Palynological dating of the upper part of the De Geerdalen Formation on central parts of Spitsbergen and Hopen

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Thesis for master degree in Petroleum Geoscience

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Submission date: June 2013
Supervisor: Gunn Mangerud
Co-supervisor: Atle Mørk

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Abstract

The Late Triassic is the most problematic period in terms of resolution and age control. The period spans about 36 million years and consists of three stages – Carnian, Norian and Rhaetian. Only four clusters of radiometric age constrain the Triassic time scale (Ogg et al., 2012), and macrofossil data are scarce, hampering exact age determination and biostratigraphic correlation. Additional knowledge on the stratigraphy and geographic ranges of different fossil groups are therefore crucial to build a better framework and thereby contribute in increasing the database.

In the Barents Sea area, a huge delta complex reached Eastern Svalbard and Hopen by the end of Late Carnian, and by the end of Late Triassic the paralic deposits had prograded over the northwestern part of the Svalbard Archipelago. Shales, siltstones and sandstones of various thicknesses alternate in the De Geerdalen, Flatsalen and Svenskøya formations, reflecting the deltaic sediments deposited during this period (Riis et al., 2008). Previous studies regarding age datings from Hopen have been conflicting, and a lot of uncertainty is related to the location of the prograding deltafront at any time during this period.

Palynological work from two sections, located at Lyngefjellet northeast on Hopen, and from Deltaneset, Central Spitsbergen, resulted in recognition of three assemblages of Late Carnian to ?Middle Norian age. The palynological assemblages are based on spores, pollen, acritarchs and other palynomorphs, and correlation to published records from the Barents Sea area and Arctic Canada have been used for age determination.

The lower part of the De Geerdalen Formation section on Hopen is assigned a Late Carnian age based on palynological assemblages similar to the palynofloras recorded in the Barents Sea area and Arctic Canada, and is believed deposited in a deltaic setting reflected in a palynoflora from typical wetland plants. For the upper part of the formation, Early Norian has been suggested based on resemblances to assemblages from the overlying ammonite dated (Korchinskaya, 1982) Flatsalen Formation. The upper section of the De Geerdalen Formation belongs to the Hopen member (Solvi, 2013), herein documented to be equivalent to the Isfjorden Member on Deltaneset, Central Spitsbergen. A coastal environment, probably a delta setting, is suggested for these sections. Svenskøya Formation overlays the Flatsalen Formation and an Early to Middle Norian age is suggested based on the stratigraphically limited taxa, and a delta-setting environment is proposed.

Acknowledgements

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Table of Contents

1 Introduction

The sedimentology of the Upper Triassic strata on Eastern and Central Svalbard as well as from the Barents Sea has been well studied the last decades, and a good understanding of the stratigraphy in the area exists. The De Geerdalen, Flatsalen and Svenskøya formations constitute Carnian to Norian sediments, and are preserved in outcrop and subsurface (Riis et al., 2008). Riis et al. (2008) interpreted the sandstone and shale sediments as being result of a major deltaic system within the western Barents Shelf, prograding north-westward. The lithostratigraphy can be correlated on eastern and central parts of Svalbard, and the sediments make up a diacronous deltaic complex system that may be followed onto the Barents Shelf (Riis et al., 2008). The Late Triassic period spans about 36 million years, and consist of three stages – Carnian, Norian and Rhaetian (Ogg et al., 2012). Major controversy has existed regarding the duration and their stratigraphic relations, and still the Late Triassic is the most problematic period in terms of resolution and age control. Also for the Barents Sea area macrofossil data are scarce from the Late Triassic, hampering exact age determination and biostratigraphic correlation. Palynology can therefore provide important contributions to the understanding of the Late Triassic stratigraphy.

However, previous studies of Upper Triassic palynology view the feasibility of palynological analysis of the De Geerdalen and Svenskøya formations. In addition, the Canadian Arctic and northern Russia provides palynology from the same paleolatitudes.

1.1 Palynology

Palynology is the study of acid resistant organic material including spores, pollen, acritarchs, dinoflagellate cysts, chitinozoa, fungal spores, green/blue algae and scolecodonts. Hyde et al. (1944) implemented the term palynology to refer to "the analysis of all microfossils that are resistant to aggressive chemicals such as hydrochloric acid (HCL) and hydrofluoric acid (HF)"(Riding et al., 2004). These palynomorphs are typically found in sedimentary rocks from Phanerozoic and an usual criterion is that the bodies are microscopic in size, normally from 5 μm to about 500 μm (Traverse, 2008). Palynomorphs represent parts of the life-cycles of various plants and animals, that at times have evolved rapidly (Traverse, 2008). This means that palynomorphs might be characteristic for a very narrow time-interval, and can therefore be used for age dating. With palynology, correlation between sections of rocks up to hundreds of kilometres apart can be done, even though the lithology and thickness are different. However, normally they are not widely spread, and palynology can then be used in petroleum research in oilfields to know the level of drilling, in order to find production levels for oil and gas (Traverse, 2008).

Spores and pollen grains are reproductive cells of vascular plants with a resistant outer wall made up of either sporopollenin or chitin. They can be dispersed over a wide area by river transfer, the ocean, insect activity, and most commonly, wind transportation, resulting in deposition in both marine and terrestrial environments, which is important in cross-correlating marine and non-marine deposits.

Acritarchs are microorganisms of sporopollenin known back from Proterozoic. They are presumably algal bodies and are mostly marine, and the knowledge of these specimens are questionable, like the term means; "of undecided or doubtful origin" (Traverse, 2008).

The dinoflagellates, or cysts of dinoflagellates, are "chiefly marine, usually solitary flagellate protest organisms with resemblances to both animals (motility, ingestion of food) and plants (photosynthesis)". They first evolved in the Late Triassic and are plankton that can inhabit all water types (Traverse, 2008).

1.2 Aim of study

Dating of the Late Triassic succession of the Boreal realm is challenging due to lack of absolute datings as well as lack of macrofossil records. Palynology is therefore an important tool in order to improve dating and aid in correlation.

In order to contribute to a better knowledge of the Late Triassic palynostratigraphy of the Barents Sea area, palynology of the Upper Triassic succession in the Deltaneset section on Central Spitsbergen, and an upper Triassic core from the CO_2- Lab in Longyearbyen were initially the targets of this thesis, and fieldwork was carried out in 2011. However, the preservation of palynomorphs were too poor and only the Deltaneset was kept as material for correlation. The thesis was therefore angled towards an Upper Triassic succession from Lyngefjellet, northeast on Hopen, already sampled and processed, while the Deltaneset got a lower priority and the CO_2-core excluded.

Hopen has for decades been studied as palynomorphs are present in most sections and also offers possibilities to correlate between continental and marine deposits, with the attempt to get a better understanding of the geology on the western Barents Sea platform. Age dating's from Hopen have, however, been conflicting, so the main aim was therefore to:

1) Identify, provide semi-quantitative counts, and document the palynomorph assemblages from the two locations on Hopen and on Deltaneset respectively.

2) Compile the palynological data with previously published data from the area.

3) Identify important index species and establish relative ages for each section and correlate the Hopen and Deltaneset sections.

4) As the sections on Hopen and Deltaneset are assumed to be part of the same paralic platform that built out during Late Triassic over the Barents Sea area, a lot of uncertainty is related to the location of the prograding deltafront at any time during this period. Identification of marine species, like acritarchs and dinoflagellates to indicate marine influence, as well as adding information on other palaeoenvironmental indicators was therefore an additional aim.

2 Geological setting and lithostratigraphy

2.1 Geological setting of the Barents Sea and Svalbard

The Svalbard Archipelago form the north-western most corner of the Eurasian plate with its approximately 63 000 km^2. This area, constituting about 5 % of the Barents Shelf, reflects the changing climate and environments Svalbard experienced on its way from the equator in Devonian and to its present day position at about N 78°45, E 16°00 (Worsley, 2008). Related to the opening of the Norwegian-Greenland Sea during Eocene/Oligocene, enormous compressive forces built up an orogenic belt along the western shelf edge, and by the end of Neogene the whole Barents Shelf were subjected to uplift due to periods of glaciation and deglaciation where the north-western part of the shelf, together with Svalbard, were uplifted as much as 3000m (Worsley, 2008). From Middle Devonian time to the present, tectonic activity along the western, northern and eastern shelf margins have mostly controlled the sedimentation, whereas fluctuating changes in sea level have contributed forming the deposition pattern of the sediments (Worsley, 2008).

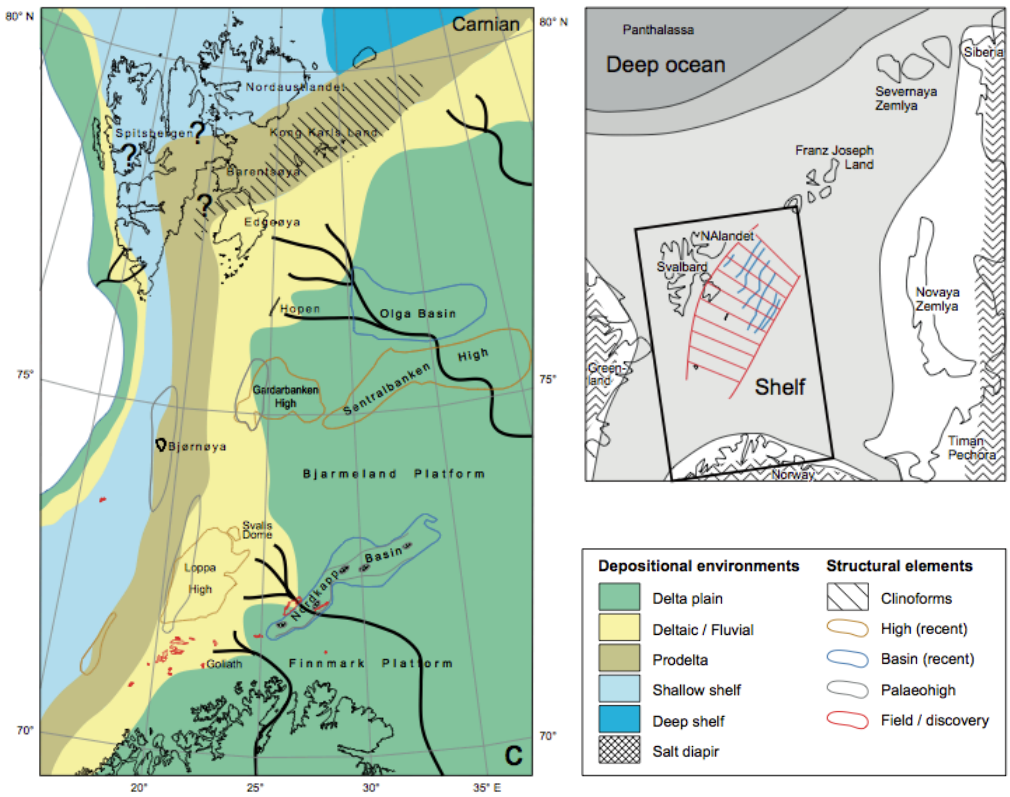


Figure 2.1 Paleogeographical map of the Carnian in the western Barents Sea area. The paralic platform evolving from the southeast in a north-westerly direction, and huge areas with deltas and floodplains where established across the shelf. From Riis et al. 2008.

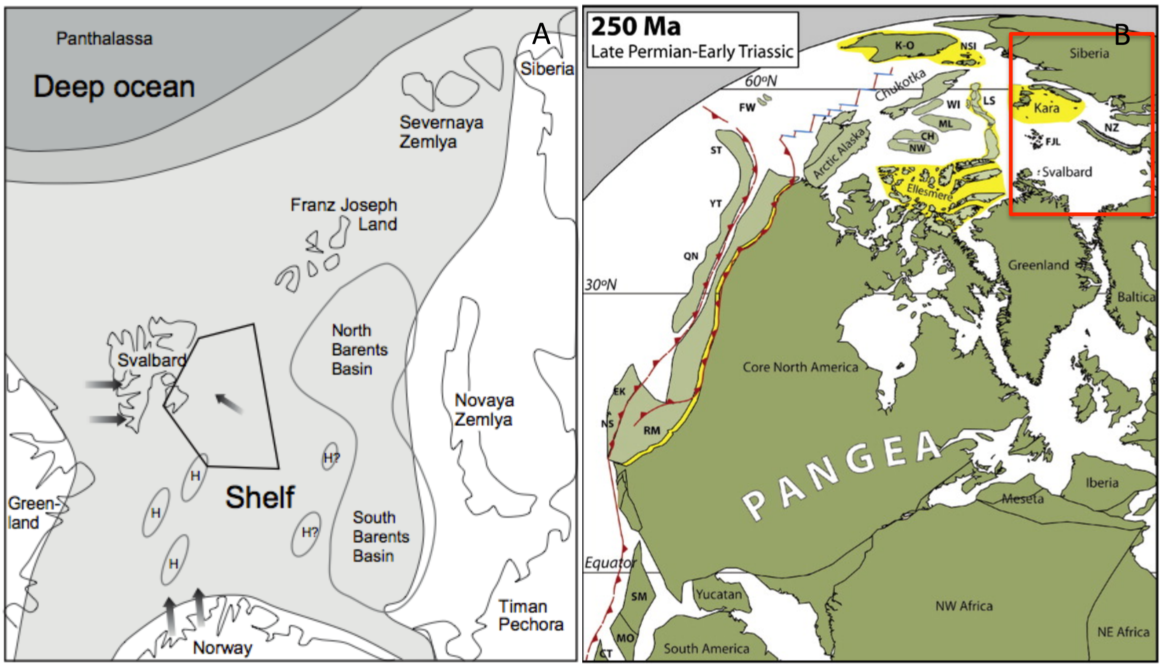


Figure 2.2 A) The plate construction in the Barents Sea area during Early and Middle Triassic. The arrow marks the sediment transport direction. From Riis et al., (2008). **B)** Terrane map of the Laurentian sector of Pangea and adjacent areas at about Permian – Triassic boundary time at 250 Ma. The Barents Shelf is marked by the red square and view the palaeo-plate construction relative to other plates. Map: Cocks et al. (2011)

2.1.1 The Triassic

The transition from Permian to the Triassic is characterized by a sudden shift from biogenic silica dominance to fine clastic material of the Sassendalen Group. Significant unconformities are recorded on highs and platforms, also shown in seismic data and in outcrops (Worsley, 2008).

From Anisian to Carnian, a paralic platform evolved from the southeast in a north-westerly direction, and huge areas with deltas and floodplains where established across the shelf (Riis et al., 2008) (Figures 2.1 and 2.2). This prograding system built out diachronous clinoform belts up to 15 km wide and 400 meters high, reaching southeastern Svalbard by Carnian time. Grey prodelta sediments recorded in the Snadd Formation on the Barents Shelf can be followed northwest onto eastern Svalbard where they coincide with the purple prodelta sediments and channel sandstones of the Tschermakfjellet and De Geerdalen formations, forming a continuous depositional system (Riis et al., 2008). See Figure 2.3 and 2.4 for comparison of formations in the Barents Sea and Svalbard; seismic lines from Sentralbanken High set up against the Lyngefjellet on Hopen (Figure 2.4).

