxypinus* spp. 105(Hopen) R13.3

Fig. 7: *Striatoabieites balmei* 30.47(C) K28.3

Fig. 8: *Striatoabieites balmei* 141.71(D) Q32.1-2

Fig. 9: *Striatoabieites balmei* 30.47(C) Q25

Plate IX
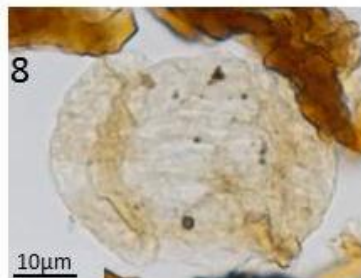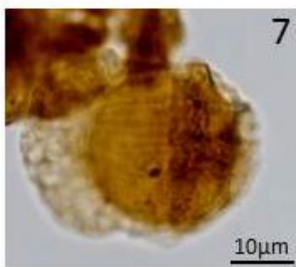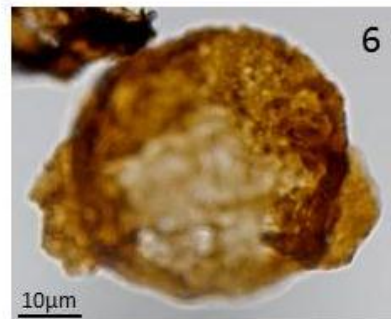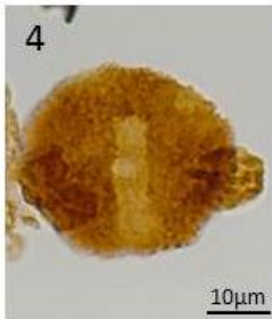
Plate X

Fig. 1: *Triadispora ?boelchii* 151.75 Q22. 3

Fig. 2: *Triadispora ?boelchii* 30.47(C) J27

Fig. 3: *Triadispora ?boelchii* 29.30 R36.3

Fig. 4: *Triadispora ?sulcata* 53.41(A) Q37

Fig. 5: *Triadispora ?sulcata* 29.30 R41

Fig. 6: *Triadispora ?suspecta* 105(Hopen) N16.1

Fig. 7: *Triadispora ?suspecta* 200.31(A) O44.4

Fig. 8: *Tetrasaccus* spp. 54.00(A) R45.1-3
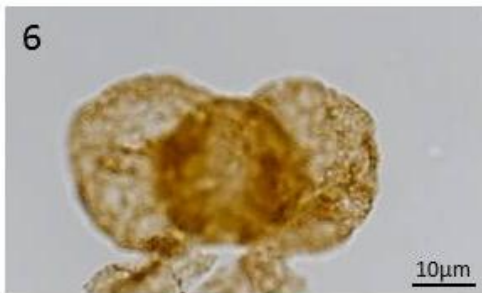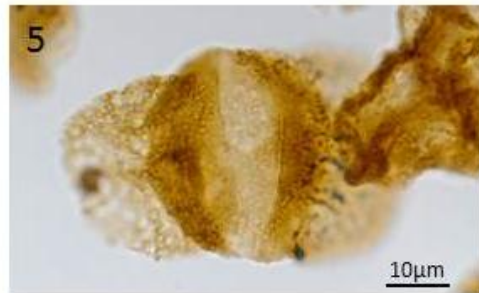
Fig. 9: *Pinuspollenites* spp. 151.75 Q34.4

Plate X

1   10μm

2   10μm

3   10μm

4   10μm
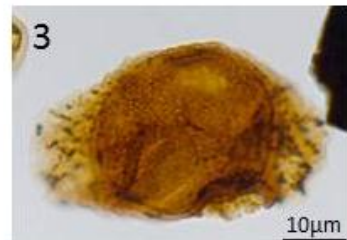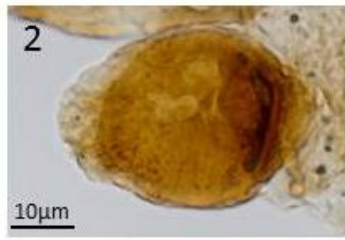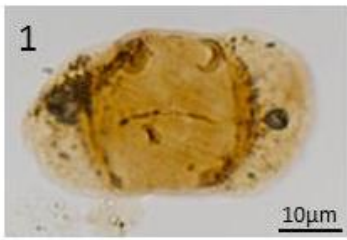
5   10μm

6   10μm

7   10μm

8   10μm

9   10μm
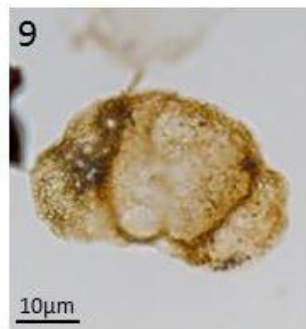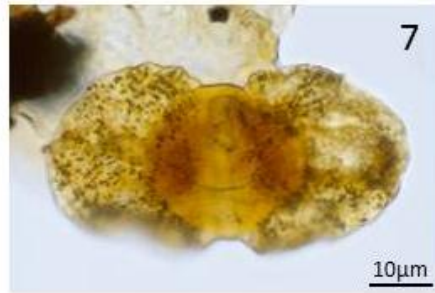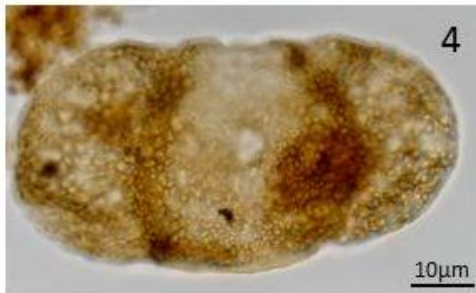
Plate XI

Fig. 1: *Micrhystridium* spp. 157.48

Fig. 2: *Micrhystridium* spp. 151.75 Q35.3-4

Fig. 3: *Leiofusa cf. jurassica* 151.75 Q34.4

Fig. 4: Veryhachium 151.75 Q33.3

Fig. 5: Veryhachium 151.75 K23.3-4

Fig. 6: *Botryococcus* spp. 41.45(C) G39

Fig. 7: *Crassosphaera* spp. 62.50(un-oxidized sample) R41

Fig. 8: *Plaesiodictyon mosellanum* 117(Hopen) M30.3-4

Plate XI