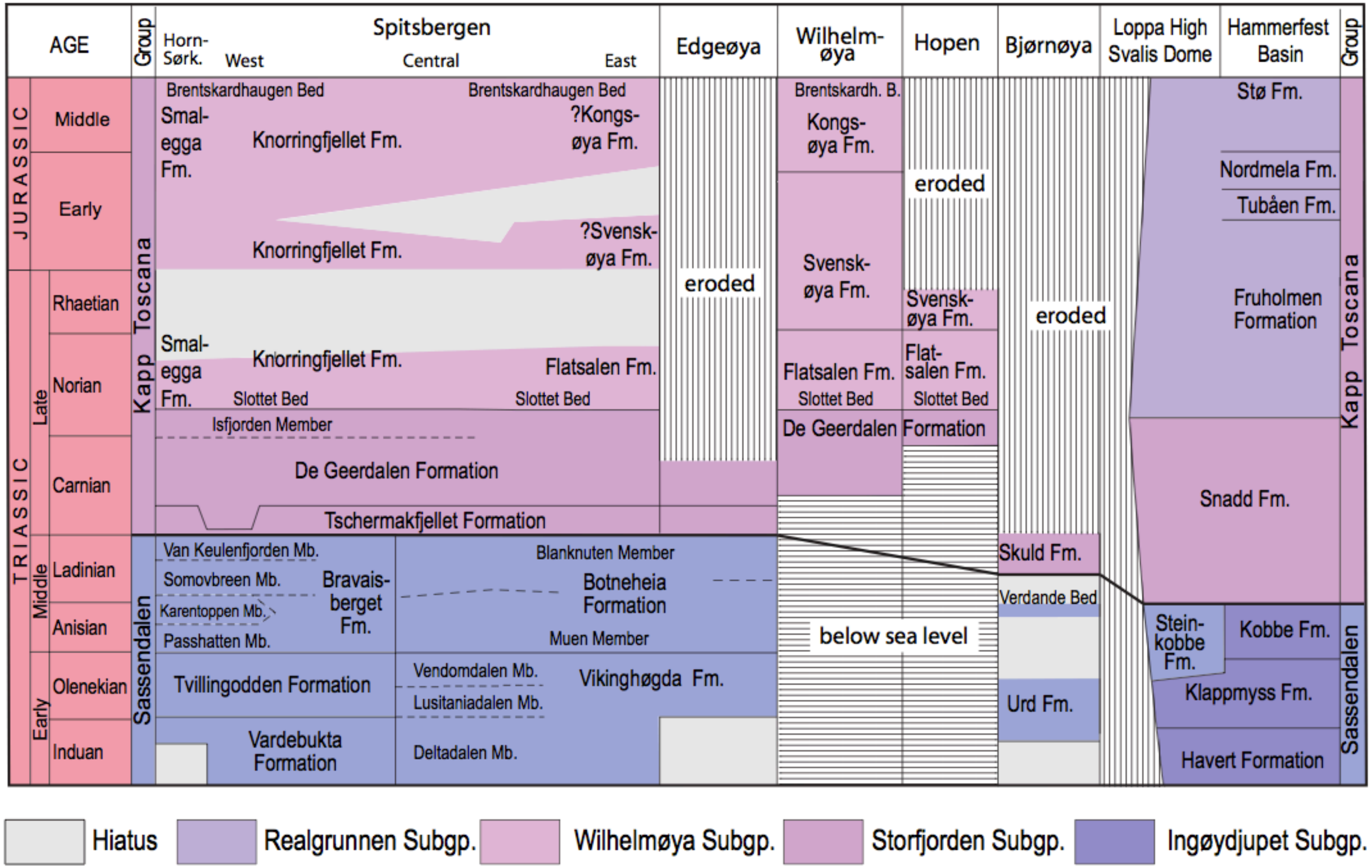
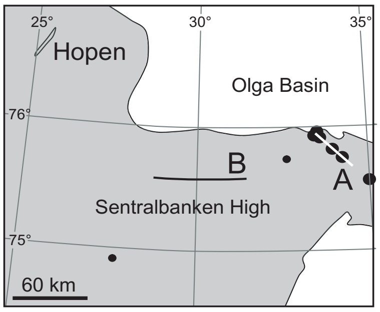


Figure 2.3 Lithostratigraphic Scheme of Svalbard. Figure from Vigran et al. (submitted)

During Late Triassic the delta system continued to fill in with sediments from the east and delta-plain environments were established, now extending to the north-eastern parts of Svalbard (Worsley, 2008).

a)



b)

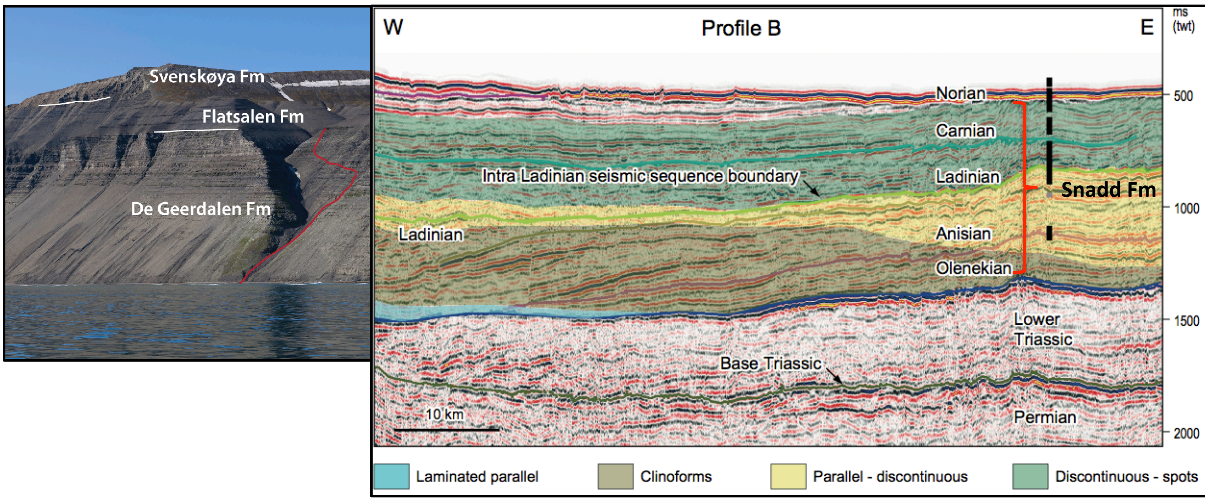


Figure 2.4 The Upper Triassic sediments on the Barents Shelf and Svalbard area form a diachronous depositional system. Prodelta sediments belonging to the Snadd Formation on the Sentralbanken High are shown in outcrop on Hopen, represented by the De Geerdalen Formation. (a) Location of the Sentralbanken section seen in Figure 2.4 b. Grey area show Triassic rocks. (b) Different facies are interpreted from seismic lines.Photo from Lyngefjellet on Hopen. Modified from *Riis et al. 2008. Photo: Terje Hellem*

2.2 Geology of Hopen

The Hopen Island belong to the Svalbard Archipelago, positioned 76° 30´N, 25°E. The Island is positioned on a partly submarine ridge, stretching from Edgeøya further north and down to Bjørnøya (Smith et al., 1975). The 37 km long island is not more than 2.5 km wide, and has a northeast to southwest trending extension with a characteristic plateau about 300 meters above sea level covering most of the island, with Iversenfjellet furthest to the south (Figure 2.5) as the highest mountain. Fieldwork on Hopen is challenging due to the shallow water surrounding the island (Figure 2.6), with steep cliffs dipping directly into the sea, and small, low raised beaches creating a problem when going ashore. Hopen was visited previously in 1898 by the Prince of Monaco´s expedition, but it was not before in the 1920s that the first scientific and topographic work were carried out by Iversen (1926) and the Norwegian Polar Institute, resulting in the first 1:100 000 map over Hopen (Smith et al., 1975).

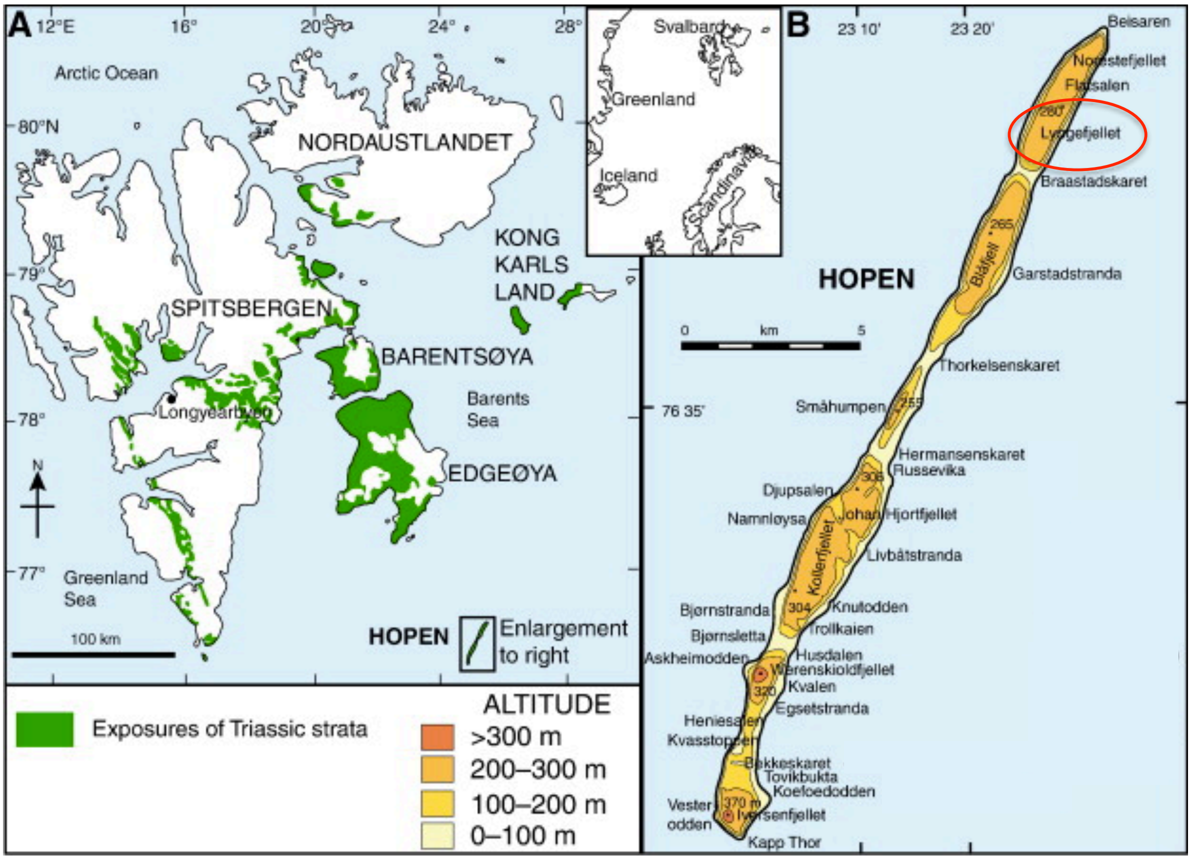


Figure 2.5 Map of the Svalbard Archipelago (A) showing the location of Hopen (modified from Vajda and Wigforss-Lange, 2009) Hopen is enlarged in (B) showing the location of Lyngefjellet and main geographic features. Base map after Harland (1997). (Strullu-Derrien et al., 2012)

Figure 2.6 Shallow water outside Gåskaret, east on Hopen. Sandstone bars in the strand plain make it hard to go ashore.

2.2.1 Lithostratigraphy

The Kapp Toscana Group was first defined by Buchan et al. (1965) and later subdivided into two subgroups (Mørk et al., 1999); the Storfjorden Subgroup and the Wilhelmøya Subgroup, with the formations; Tschermakfjellet, De Geerdalen, Flatsalen and Svenskøya. The Slottet Bed forms the base of the Flatsalen Formation (Figures 2.3 and 2.7).

The sedimentary strata on Hopen constitutes mainly sandstones, siltstones and shales, with random thin beds of carbonaceous, calcareous and ferruginous material deposited during the Late Triassic (Mørk et al., 1999). Several early workers deal with the lithostratigraphic succession on Hopen including Flood et al. (1971), correlating the sediments to the De Geerdalen Formation on Spitsbergen, Worsley (1973) divided the succession into the De Geerdalen and the Wilhelmøya formations, including four members in the latter (Figure 2.7). A few years later Smith et al. (1975) divided the succession into three formations: the lowermost Iversenfjellet Formation, the Flatsalen Formation and the youngest Lyngefjellet

Formation. Bjærke et al. (1977) followed this subdivision, with the exception of the boundary between the De Geerdalen and the Flatsalen formations which they placed lower, equalling Worsley (1973) division (Figure 2.7).

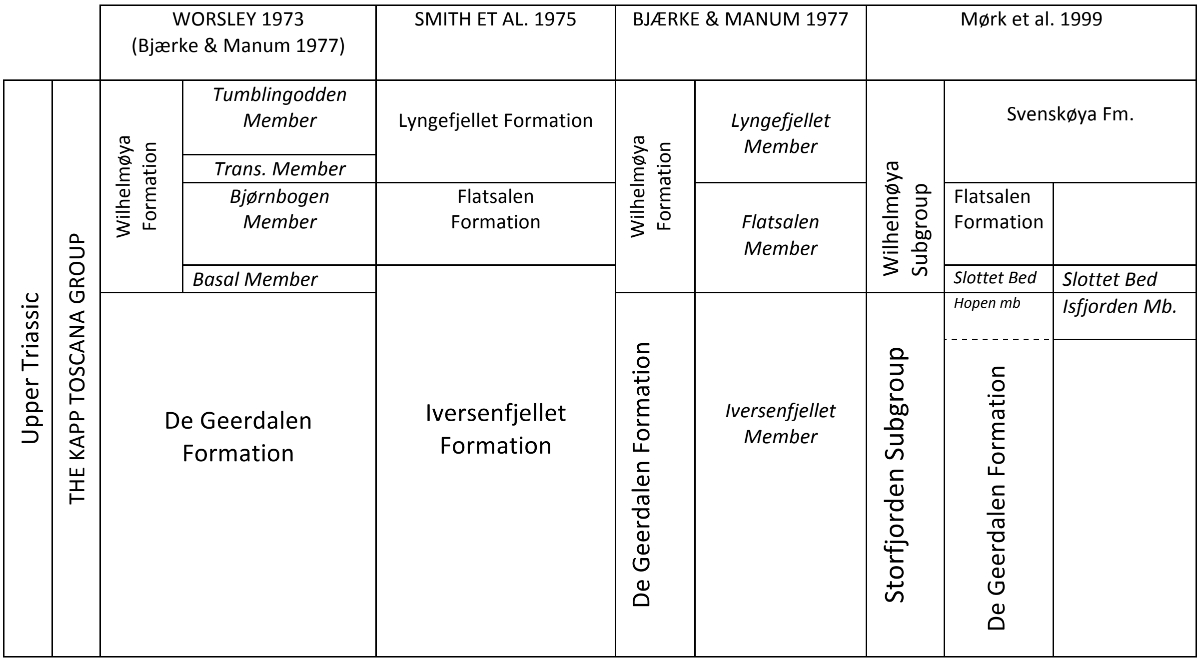


Figure 2.7 Lithostratigraphy of the Kapp Toscana Group on Hopen. Through time several divisions of the Kapp Toscana Group have been suggested. Hopen Member included by Solvi (2013). Modified from Bjærke et al. (1977).

The studied section is located at Lyngefjellet (Figure 2.5) and the base of the profile starts with the first prominent sandstone layer (Figure 2.8). Only the upper part of the De Geerdalen Formation is recorded from Hopen (Worsley, 2008). The De Geerdalen Formation is recognized by its massive sandstone packages protruding the mountainside, alternating with thinner beds of shale. The uppermost section in the De Geerdalen Formation is darker in colour and equivalent to the Isfjorden Member (Figure 2.3). The type section of the Slottet Bed is 5.2m thick, but occur most often as a 2m thick deposit, containing quartzose sandstones, alternating with phosphatic nodules and siltstones, representing a condensed shelf deposit. Both on Wilhelmøya and Hopen, a yellow-brown carbonate layer is present in the upper part, and bivalves, brachiopods and ammonoids are recorded (Mørk et al., 1999). The Slottet Bed initiates the Flatsalen Formation which consists of coarsening upward units with marine shales becoming more silty to sandy towards the top (Mørk et al., 1999). A sandstone unit forming the highest peaks on Hopen are assigned to the Svenskøya Formation (Mørk et al., 1999).

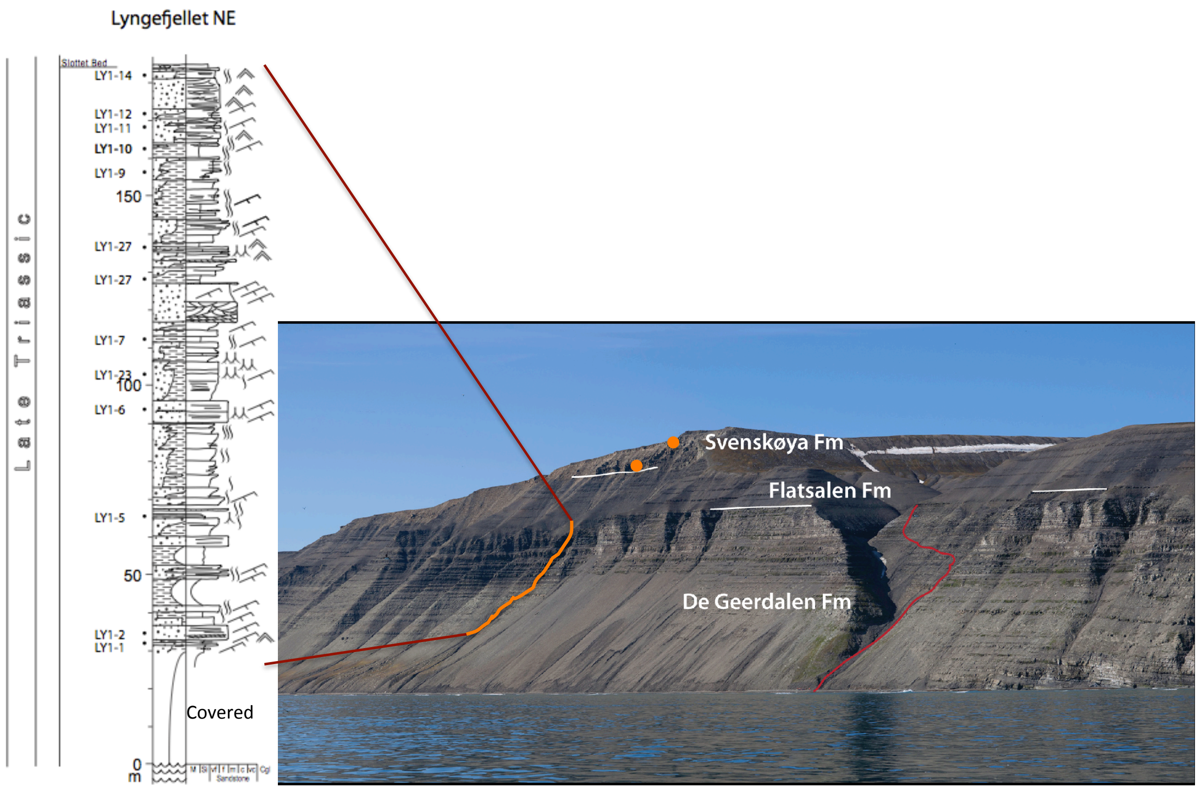


Figure 2.8 The studied section from Lyngefjellet, northeast on Hopen, is marked with an orange line on the photo. The studied palynological samples are shown on the log, logged in 1995 by G.B. Larssen and others, and redrawn by Atle Mørk in 2013. Two orange dots represent the material sampled from the Svenskøya Formation. The red line represents the Binnedalen section, which I participated logging in 2011. See Appendix for the log in larger view. *Photo: Terje Hellem*

2.2.2 Previous biostratigraphic work

Several papers dealing with age interpretation of the Hopen successions have been published, and Smith et al. (1975) refers to Richard (1899), Hoel (1925, 1926), Werenskiöld (1926), Bodylewsky (1926), Horn (1932), Frebold (1935, 1951), Orvin (1940), Iversen (1944, 1945 and 1951), Buchan et al. (1965) and Thorén (1969), ranging from late Triassic to an early Cretaceous age. More recent studies suggested a Late Triassic age based on macrofossils (Flood et al., 1971), while Worsley (1973) suggested a Rhaetian to lower Jurassic age. The Norwegian Cambridge Svalbard Expedition preformed fieldwork on Hopen with the purpose of getting a better understanding of the geology and the petroleum potential, which resulted in two publications, including palynological investigations, by Smith (1974) and Smith et al. (1975). Smith (1974) concluded with a Rhaetian age, possible Norian and Hettangian ages, of the Hopen succession based on palynological studies, and

Smith et al. (1975) supports this conclusion for upper sections on Lyngefjellet, Johan Hjortfjellet and Iversenfjellet (Figure 2.5). Bjærke et al. (1977) suggests an Rhaetian age for the upper part of the Iversenfjellet, which is consistent with Smith et al. (1975). The latter did, however, argue that the palynological evidence for a Norian or Hettangian age as suggested by Worsley (1973) was faint. It should be noted that both Bjærke et al. (1977) and Smith et al. (1975) concluded with a Rhaetian age for the Flatsalen Formation on palynological evidence alone, despite the fact that *Sirenites* ammonoids recorded by Flood et al. (1971) and Smith et al. (1975), was not recorded from younger strata than Norian. In addition the Soviet geologist Pchelina (1972) suggested a Carnian to Norian age based on macrofossil finds, and Korchinskaya (1982) suggested an Early Norian age due to several macrofossil finds on Lyngefjellet (See Figure 2.9 and Table 2.1 for location of macrofossil finds). Based on these data Smith (1982) suggested that the palynomorph assemblages recorded by Bjærke et al. (1977) and Smith et al. (1975) should be pre-Rhaetian, and that the Flatsalen Formation on Hopen was of Early Norian (*kerri* Zone) in age from associated ammonites.

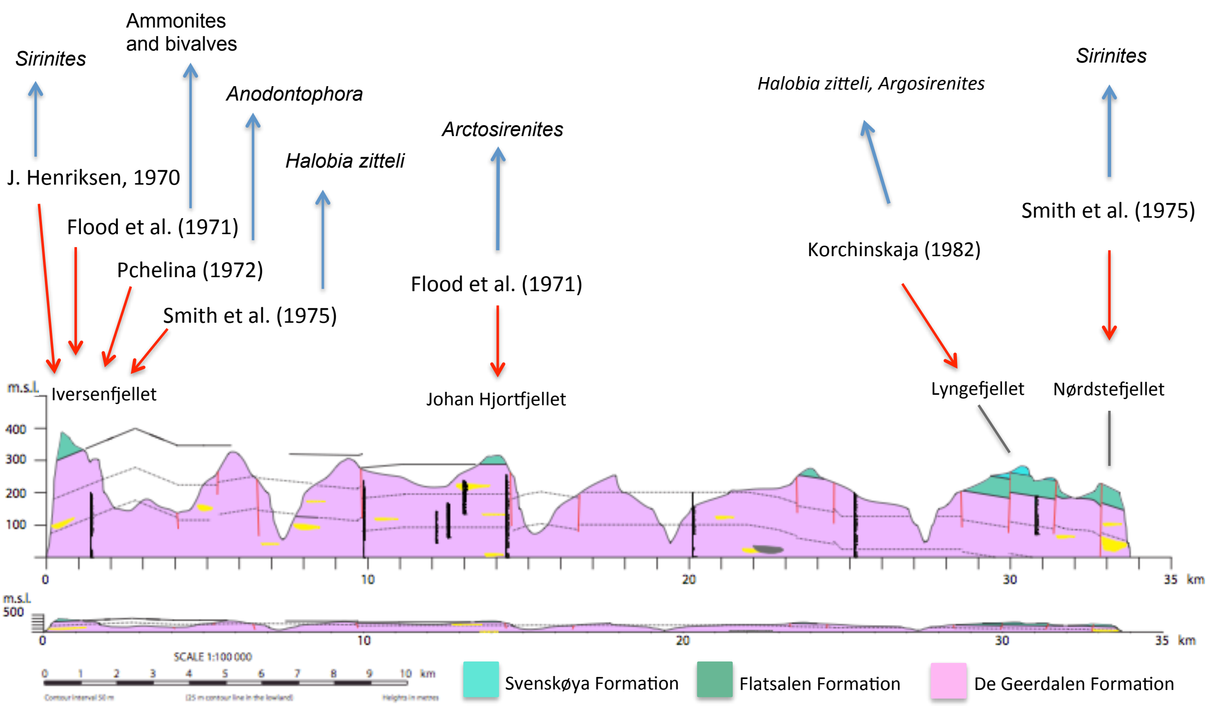


Figure 2.9 Hopen profile showing location on published macrofossil finds. See Table 2.1 for a more complete overview. Figure modified by Klausen et al. (2013) from Smith et al. (1975), and modified again herein.

Table 2.1 Overview of macrofossil finds. The formation, location and type of species are noted. The ages are suggested by the authors.

Found by	**Formation**	**Location**	**Macrofossil type**	**Species**	**Age**
Flood et al., (1971)	Flatsalen	Johan Hjortfjell	Ammonite, bivalve	*Arctosirenites, Halobia zitteli*	Carnian
Jarle Henriksen 1970 (Smith et al., 1975)		Iversenfjellet	Ammonite	*Sirinites*	Carn/e.Nor
Smith et al. (1975)	Flatsalen	Nørdstefjellet	Ammonite	*Sirinites*	Carn/e.Nor
Pchelina (1972)	Flatsalen	Iversenfjellet	Bivalve	*Anodontophora* cf. *ovalis*	Norian
Smith et al. (1975)	Flatsalen	Iversenfjellet	Bivalve	*Halobia zitteli*	Carnian
Pchelina (1972)	De Geerdalen	Iversenfjellet		Plant-bearing horizons	Carnian
Korchinskaya (1982) (Smith 1982)	Flatsalen	Lyngefjellet	Bivalve, ammonoids	*Halobia, Argosirenites nelgehensis, A.* cf. *obruchevi*	Early Norian
Flood et al. (1971) (Smith 1974)	De Geerdalen and Flatsalen	Iversenfjellet	Ammonites and bivalves		Carnian

2.3 Geological setting of Deltaneset area

2.3.1 Lithostratigraphy

The Deltaneset is located southeast in Isfjorden on Central Spitsbergen, east of Longyearbyen (Figures 2.10 and 2.12). The section on Deltaneset belongs to the Storfjorden Subgroup (Figure 2.3) and is believed to be a part of the uppermost section of the De Geerdalen Formation. The strata have a south-eastern dip and consists of alternating mudstones, siltstones and sandstones, disrupted of covering (Figure 2.11). The sediments are a part of the paralic platform that was build out over the western Barents Sea region during the Middle- to Late Triassic (Riis et al., 2008).

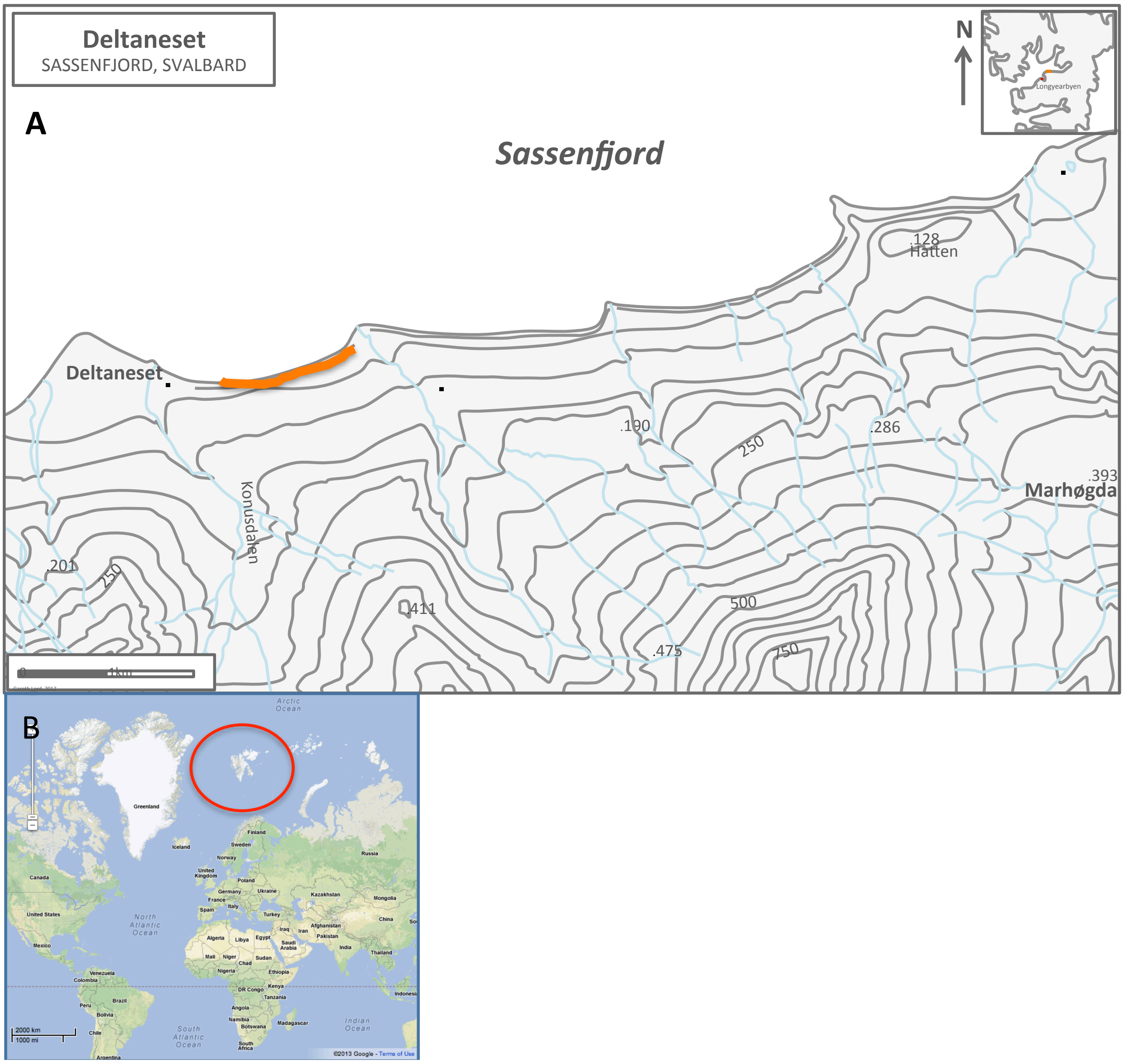


Figure 2.10 A) The studied section on Deltaneset, central Spitsbergen, is marked with an orange line. See Figure 2.12 for the position of Deltaneset compared to Longyearbyen. Map by Lord (2013 (in pres)). B) The position of Svalbard relative to the other continents. Map: Google Maps

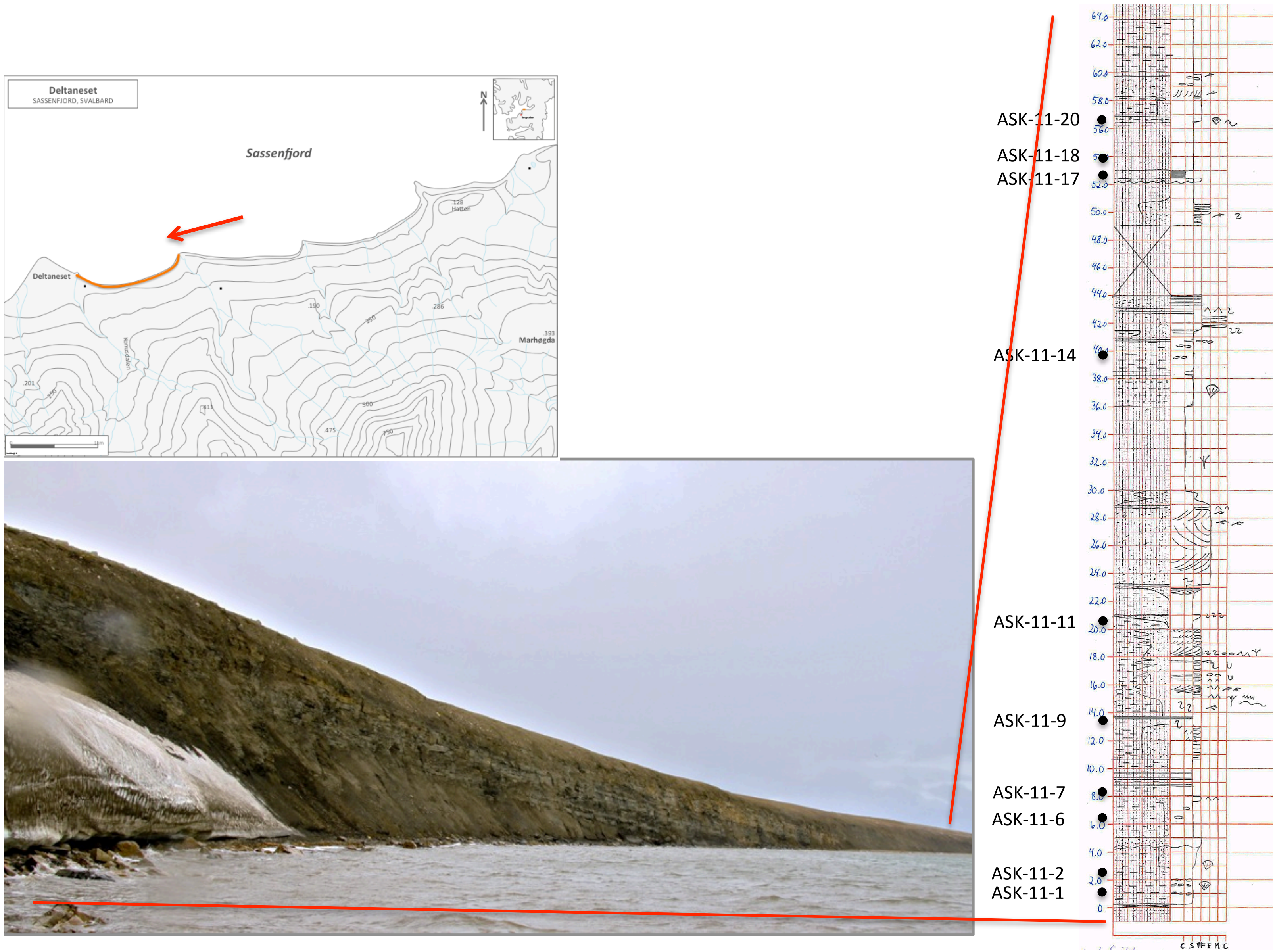


Figure 2.11 The studied section from Deltaneset, central on Spitsbergen. The associated log is shown to the right, logged in 2011 by Marianne Ask and Benedikte Jarstø. Map: Lord (2013 (in pres)).

2.3.2 Previous work on Deltaneset

No palynological investigations have previously been done on the Deltaneset section, but nearby palynological studies in the Kapp Toscana Group have been conducted by Bjærke et al. (1976) and Nagy et al. (2010) in Sassenfjorden and on Juvdalskampen section, respectively (Figure 2.12).

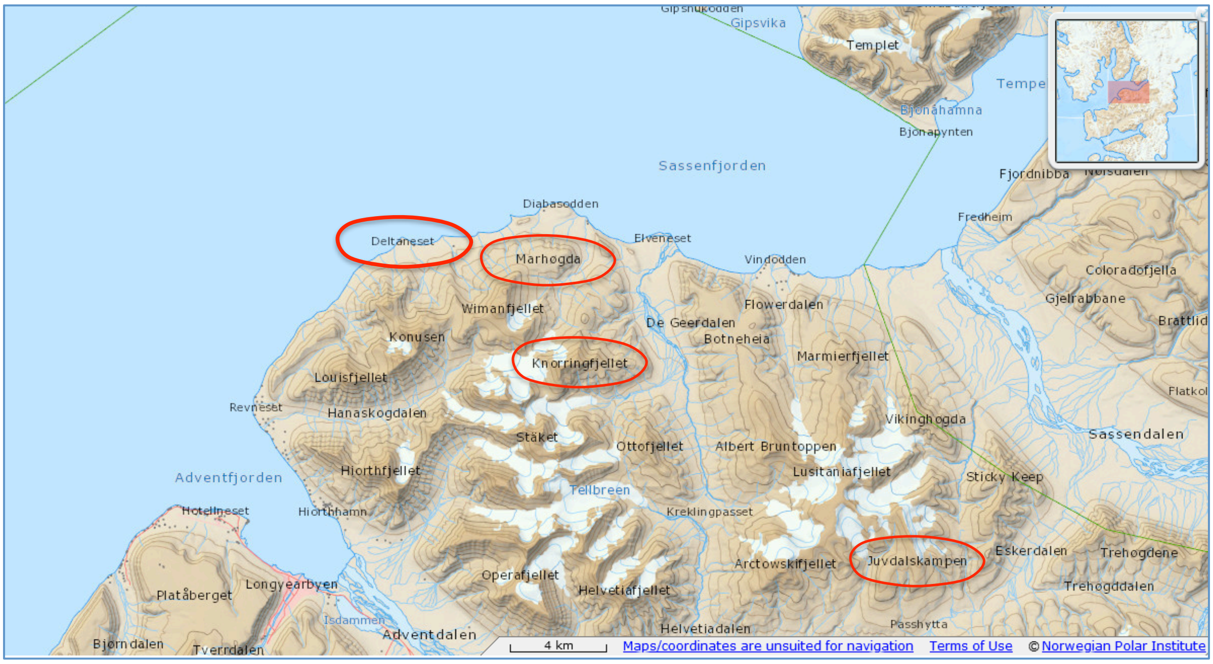


Figure 2.12 Palynological study areas in Sassenfjorden, Isfjorden. Marhøgda and Knorringfjellet were studied by Bjærke et al. (1976), while analysis on the Juvdalskampen section were recorded by Nagy et al. (2010). Map from Norwegian Polar Institute.

Bjærke and Dypviks work from 1977 was carried out in the area between Diabasodden and De Geerdalen (Figure 2.12). The upper 20 m of the Kapp Toscana Group section was measured and sampled at Marhøgda and Knorringfjellet localities, where the lowermost 3 meters represents the De Geerdalen Formation (= De Geerdalen Member in 1977 (Bjærke et al., 1976)). Three palynological samples from the De Geerdalen Formation were studied: two samples were nearly barren and yieled only black, organic debris. One sample recorded from top De Geerdalen Formation at Marhøgda was analysed and yielded an assemblage which was correlated to sections on Hopen and Edgeøya (Bjærke et al., 1976). The overlying succession, representing the Knorringfjellet Formation with the lower part making up the Slotted Bed (Nagy et al., 2010), yielded well-preserved palynomorphs charaterized by Rhaetian assemblages (Bjærke et al., 1976), proceeding to the Triassic – Jurassic boundary.

Detailed biostratigraphic work from Juvdalskampen section (Figure 2.12) was conducted by Nagy et al. (2010), who established five microfossil-based biofacies zones. The biofacies zonation contains pollen and especially spores typical for a deltaplain-environment, that strengthens Riis et al. (2008) suggestion of a north-west prograding paralic system over Svalbard during Late Triassic, and the biofacies are useful in correlation of strata deposited in this region during the time interval.

3 Material and Methods

3.1 Collection of material

Fieldwork on Deltaneset was carried out during the summer 2011 and one section was logged and sampled. 24 samples of shale-silt lithology were processed for palynology and ten turned out to be productive. Core samples were recorded from the DH4 CO_2-core in the Longyearbyen CO_2 Lab at UNIS the same summer. The palynological samples processed from this core did, however, not have preservation satisfying for a master thesis study.

The samples from Hopen were sampled by Norwegian Petroleum Directorate during the summer of 1995 and cover one section east on Lyngefjellet (Figure 2.8).
Fourteen samples were processed and one was almost barren.

The sections and distribution of the samples are shown on Figures 2.8 and 2.11. Only the productive samples recorded from Deltaneset are marked.

3.2 Preparation

Palynological Processing version 5 (Method PP/5)

The samples were processed following standard palynological techniques. This includes hydrofluorid acid (HF) and hydrochloric acid (HCl) for silicate digestion, followed by oxidation using nitric acid. For mounting the solution is mixed with a copper sulphate solution for the inhabitation of fungal growth and glycerine jelly for glue, and mount on a slide over a heat table for drying. Figure 3.1 shows a simplified step-by-step procedure for the preparation method.
In order to learn the palynological preparation technique, I was trained during a two days course at Applied Petroleum Technology in Lillestrøm the winter of 2013. The main purpose was to achieve practical experience on how the procedure is performed, get to know the critical stages in preparation and how this can be taken into consideration during palynological analysis.

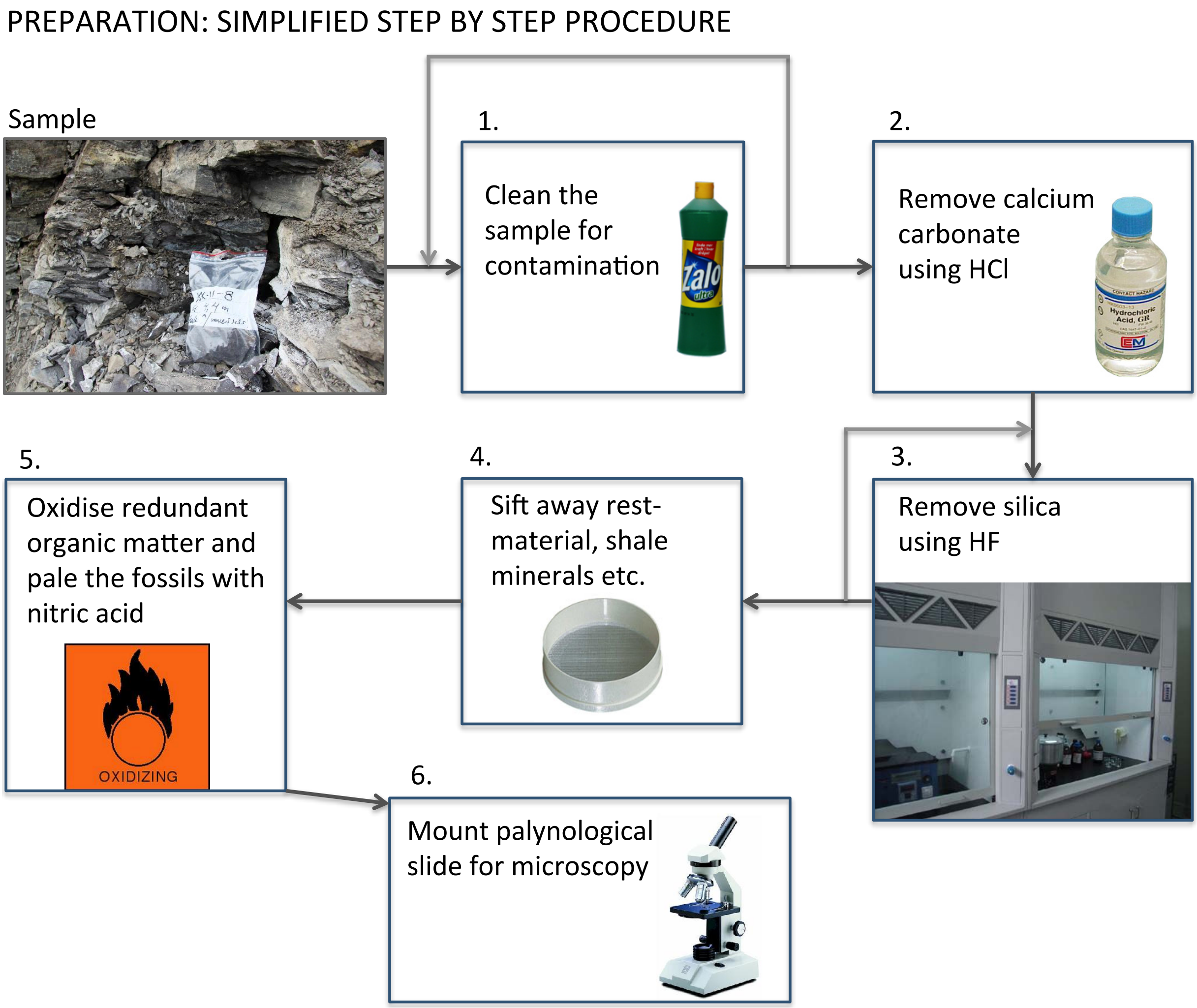


Figure 3.1 The procedure for processing palynological samples. The technic is simplified, but includes the important steps in the method; hydrofluid acid (HF) and hydrochloric acid (HCl) for silicate digestion, followed by oxidation using nitric acid.

3.3 Microscopy

Preparation analyses were preformed on a Zeiss Axioplan microscope, using magnification of 10x, 20x, 40x and 63x objectives. The pictures where taken with a Zeiss Axio Imager.A2, AxioCam ERc 5s. Approximately all of the pictures were photographed with 100x oil magnification. The pictures that do not have a scale (some overview pictures and palynomorphs) are photographed with 20x or 40x magnification.

3.4 Method

A total of 200 species were counted in each slide. To achieve a representative result, all counts were started to the left in the middle of the slide. The counting includes spores, pollen grains, acritarchs, dinoflagellates and other species, examining all taxa that are present, also when the preservation was to poor for identification to species level. The slide was then scanned for additional species (marked with “p” = present in the range charts). The publications of Bjærke et al. (1977) and (Lund, 1977) have been a great help in determination of species, together with among others Playford et al. (1965), Morbey (1975) and Mädler (1964).

3.4.1 Palynofacies

Since no specially prepared palynofacies slides were available, palynofacies is just commented on in a qualitative manner.

4 Results

4.1 Preservation

A total of 24 slides were analysed. All contained organic debris, carbonized tracheidal matter, and the palynomorphs were poorly preserved in most of the slides. Spores dominate the assemblage in all the slides (Appendix III and IV), and most of the recorded pollen grains are corroded and difficult to identify. Pollen are therefore lumped together and notified as “bisaccate pollen” or “striate pollen”, with a few exceptions where the preservation allowed identification to genera or species level.
High diversity in the slides is defined by more than 20 different taxa.

4.1.1 Palynomorph preservation on Lyngefjellet, Hopen

Among the Lyngefjellet samples, slides LY-1-5, LY-1-6, LY-1-23, LY-1-27A, LY-1-36 and LY-1-40 (Figure 2.8) have relatively good palynomorph preservation, whereas one sample LY-1-7 was barren (Appendix III).
Samples LY-1-1 and LY-1-2 recorded from the lower part of De Geerdalen Formation on Hopen are very poor and contain a high content of dark material. The exines are ragged and the spores are generally corroded. Samples recorded from the middle section of De Geerdalen Formation, between LY-1-5 to LY-1-27A, do however, have a high diversity and preserved spores with exception of sample LY-1-7, which is totally corroded and oxidised. Imprints of minerals in taxa from the upper part of De Geerdalen Formation are observed in slides LY-1-9, LY-1-10 and LY-1-11, and are probably of pyrite. The preservation in these slides are poor, also containing a lot of dark, carbonized matter. High content of spores in samples LY-1-12 and LY-1-14 from the uppermost section of the De Geerdalen Formation (Figure 2.8) is noted. However, identification to species level was problematic because they were covering each other, as well as morphological features blurred by corrosion. Samples LY-1-36 and LY-1-40, from the Svenskøya Formation, yield a high diversity of spores that are well preserved.
The diversity is relatively high in all samples, except LY-1-23, which has generally few palynomorphs. Content of organic debris and carbonized tracheidal matter seem to be higher in the samples with poorly preserved palynomorphs (Table 4.1).

Table 4.1 Palynomorph preservation and different features, Lyngefjellet, northeast on Hopen

LYNGEFJELLET, NE HOPEN								
Sample	masl	Preservation	Organic debris	Carbonized tracheidal matter	Diversity (nmb. of taxa)	Pyrite crystl.	Marine influence	Lithology
LY-1-1	30	Poor	X	Very little	26		X	Sandstone
LY-1-2	35	Poor	X	Yes	28		X	Sandstone
LY-1-5	69	Good	X	Very little	23		X	Shale
LY-1-6	93	Good	X	Yes	25		X	Sandstone
LY-1-23	105	OK	X	Very much	17		X	Silty sandstone
LY-1-7	113	Very poor	X	Very much	Barren sample		Unknown	Shale
LY-1-27A	128	Good	X	Very much	21		No	Shale
LY-1-9	137	Poor	X	Yes	29	X	X	Sandy siltstone
LY-1-10	147	Poor	X	Yes	30	X	X	Shale
LY-1-11	162	Poor	X	Yes	29	X	X	Sandy siltstone
LY-1-12	171	Poor	X	Yes	34		X	Silty sandstone
LY-1-14	183	Poor	X	Yes	19		X	Silty sandstone
LY-1-36	236	OK	X	Yes	37		X	
LY-1-40	275	Good	X	Yes	29		No	

masl = meters above sea-level

4.1.2 Palynomorph preservation on Deltaneset, Central Spitsbergen

All the palynological slides from Deltaneset have a high diversity of palynomorphs, but the exines are ragged and the specimens look generally corroded, in addition to organic debris and carbonized tracheidal matter covering over palynomorphs. Few specimens are well preserved, and in samples ASK-11-1 and ASK-11-6, more than half of the counted spores are not possible to identify either to genera or species level (Appendix IV and Figure 2.11). 21 samples were collected on Deltaneset, but only ten were workable.

Samples ASK-11-1, ASK-11-2 and ASK-11-7 from the lowest part of the section on Deltaneset contain palynomorphs with imprints of, probably, pyrite minerals. Some palynomorphs from sample ASK-11-2 are well preserved, but the majority are corroded and difficult to identify. Samples ASK-11-11 and ASK-11-14 (Figure 2.11) yielded palynomorphs of similar preservation as observed in sample ASK-11-2. Pyrite crystals are also found from 52.40 m on the profile in sample ASK-11-17 (Figure 2.11). The preservation of palynomorphs in this sample is poor, but it has the highest diversity of specimens (Table 4.2). Samples ASK-11-18 and ASK-11-20, from the uppermost part of the sampled section (Figure 2.8), yielded the most well-preserved taxa (See Appendix IV for exact counting of palynomorphs).

Table 4.2 Palynomorph preservation and different features, Deltaneset, Central Spitsbergen

DELTANESET, CENTRAL SPITSBERGEN								
Sample	Meter above base log	Preservation	Organic debris	Carbonized tracheidal matter	Diversity (nmb. of taxa)	Pyrite crystl.	Marine influence	Lithology
ASK-11-1	1.20	Poor	X	Yes	32	X	X	Shale
ASK-11-2	2.60	Poor	X	Yes	30	X	X	Shale
ASK-11-6	6.40	Very poor	X	Yes	30		X	Sandy siltstone
ASK-11-7	8.32	Poor	X	Yes	35	X	X	Shale
ASK-11-9	13.45	Poor	X	Yes	29		X	Shale
ASK-11-11	20.60	Poor	X	Very little	28		X	Sandy siltstone
ASK-11-14	40.80	Poor	X	Yes	24		X	Shale
ASK-11-17	52.40	Poor	X	Yes	41	X	X	Dark siltstone/coal
ASK-11-18	53.80	Poor	X	Yes	31		X	Shale
ASK-11-20	56.60	OK	X	Yes	30			Shale

4.2 Palynomorph distribution

4.2.1 Palynomorph distribution on Lyngefjellet

The assemblage of palynomorphs varies vertically considering to taxa, diversity of species and the frequency of the individual species (Table 4.1). All results are documented in the range chart, Appendix III. *Deltoidospora* spp. was the dominating taxa in most of the samples, but some important observations are listed below, ranging from the lowermost:

(1) The lowermost sample from De Geerdalen Formation, LY-1-1, contains the dinocyst *Pareodinia ceratophora.* The occurrence of this marine specimen was also recorded from eastern Svenskøya, Kong Karls Land, by Bjærke et al. (1977). *Pareodinia* spp. is also observed in LY-1-2 and LY-1-5, while *Pareodinia evetti* is recorded from LY-1-36, 236 m from base profile (Figure 2.8).

(2) At 93 m above base profile (Figure 2.8), an acme of the spore *Leschikisporis aduncus* characterize sample LY-1-6. A similar occurrence is recorded in a coal sample from the De Geerdalen Formation about 100 m at Iversenfjellet by Bjærke et al. (1977).

(3) An assemblage of *Calamospora nathorstii, Chasmatosporites* spp., *Conbaculatisporites* spp., *Neoraistrickia taylorii, Eucommiidites* spp., *Dictyophyllidites mortonii* and *Leschikisporis aduncus* is present in sample LY-1-23 and LY-1-27A, and a

similar association is recorded in the upper section of De Geerdalen Formation by Bjærke et al. (1977) from Kollerfjellet (Figure 2.5).

(4) Sample LY-1-27A contain the species *Cingulizonates rhaeticus*, which is not observed in other samples. Bjærke et al. (1977) recorded this taxa in one sample from the Flatsalen Formation on Johan Hjortfjellet (Figure 2.5).

(5) Sample LY-1-10 and LY-1-236 yield the occurrence of *Riccisporites* spp. and *Riccisporites tuberculatus.* These specimens are also recorded by Smith et al. (1975) from eastern Lyngefjellet at approximately the same levels (Figure 2.8. LY-1-236 is recorded from base Svenskøya Formation).

(6) *Deltoidospora* spp.*, Protodiploxipinus* spp.*, Calamospora nathorstii, Conbaculatisporites* spp., and *Kyrtomisporis spp.* are common taxa in sample LY-1-10, LY-1-11, LY-1-12, LY-1-14 and LY-1-36.

(7) *Semiretisporis gothae* is a characteristic component of sample LY-1-14. The specimen is also observed in LY-1-14 and LY-1-36 (Figure 2.8).

(8) The sample in the top section, LY-1-40, contain the important species *Limbosporites lundbladii,* which is not recorded further south on Hopen*.* This specimen is common in the lower section on Kong Karls Land together with *Riccisporites tuberculatus* (Bjærke et al., 1977). Hochuli et al. (1989) have used *Limbosporites lundbladii* and *Riccisporites tuberculatus´* occurrences, inter alia, as marker species in their publication.

(9) *Limbosporites lundbladii, Semiretisporis gothae, Riccisporites* spp., *Cingulizonates rhaeticus, Zebrasporites interscriptus,* among others, are recorded from dated core samples in the Arctic Canada Archipelago (Fisher, 1979). *Limbosporites lundbladii* and *Ovalipollis ovalis* are also common in higher middle Keuper facies in Europe (Fisher et al., 1975).

(10) Marine influence is identified in all samples except LY-1-23, LY-1-27A and LY-1-40 (Figure 2.8). Cf. *Rhaetigonyaulax rhaetica* is present in the samples from the De Geerdalen Formation, whereas the acritarchs *Veryhachium reductum* and *Micrystridium* spp. are more common in samples LY-1-10 to LY-1-14. The marine species *Suessia swabiana* is observed in sample LY-1-2, LY-1-6 and LY-1-14, and is also recorded in the lowermost section of Romulus Member in Heiberg Formation from east and central Sverdrup Basin in Arctic Canada (Suneby et al., 1988).

4.2.2 Palynomorph distribution on Deltaneset

The distribution of palynomorphs changes through the profile, both in species, diversity and quantity. All results are documented in the range chart, Appendix IV. Although the palynomorphs are poorly preserved, some essential features are observed and summarized below:

1) Sample ASK-11-1 is dominated by *Deltoidospora* spp. and *Dictyophyllidites mortonii.* Other species that are observed are among others; *Annulispora* spp., *Zebrasporites interscriptus, Duplexisporites problematicus, Camarozonosporites rudis, Aratrisporites macrocavatus,* together with the marine acritarchs *Veryhachium* spp. and *Micrhystridium* spp. The occurrence of these species was also recorded by Bjærke et al. (1976) from Marhøgda (Figure 2.12).
2) *Lycopodiacidites rugulatus* has its only occurrence in sample ASK-11-2. *Semiretisporis gothae* has its first occurrence in sample ASK-11-2.
3) Sample ASK-11-6 from 6.40 m in the profile (Figure 2.11) contains *Taeniasporites rhaeticus* and *Guthoerlisporites cancellousus*, which have not been observed in other samples. *Taeniasporites rhaeticus* has been observed by Bjærke et al. (1976) from Marhøgda and Bjærke et al. (1977) on Hopen. *Deltoidospora* spp. and *Dictyophyllidites mortonii* are the dominat spores in this sample.
4) *Schizaeoisporites worsleyi, Converrucosisporites cameronii* and cf. *Schizosporis* spp*.* are recorded in sample ASK-11-7. cf. *Schizosporis* spp. is only present in this sample.
5) *Leschikisporis aduncus* occur for the first time in ASK-11-6, but has a peak in ASK-11-14, at 40.80 m in the measured profile (Figure 11). This trend was also recorded by Nagy et al. (2010) from Juvdalskampen section, and from the Lyngefjellet samples on Hopen. *Leschikisporis aduncus* is absent in samples from Marhøgda and Kollerfjellet by Bjærke et al. (1976).
6) At 52.40m, sample ASK-11-17 (Figure 2.11), a higher quantity of pollen is registered. At this level, *Krauselisporites dentatus* and *Riccisporites umbonatus* are observed. *Protodiploxipinus* spp. is the dominating taxon, while *Kyrtomisporis* spp. is recorded for the first time at this level. *Kyrtomisporis spesiosus* is recorded in strata above the De Geerdalen Formation from Juvdalskampen by Nagy et al. (2010). *Riccisporites umbonatus* is also present in sample ASK-11-20 (Figure 2.11).

All the samples from Deltaneset, except for ASK-11-20, show marine influence. *Veryhachium* spp. is present in all slides, while *Micrhystridium* spp. or *Baltisphaeridium* spp. are recognised in most (See range chart in Appendix IV). The dinoflagellate cf. *Rhaetigonyaulax rhaetica* is recorded in samples ASK-11-1, ASK-11-6, ASK-11-7 and ASK-11-14 (Figure 2.11). These marine species are also recorded from Marhøgda and Knorringfjellet (Bjærke et al., 1976)(Figure2.12), with the exception of *Baltisphaeridium* spp.
The palynomorph assemblages from Deltaneset are similar to assemblages in the De Geerdalen and Knorringfjellet formations from Juvdalskampen section by Nagy et al. (2010).

5 Discussion

5.1 Dating and correlation

5.1.1 Lyngefjellet, Hopen

Three assemblages are defined from the section on Lyngefjellet, eastern Hopen. These are compared to palynological assemblages from the western Barents Shelf, the Svalbard region and Arctic Canada.

Assemblage L-1
Formation: The De Geerdalen (the lower and middle section represented on Hopen)
Age: Late Carnian
Interval: LY-1-1 – LY-1-23 (Figures 5.1 and 5.2)

In the lower and middle section of the De Geerdalen Formation on Hopen, siltstones and coal layers intercalate with sandstones. The palynomorphs recorded are dominated by long-ranging taxa like *Deltoidospora* spp., *D. toralis, D. auritora, Calamospora nathorstii* and *Leschikisporis aduncus*, appearing as common or abundant. None of these species are of stratigraphic importance, however, the abundance characterize wetland environments and can be used for local correlation. In a not published industry report from the Barents Sea area (Veen) similar assemblages are documented in the Triadispora verrucata – Leschikisporis aduncus Palynozone (Tr V), from sediments assigned a Carnian age, based on ammonites. However, no further documentation is included, neither the location nor genus of ammonite finds.

Abundant *Deltoidospora* spp. and *Leschikisporis aduncus* are also characteristic of the assemblages of Nagy et al. (2010), MB 2 and MB 3 (Figure 5.3) from the Juvdalskampen, Central Spitsbergen (Figure 2.5). A middle- to late Carnian age is suggested for the Juvdalskampen section, based on palynological correlation (Bjærke et al., 1976; Bjærke et al., 1977). Assemblages from the lower part of the De Geerdalen section on Hopen are not recorded by Bjærke et al. (1977), but according to (Smith et al., 1975) the age of the lower half of the De Geerdalen section on Iversenfjellet, Southern Hopen (Figure 2.5), is Carnian based on work done by Pchelina (1972), who studied Late Triassic flora in this section. It is unclear what Pchelina based her age assignments on, but most probably by comparison with similar floras from the Russian Arctic.

A Late Carnian age is suggested for Assemblage L-1 based on palynological correlation. Relatively few taxa range from the Carnian into the Norian, where new species become common (Fisher 1979). However, dominance of long ranging taxa often hampers an exact definition of the Carnian to Norian boundary based on palynology. Assemblage L-1 is dominated by terrestrial wetland species, and according to Riis et al. (2008), the prograding deltafront reached Eastern Svalbard by Late Carnian (Chapter 2.1), which is supported by the present study.

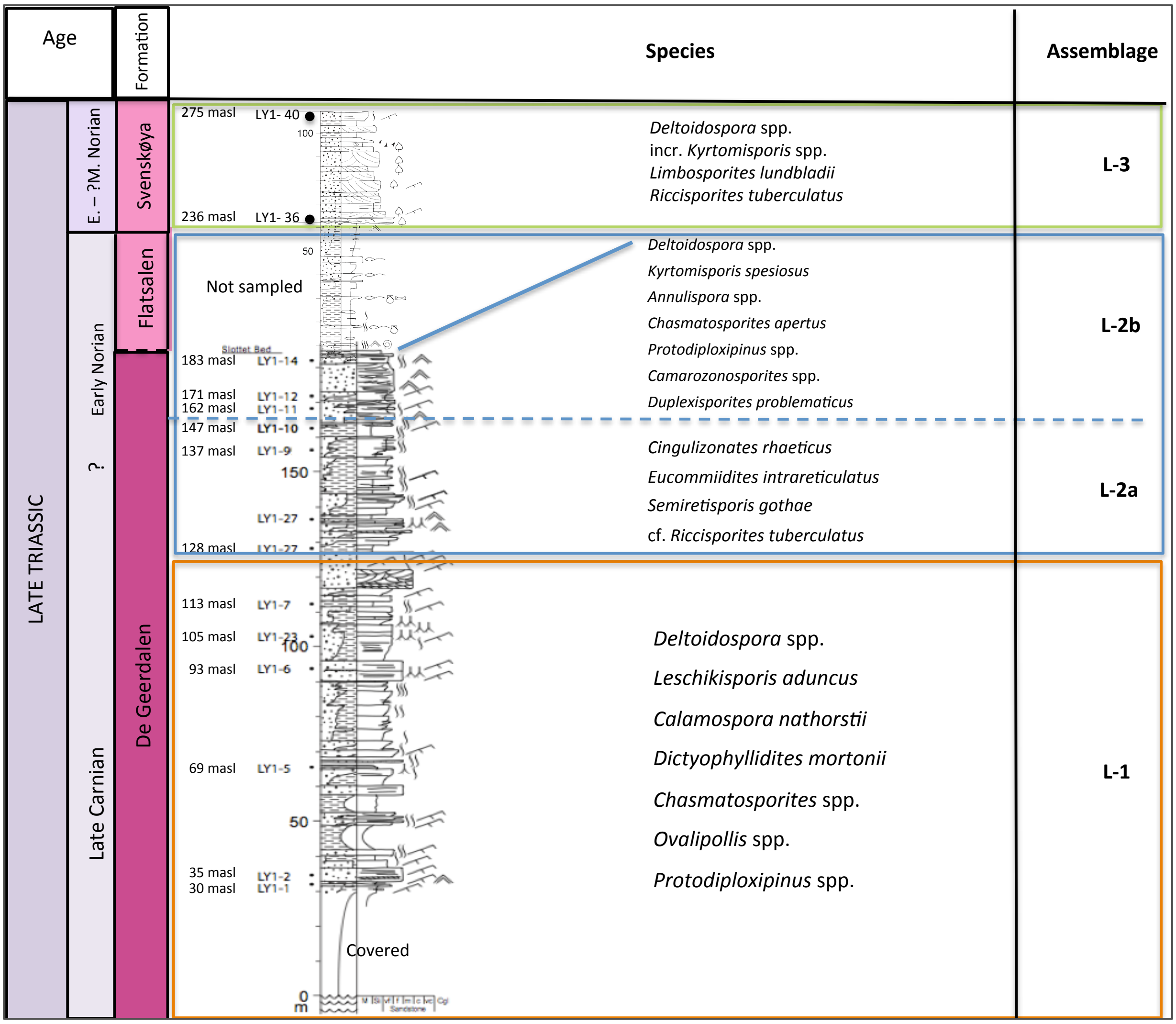


Figure 5.1 Assemblages compared to the log from Lyngefjellet, northeastern Hopen (Figure 2.5). The samples are shown to the left for the log, marked with sample number and meters above sea-level (masl). The species are either important stratigraphically or represented in a high number (Ch. 5.1.1, Figure 5.2). The age is based on palynology.

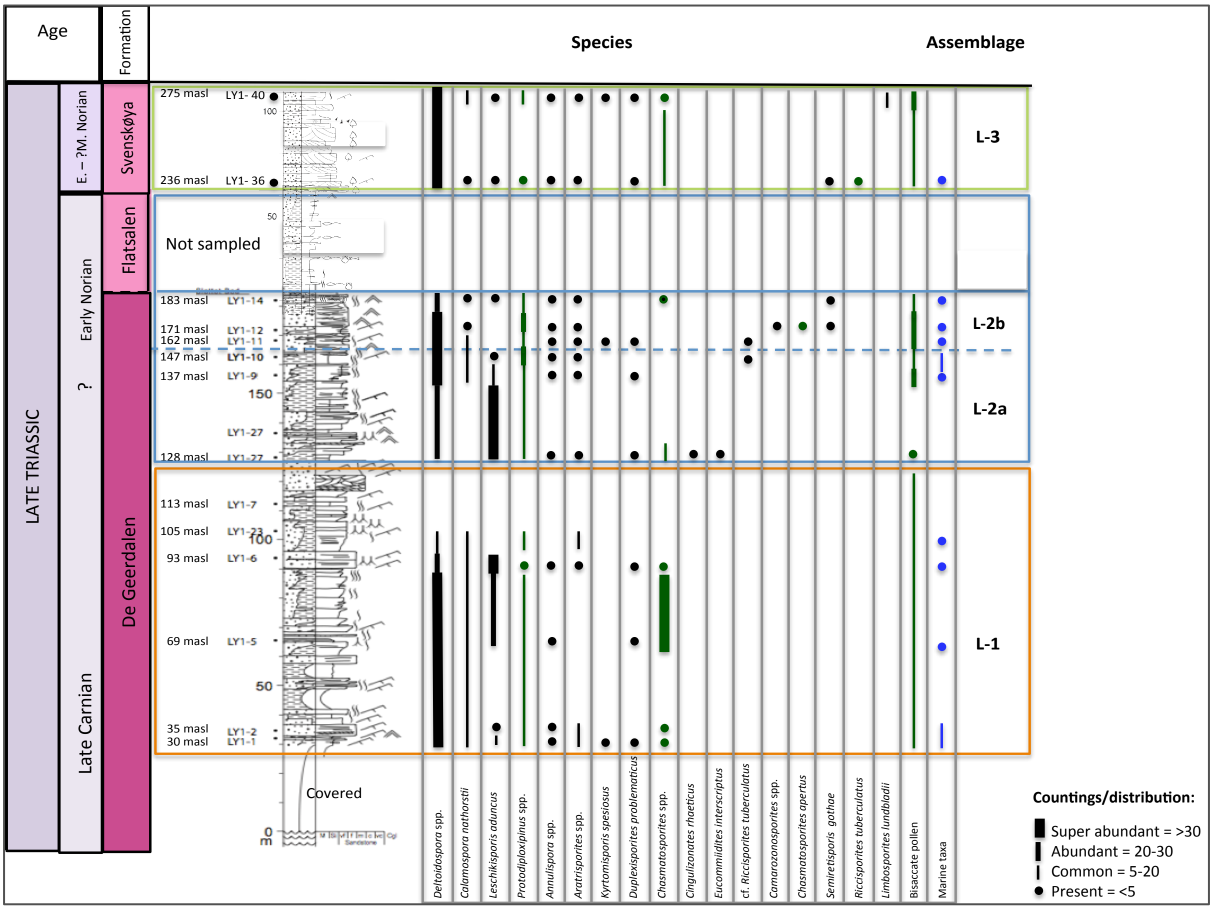


Figure 5.2 The distribution of selected species, bisaccate pollen and marine forms are compared to the log from Lyngefjellet, south-eastern Hopen (Figure 2.5). The age is based on palynology.

Assemblage L-2

Formation: The De Geerdalen (the upper part of the section on Hopen)

Age: Early Norian

Interval: LY-1-27A – LY-1-14 (128-183 masl) (Figures 5.1 and 5.2)

Assemblage L-2 is divided into two sub-assemblages: Assemblage L-2a and Assemblage L-2b (Figure 5.1). Several taxa have first occurrence in this interval, including *Cingulizonates rhaeticus, Eucommiidites intrareticulatus, Camarozonosporites* spp., cf. *Riccisporites tuberculatus, Chasmatosporites apertus, Schizaeoisporites worsleyi* and *Semiretisporis gothae.* The composition of the palynoflora still shows a dominance of *Deltoidospora* spp., whereas the spores *Leschikisporis aduncus* and *Calamospora nathorstii* are diminishing (Figure 5.2). Within Assemblage L-2, there is also an increase in *Kyrtomisporis* spp. and *Duplexisporites* spp. (Appendix III), together with bisaccate pollen, especially *Protodiploxipinus* spp. (Figure 5.2). The taxa listed above are also documented in sediments assigned to Early Norian age in the Barents Sea area (Hochuli et al., 1989) (Assemblage B-2, Figure 5.3) who mainly based their ages upon palynomorph ranges known in the Germanic and Alpine realm. Also assemblages from Arctic Canada are similar, where ammonite, pelecypod and plant fossils were collected for age assessment in the Heiberg Formation from Eastern Sverdrup Basin (Suneby et al., 1988). The palynological assemblage in the SC Subzone (Suneby et al., 1988)(Figure 5.3) from the Heiberg Formation is assigned an Early to Middle Norian age. However, which macrofossils Suneby et al., (1988) based their age on is unclear, as they refer to an unpublished paper by Suneby.

Annulispora spp., *Duplexisporites problematicus, Lycopodiacidites rugulatus, C. rhaeticus, Kyrtomisporis* spp., *Eucommiidites intrareticulatus*, *Camarozonosporites* spp. and cf. *Rhaetigonyaulax rhaetica* were also recorded at Iversenfjellet and Johan Hjortfellet (Figure 2.5) on Hopen by Bjærke et al. (1977). *Cingulizonates rhaeticus* is, however, only recorded from the base Flatsalen Formation at Johan Hjortfjellet (Bjærke et al., 1977). The palynological assemblage recorded from Lyngefjellet (Smith et al., 1975) resembles the palynoflora in the present study.

		LYNGEFJELLET (Ask, 2013)	DELTANESET, CENTRAL SPITSBERGEN (Ask, 2013)	CANADIAN ARCTIC ARCHIPELAGO (Fisher 1979)	EASTERN SVERDRUP BASIN, ARCTIC CANADA (Suneby & Hills, 1988)	THE BARENTS SEA AREA (Huchuli, 1989)	SASSENFJORDEN, SPITSBERGEN (Bjærke & Dypvik, 1976) (Suggested in this report)	KNORRINGFJELLET, CENTRAL SPITSBERGEN (Nagy et al., 2010)
Upper Triassic	Rhaetian			(Assemblage IX) *Conutisporites seebergensis* *Classopollis torosus* *Kraeuselisporites reissingeri* *Semiretisporis maljavkinae* *Triancoraesporites reticulatus* (incl. the Norian species)	(LT Biozone) *Cingulizonates rhaeticus* *Limbosporites lundbladii* *Riccisporites tuberculatus* *Triancoraesporites ancorae* *Zebrasporites interscriptus* *Aratrisporites laevigatus* *Riccisporites umbonatus* *Zebrasporites laevigatus*	(Assemblage A) *Riccisporites tuberculatus* (A) *Limbosporites lundbladii* (A) *Ovalipollis pseudoalatus* *Chasmatosporites* spp. *Q. anellaeformis* *A. macrocavatus* *Protodiploxipinus* *Triancoraesporites reticulatus*		
	Late Norian			(Assemblage VIII) *C. magnolioides* *Cingulizonates rhaeticus* *Perinosporites thuringiacus* *Semiretisporis gothae* *Chasmatosporites apertus* *Granuloperculatipollis rudis* *Kyrtomisporis spesiosus* *Limbosporites lundbladii* *Rhaetipollis germanicus* *Riccisporites* spp. *Triancoraesporites ancorae* *Zebrasporites interscriptus* *Z. laevigatus*	(PA Subzone) *Rhaetigonyaulax* spp. *Porcellispora longdonensis* *Tetitriletes semimuris* *Perinopollenites elatoides* *Rhaetipollis germanicus* *Aratrisporites macrocavatus* *Granuloperculatipollis rudis* *Limbosporites lundbladii* *Riccisporites tuberculatus*	(Assemblage B-1) *Riccisporites tuberculatus* (P) *Limbosporites lundbladii* (P) *Deltoidospora* spp. *Concavisporites* spp. *Kyrtomisporis laevigatus* *K. gracilis* *Annulispora* spp. *Chasmatosporites* spp. *Q. anellaeformis* *Rhaetegonyaulax rhaetica*		
	Middle Norian	Assemblage L-3 (E.-?M. Norian) *Deltoidospora* spp. (A) incr. *Kyrtomisporis* spp. *Limbosporites lundbladii* (P) *Riccisporites tuberculatus* (P)			(SC Subzone) *Camarosonosporites laevigatus* *Kyrtomisporis spesiosus* *Triancoraesporites ancorae* *Zebrasporites interscriptus* *Z. laevigatus* *Acantotriletes varius* *Aratrisporites coryleseminis* *A. macrocavatus* *Cingulizonates rhaeticus* *Duplexisporites problematicus* *Kyrtomisporis laevigatus* *Rogalskaisporites cicatricosus* *Riccisporites tuberculatus* *Limbosporites lundbladii* cf. *Suessia swabiana*			(MB 5) *Kyrtomisporis spesiosus* *Veryhachium reductum* *Rhaetigonyaulax rhaeticus*
	Early Norian	Assemblage L-2b *Deltoidospora* spp. (SA) *Kyrtomisporis spesiosus* *Annulispora* spp. *Chasmatosporites apertus* Protodiploxipinus (C) *Camarozonosporites* spp. *Duplexisporites problematicus* - - - - - - - - - Assemblage L-2a *Semiretisporis gothae* *Cingulizonates rhaeticus* *Eucommiidites intrareticulatus* cf. *Riccisporites tuberculatus*	(Assemblage D-I) *Deltoidospora* spp. *Camarozonosporites rudis* *Aratrisporites macrocavatus* *Duplexisporites problematicus* *Zebrasporites interscriptus* *Riccisporites umbonatus* *Riccisporites* spp. *Protodiploxipinus* spp. *Semiritisporis gothae* cf. *Rhaetigonyaulax rhaetica* *Leschikisporis aduncus (C)*			(Assemblage B-2) *Leshikisporis aduncus* *Protodiploxipinus gracilis* *Striatoabieites aytugii* *Triadispora* spp. *Plasiodictyon mosellanum* *Heibergella asymetrica* *Sverdrupiella mutabilis* *Rhaetigonyaulax arctica*	(UNIT D) *Kyrtomisporis spesiosus* *Annulispora folliculosa* cf. *Rhaetigonyaulax rhaetica* *Veryhachium* spp. *Duplexisporites problematicus* *Camarozonosporites rudis* *C. laevigatus* *Zebrasporites laevigatus* *Z. interscriptus* *Protodiploxipinus* spp *Aratrisporites macrocavatus*	(MB 4) *Botryococcus* spp. *Leschikisporis aduncus* (A/SA) *Aratrisporites plicabilis* *Duplexisporites* *problematicus* *Tasmanites* spp.
	Late Carnian	Assemblage L-1 *Leschikisporis aduncus* (SA) *Calamospora nathorstii* *Deltoidospora* spp. (SA) *Dictyophyllidites mortonii* *Chasmatosporites* spp. *Ovalipollis* spp. Incr. *Protodiploxipinus* spp. (C)				(Assemblage C) *Protodiploxipinus* spp. *Schizaeoisporites worsleyi* *Thomsonisporites toralis* *Triadispora verrucata* *Pseudenzonalasporites summus* *Semiretisporis* sp. *Striatoabieites balmei*	(Unit A) Smooth, trilete spores and bisaccate pollen with no marine species	(MB 3) Bisaccate pollen *Duplexisporites* *problematicus* *Deltoidospora minor* *Tasmanites* spp. *Micrhystridium* spp. *Cymatiosphaera* spp.

(P) = Present, (C) = Common, (A) = Abundant, (SA)= Super abundant

Figure 5.3 A comparison of palynological data from earlier publications in the Arctic area.

Assemblage L-2a

Formation: The De Geerdalen (upper part of the section)

Age: ? Early Norian

Interval: LY-1-27A – LY-1-10 (128-147 masl) (Figures 5.1 and 5.2)

Several of the genera known from Upper Triassic successions are long ranging, making it hard to distinguish between Carnian and Norian assemblages (Hochuli et al., 1989). Assemblage L-2a (Figure 5.1) is defined based on the presence of the taxa *Cingulizonates rhaeticus* in LY-1-27A and cf. *Riccisporites tuberculatus* in sample LY-1-10 (Figure 5.2 and Appendix III), not recorded below. *C. rhaeticus* is recorded from the upper part of De Geerdalen Formation from Lyngefjellet in sample LY-1-27A at 128 masl (Figure 5.2). This species has previously been regarded as of Norian age in Arctic Canada (Fisher, 1979; Suneby et al., 1988). Fisher (1979) recovered his assemblages from core samples dated with macrofossils diagnostic of the *columbianus* Zone (Tozer, 1967, 1971), however the publication lacks a proper range chart and the exact location and sample level of the macrofossil findings are not documented. *C. rhaeticus* has its first occurrence in deposits assigned to Early Norian in the Barents Sea area (Hochuli et al., 1989) (Assemblage B-2, Figure 5.3). This is also the case for cf. *Riccisporites tuberculatus* recorded in sample LY-1-10 (Figures 5.1 and 5.2). According to Hochuli et al. (1989) and Suneby et al. (1988), *R. tuberculatus* first appears in the early Norian. Assemblage L-2a resembles the assemblage recorded from Flatsalen Formation by Bjærke et al. (1977). They concluded a Rhaetian age for the upper part of the De Geerdalen Formation based on palynological correlation with distant basins, i.e. of N.W. Europe, Britain, and the Canadian Arctic. Buchan et al. (1965) suggested a Norian age for the upper section of the De Geerdalen Formation on Hopen, based on the Late Carnian bivalve *Halobia zitteli* in the underlying section and Rhaetian plant remains described by Nathorst (1910, 1913) and Böhm (1912) in the uppermost part of the formation.

In conclusion, the age of the Assemblage L-2a is somewhat uncertain because of long ranging taxa in Late Carnian and Early Norian sediments and due to few records of stratigraphically important taxa. However, based on palynological similarities to assemblages calibrated to an Early Norian age in Arctic Canada and in the Barents Sea area, an Early Norian age is suggested.

Assemblage L-2b

Formation: De Geerdalen (the uppermost part of the section)

Age: Early Norian

Interval: LY-1-11 – LY-1-14 (162-183 masl) (Figures 5.1 and 5.2)

The first occurrence of *Chasmatosporites apertus* and *Semiretisporis gothae* defines the base of this assemblage (Figures 5.2 and Appendix III). In Fisher (1979), the lowermost occurrences of these taxa in association with *Cingulizonates rhaeticus, Kyrtomisporis spesiosus* and *Riccisporites* spp. are recorded from core samples from the Canadian Arctic Archipelago, where the taxa are described as characteristic Norian morphotypes. However, as previously mentioned, Fisher did not include a reliable documentation. In sample LY-1-11 (Appendix III), *C. apertus* and *S. gothae* are found in association with *Chasmatosporites* spp., *Kyrtomisporis spesiosus, Annulispora* spp., *Duplexisporites problematicus, Lycopodiacidites rugulatus* and *Camarozonosporites* spp. which is similar to the assemblages earlier found in the Flatsalen Formation from Iversenfjellet and Johan Hjortfjellet (Bjærke & Manum, 1977). The age of the Flatsalen Formation has previously been discussed by several researchers, including Bjærke et al. (1977) and Smith et al. (1975), who suggested a Rhaetian age. Both authors correlated to palynofloral assemblages from northwestern Europe. The assemblages in northwestern Europe are calibrated to dated ammonoids in the Alpine and Germanic region. Calibration with alpine palyno-assemblages are, however, uncertain due to the different latitudes (Figure 5.4) and climatic belts, and lack of calibration to other fossil groups for good datings therefore hampers exact dating. In Late Triassic the diversity and abundance of spores were scarce in the Alpine area, and the flora was dominated by the gymnosperm circumpolles group, which barely was represented in the Boreal realm (Hochuli et al., 1989).

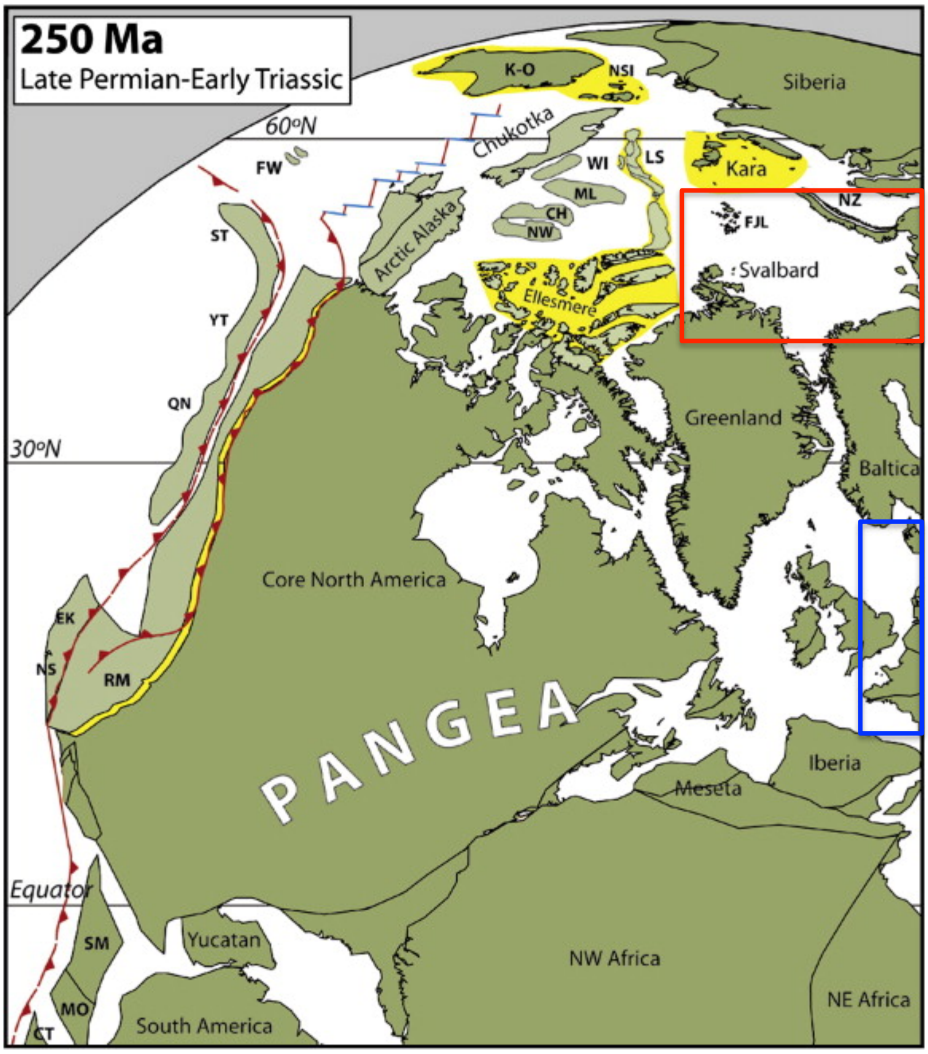


Figure 5.4 Terrane map showing the position of the Svalbard and Barents Sea area (red square) around the Jurassic – Triassic transition relative to Arctic Canada (Ellesmere), Koluma-Omolon (K-O), New Siberian Islands (NSI) and NW Europe (blue square). From Cocks et al. (2011).

Three reports of ammonites from the Flatsalen Formation of Hopen are documented from the 1970s (Flood et al., 1971; Smith et al., 1975)(Figure 2.9 and Table 2.1). According to Smith et al. (1975), Flood et al. (1971) reported the ammonite *Arctosirenites* from near the mountaintop on Johan Hjortfjellet (Figure 2.5), where the Flatsalen Formation only crops out in a small, restricted area. A second specimen of the same genus was recorded on Iversenfjellet by the Norske Fina (Smith et al. 1975). This ammonoid genus is however typical for the Carnian in Arctic Canada (Tozer, 1971). Ammonoids of the *Sirenites* genus was also found in the Flatsalen Formation on Nørdstefjellet (Smith et al. 1975), the northernmost tip on Hopen (Figures 2.5 and 2.9), but instead of accepting that the formation was older, they suggested that the Svalbard area had a relict group of ammonoids, which elsewhere did not survive longer than Early Norian and concluded that the Flatsalen Formation was of Rhaetian age due to the similarities to the Rhaetian palynological assemblage in Western Europe.

According to Smith et al. (1975), Pchelina (1972) recorded the bivalve cf. *Anodontophora ovalis* from the upper part of the De Geerdalen Formation, regarded as being of probably Norian age, and at a similar locality from Iversenfjellet, the bivalve *Halobia zitteli* was recorded by Flood et al. (1971), which is indicative of Carnian age (Tozer et al., 1968). The *Halobia* type was also recorded from the Flatsalen Formation near the type section on Iversenfjellet, however, as Smith et al. (1975) believed that the Flatsalen Formation was of Rhaetian age, they concluded that the identification of *H. zitteli* was incorrect. Korchinskaya (1982) recorded the presence of *Halobia* bivalves associated with the characteristic ammonoid *Argosirenites* (*Pterosirenites* fauna) in the Flatsalen Formation from Lyngefjellet. This ammonoid in association with *Halobia,* are widely distributed in Lower Norian deposits in the New Siberian Island and in the Eastern Omolon area in Russia (Figure 5.4), and in British Columbia, representatives of the *Argosirenites* are typical in Lower Norian sediments (Korchinskaya 1982). Korchinskaya (1982) has recorded both the bivalve *Halobia* and the *Argosirinites* ammonoid present in the same beds on Lyngefjellet, which strongly supports an Early Norian age of the Flatsalen Formation. Smith (1982) agreed with this age assignment.

Assemblages L-2a and b resembles assemblages assigned to Early Norian age in the Barents Sea area and in Arctic Canada. Although no macrofossils calibrated to Early Norian age are recorded from the Upper De Geerdalen Formation on Hopen, the palynofloras recorded in the formation continues into the Flatsalen Formation, suggesting the same age for these sediments.

Assemblage L-3

Formation: Svenskøya

Age: Early – ?Middle Norian

Interval: LY-1-36 – LY-1-40 (Figures 5.1 and 5.2)

Assemblage L-3 is recognised in the uppermost section on Lyngefjellet, belonging to the Svenskøya Formation, previously described as the Lyngefjellet Formation by Smith et al. (1975). This sandstone unit is only present on Lyngefjellet (Smith et al., 1975)(Figure 2.9). *Deltoidospora* spp. continues to dominate the palynoflora, together with an increased amount of *Dictyophyllidites mortonii,* cf. *Araucariacidites australis, Kyrtomisporis* spp. and *Apiculatisporites parvispinosus.* The assemblage is characterized by the first appearance of *Riccisporites tuberculatus* and *Limbosporites lundbladii.* These species are not recorded below, and according to Hochuli et al. (1989), *R. tuberculatus* and *L. lundbladii* have their first occurrences in Early Norian.

Limbosporites lundbladii was also recorded by Smith et al. (1975) from approximately 275 meters above sea-level on Lyngefjellet (Figure 5.2), and the species is not recorded further south on Hopen by any workers. The occurrence of *R. tuberculatus* and *L. lundbladii* are recorded several places in the Arctic. On Kong Karls Land, Bjærke et al. (1977) recorded both taxa in the lowermost 80 meters of the Flatsalen Formation on Hårfagrehaugen, northwest on Kongsøya (Figure 2.5 – Kong Karls Land). Bjærke et al. (1977) found similarities in the assemblage from this section with the Flatsalen Formation on Hopen and from the upper part of Heiberg Formation in the Sverdrup Basin in Canada, concluding with a Rhaetian age based on palynology. *L. lundbladii* and *R. tuberculatus* are recorded in SC Subzone (Figure 5.3) of Early Norian – Late Middle Norian age in the Eastern Sverdrup Basin by Suneby et al. (1988), together with the presence of *Zebrasporites interscriptus, Kyrtomisporis spesiosus* and *K. laevigatus.* Suneby et al. (1988) noted an increase the abudance of *L. lundbladii* and *R. tuberculatus* (Figure 5.5) higher up in the Heiberg Formation, assigning these assemblages to a Late Norian – Rhaetian age. However, as mentioned previously, the macrofossils Suneby et al. (1988) used as age calibrations are not published.

In the present study, *L. lundbladii* and *R. tuberculatus* occur only sporadically in Assemblage L-3 from the Svenskøya Formation on Lyngefjellet (Figure 5.2 and Appendix III). This trend is also observed from SC Subzone in the Sverdrup Basin (Suneby et al., 1988). An increase in abundance of these species in the Sverdrup Basin and in the Barents Sea area is characteristic for younger sediments (Hochuli et al., 1989; Suneby et al., 1988) and can be used as negative indication of a younger age. The quantitative increase of palynomorphs like *L. lundbladii* and *R. tuberculatus* reflects a typical development of plant communities: in this case they first develop during Early to Middle Norian, and by Late Norian to Rhaetian time, the mother plants have expanded, also reflected in the quantitative composition of the palynoflora.

According to Korchinskaya (1982), there is no fossil evidence anywhere on Svalbard for the existence Triassic rocks younger than lower Norian. Korchinskaya (1982) did not record any fossils applicable for dating above the Flatsalen Formation on Lyngefjellet, implying that at least 40 meters of the Svenskøya Formation in the top section of Lyngefjellet does not have any macrofossil calibration. An earlier age for the sediments can therefore not be excluded. In conclusion, the occurrence of *L. lundbladii* and *R. tuberculatus,* Assemblage L-3 is regarded to indicate an Early - ?Middle Norian age for the Svenskøya Formation.

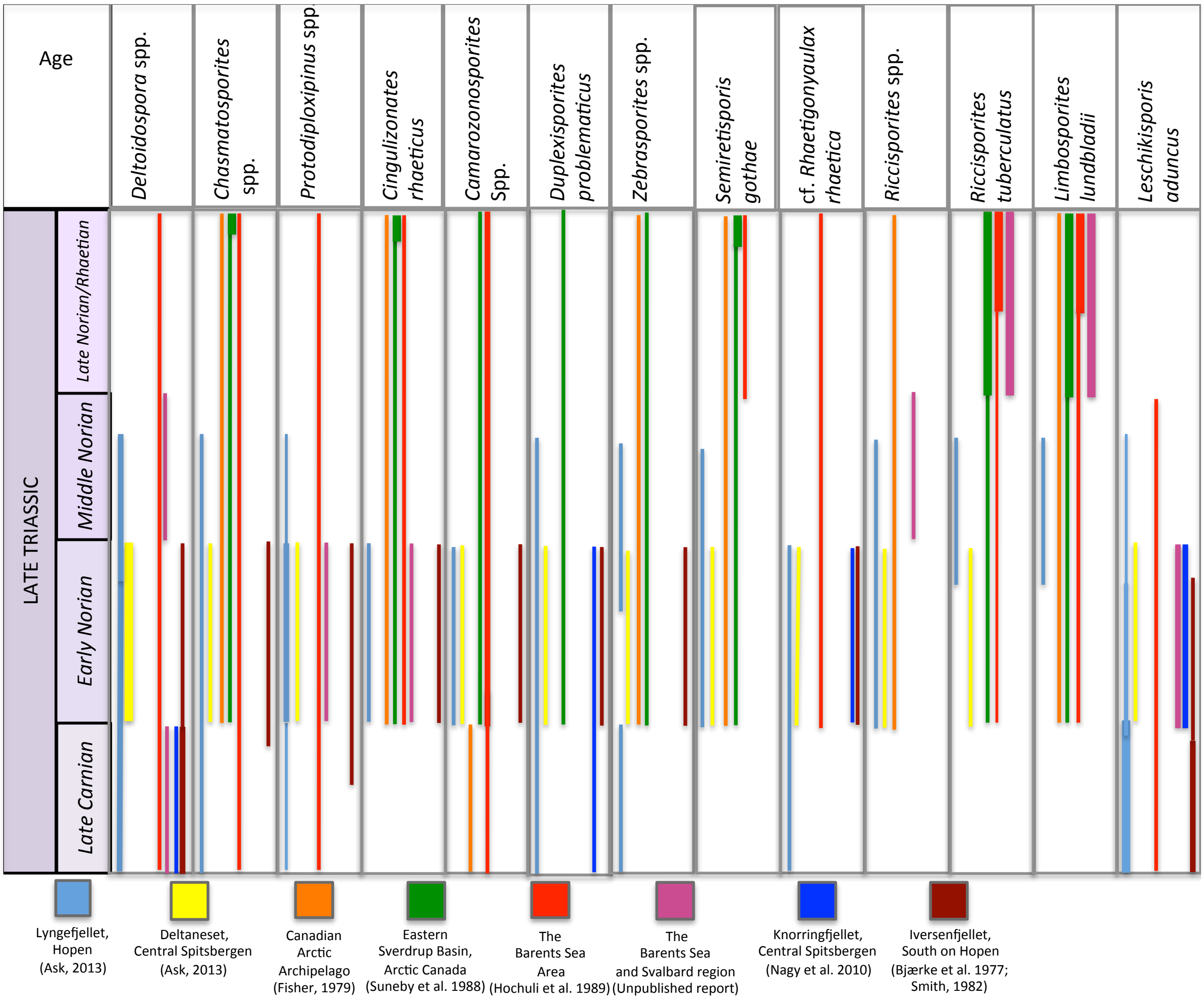


Figure 5.5 The appearance of selected taxa and the suggested age range are compared. The figure is based on palynological documentation from the publications listed below the figure. Van Veen is the author of the unpublished report (pink colour).

5.1.2 Deltaneset, Central Spitsbergen

One assemblage is recorded form the Deltaneset section.

Assemblage D-1

Formation: the upper part of the De Geerdalen (Isfjorden Member)

Age: Early Norian

Interval: ASK-11-1 – ASK-11-20 (Figures 5.6 and 5.7)

Assemblage D-1 is recorded from the Isfjorden Member (Mørk et al., 1999) and consists of shale alternating with siltstones and sandstones of various thickness.

Deltoidospora spp. is the dominant taxa throughout the section. The recorded assemblage consisting of *Aratrisporites macrocavatus, Camarozonosporites* spp., *Duplexisporites problematicus, Duplexisporites* spp., *Kyrtomisporis* spp. and *Zebrasporites interscriptus,* is similar to the SC Subzone (Figure 5.3) in Eastern Sverdrup Basin (Suneby et al., 1988). Appearances of *Semiretisporis gothae* and *Z. interscriptus* have been calibrated to Norian ammonoids in the Arctic Archipelago in Canada (Fisher, 1979). However, as mentioned in Chapter 5.1.1, Fisher did not include proper documentation.

In the local area close to Deltaneset (Figure 2.12), palynological investigations have been conducted on Marhøgda and Knorringfjellet (Bjærke et al., 1976), who studied a section of 20 meters of the Upper Kapp Toscana Group, covering the uppermost three meters of the De Geerdalen Member (= the De Geerdalen Formation), and the Wilhelmøya Formation (= Knorringfjellet Formation, equivalent to the Flatsalen and Svenskøya formations, see Figure 2.3). The De Geerdalen samples (Bjærke et al., 1976) contained assemblages of smooth trilete spores and bisaccate pollen, and no marine taxa were recorded. However, Bjærke et al. (1976) do not include a range chart documenting these observations. Their Unit D (Figure 5.3), from the Knorringfjellet Formation, show a diverse assemblage of palynomorphs, including *Annulispora folliculosa, Kyrtomisporis spesiosus, Veryhachium* spp. *Ovalipollis ovalis, Duplexisporites problematicus, Camarozonosporites rudis, Z. interscriptus, Aratrisporites macrocavatus, Chasmatosporites hians* and *Lycopodiacidites rugulatus,* which closely resembles the assemblages recorded from Deltaneset in the present study, although their samples are from a higher stratigraphic level (Figure 2.3). Bjærke et al. (1976) calibrated their results to assemblages from the Flatsalen Formation on Hopen and Kong Karls Land suggesting a Rhaetian age. However, as discussed previously (See Ch. 5.1.1) the Flatsalen Formation is considered to be of Early Norian age due to macrofossil datings by Korchinskaya (1982) implying a similar age also for this section.

At Juvdalskampen (Figure 2.12), Nagy et al. (2010) did palynology through the De Geerdalen and Knorringfjellet formations, including microfossil biofacies studies. Terrestrial forms *Deltoidospora minor, Chasmatosporites apertus, Kyrtomisporis spesiosus* and bisaccate pollen, together with marine taxa of *Veryhachium* spp. and *Rhaetigonyaulax* spp. characterize their MB 5 biozonation (Figure 5.3). This observation resembles the assemblage on Deltaneset, but like the assemblages reported by Bjærke et al. (1976) in Sassendalen (Figure 2.12), MB 5 is from the stratigraphically higher/younger Knorringfjellet Formation (Figure 2.3).

The two samples ASK-11-17 and ASK-11-18 (Figures 5.6 and 5.7) contain the species *Riccisporites umbonatus.* This taxon is stratigraphically limited and first described by Felix et al. (1977) from the Schei Point Formation in the Sverdrup Basin, Arctic Canada, and assigned a Late Carnian to Norian age (Felix et al., 1977; Fisher et al., 1975). Felix et al. (1977) recorded *R. umbonatus* associated with, among others, *Z. interscriptus* and *Ovalipollis ovalis* and numerous specimens of bisaccate pollen, mostly assigned to *Protodiploxipinus* spp. On Deltaneset, *R. umbonatus* occurs in association with the same assemblage, and samples ASK-11-17 and ASK-11-18 also contain the highest number of *Protodiploxipinus* spp. and other pollen grains in general. *Riccisporites* spp. is recorded in sample ASK-11-20. Vigran et al. (2008) reported the base occurrence of *Riccisporites* spp. from the Carnian on Svalbard. Although *L. lundbladii* and *R. tuberculatus* are missing in Deltaneset, in conclusion the Deltaneset section is interpreted to be of Early Norian age based on correlation to the similar assemblages in Arctic Canada, Knorringfjellet and Marhøgda in Sassendalen (Figure 2.12), and Lyngefjellet on Hopen (Figure 2.5).

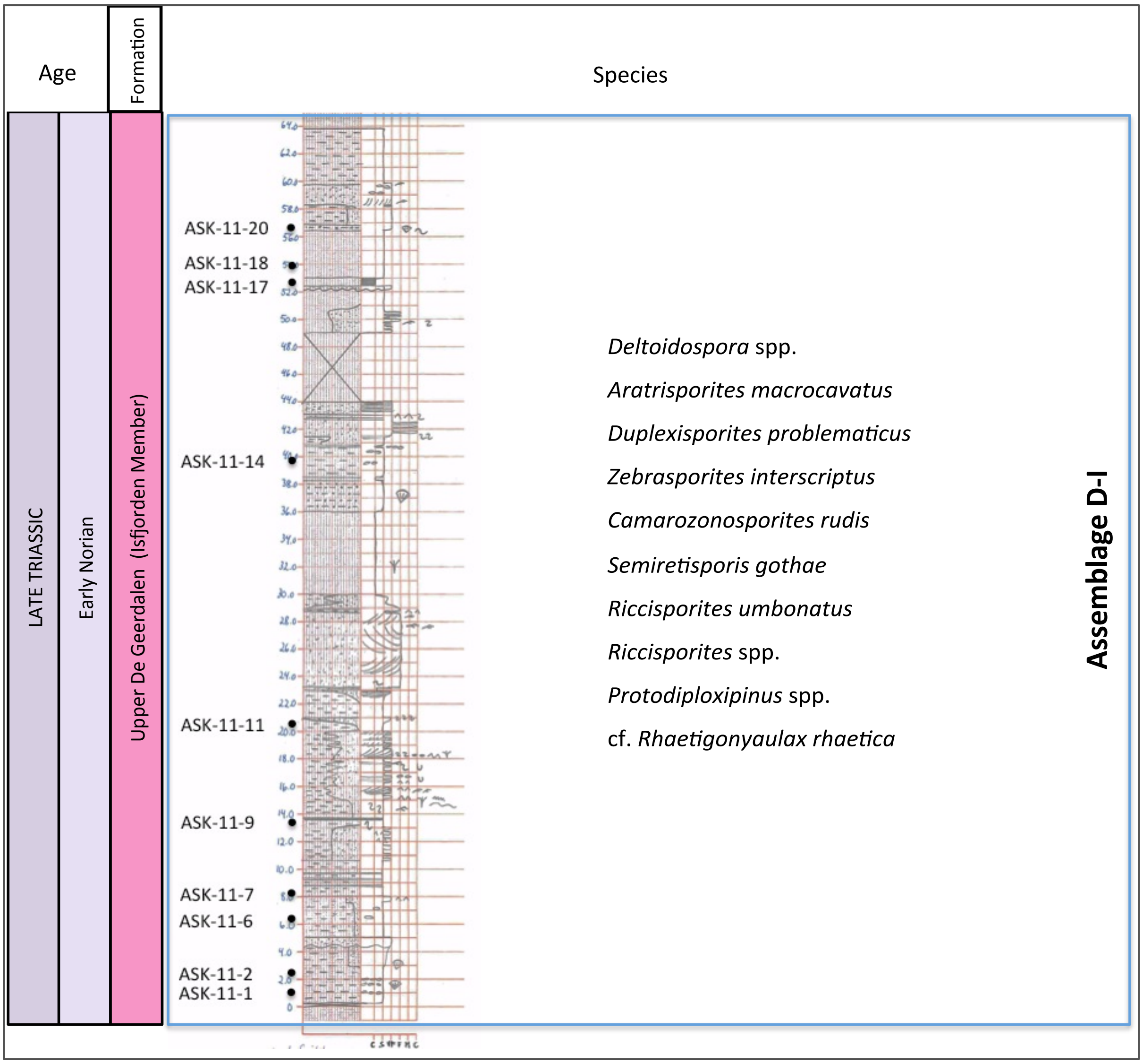


Figure 5.6 The assemblage is compared to the log from Deltaneset Central Spitsbergen (Figure 2.10). The samples are shown to the left for the log, marked with sample number. The species are either important stratigraphically or represented in a high number (Ch. 5.1.2, Figure 5.7).

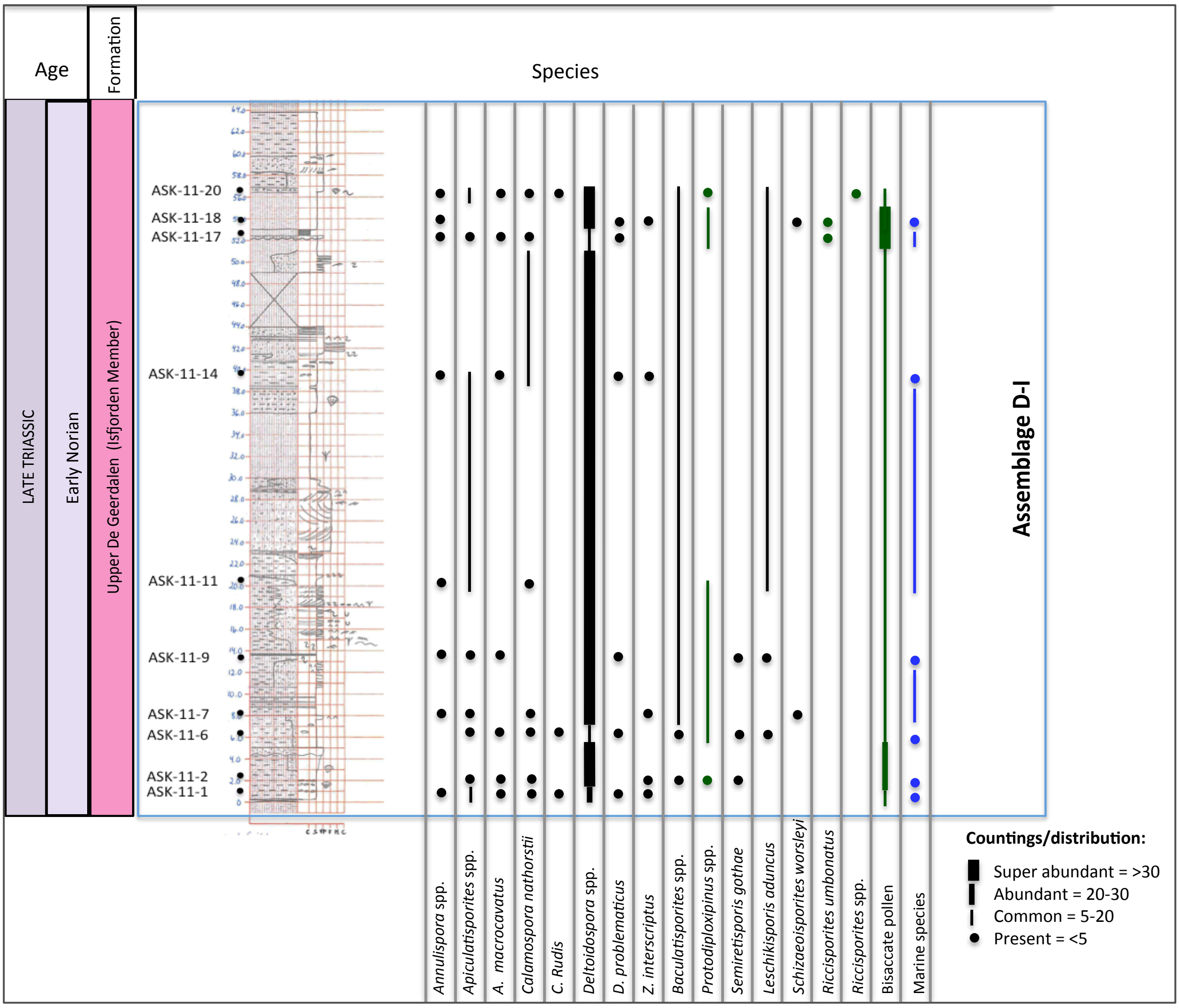


Figure 5.7 Distribution of selected species, bisaccate pollen and marine forms are compared to the log from Deltaneset, Central Spitsbergen (Figure 2.10).

5.1.3 Correlation, Lyngefjellet – Deltaneset

Correlation of the Deltaneset and Lyngefjellet sections on Central Spitsbergen and on Hopen, shows an overlap between Assemblage D-1 on Deltaneset and Assemblages L-2a and L-2b on Hopen. *Deltoidospora* spp. is dominant in both sections, together with species like abundant *Leschikisporis aduncus, Ovalipollis ovalis, Semiretisporis gothae, A. macrocavatus, Riccisporites* spp. and *Kyrtomisporis* spp. Marine taxa including *Veryhachium* spp., *Micrhystridium* spp. and cf. *Rhaetigonyaulax rhaetica* are also recorded from both locations.

The main differences between the sections are the lack of *Limbosporites lundbladii* and *Riccisporites tuberculatus* on Deltaneset, and the occurrence of *R. umbonatus* on

Deltaneset. However, long distance between the two locations (Figure 5.8), very few published studies, and the long duration of the Carnian epoch of millions of year of deposition during outbuilding of the delta-system (Chapter 2.1) complicates exact correlation.

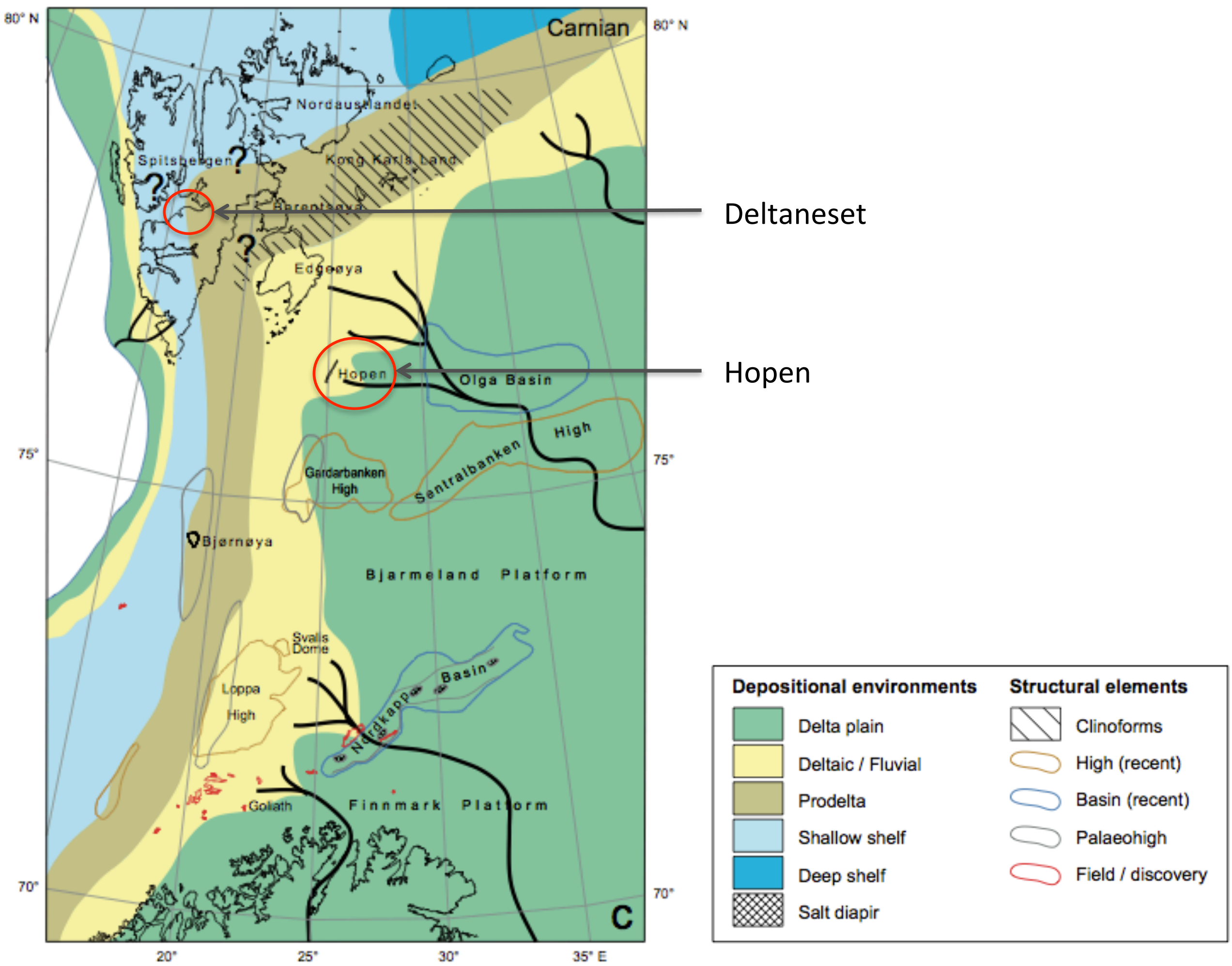


Figure 5.8 Paleogeographical map showing the distance between the two locations in Carnian. From Riis et al. (2008).

5.2 Palaeoenvironment

The De Geerdalen Formation; Delta setting.

The section consists of alternating sandstones, siltstones, shales and coal layers. The entire succession is heavily dominated by terrestrial taxa, composed mainly of various types of psilate, monolete and trilete spores. The dominant taxon is *Deltoidospora* spp., including *D. minor, D. auritora, D. toralis* and the similar taxon *Dictyophyllidites mortonii.* These are found in association with *Leschikisporis aduncus, Calamospora nathorstii, Chasmatosporites* spp., *Aratrisporites* spp. and *Conbaculatisporites* spp.

Deltoidospora spp., *C. nathorstii* and *L. aduncus* are abundant in most samples. Their producers are smaller non-vascular plants that need a wet environment to grow. *Aratrisporites* spp. is a wide-ranging lycopod indicating prevalence of marshy environment (de Jersey, 1982). *Calamospora nathorstii* comes from the seed fern *Calmanites*, which typically is a minor constituent in coals (Traverse 2001, Ch. 11). The producing plant lived probably outside the swamp or on levees. Sample LY-1-6 (Figure 2.8 and Appendix III) contains super abundant *Leschikisporis aduncus*. This acme is also recorded at Iversenfjellet (Bjærke et al., 1977), southern Hopen. Bisaccate pollen shows a gradually increase upwards, and might be an indication of a gradual change in the environmental position. Bisaccate pollen have producer plants typical in mid- and high-land environments (upland flora), and the increase in pollen might be a result of progradation of the system and the environmental position will gradually be moved landward. Increase in pollen can also be related to climatic effects or changes. If the CO_2 –content in the atmosphere or the temperature increase, the producer plants will increase its manufacture, or increased wind could have resulted in dispersal of more pollen grains.

Corroded palynomorphs are consistently in all samples and could be a result of higher accessibility to oxygen. Black carbonized tracheidal and brown woody matter, are together with other tissue fragments dominant of the organic material in all samples, indicating a terrestrial environment. Pyrite is found in some of the samples. Pyrite can crystallize during the decomposition of organic matter, and if the access to oxygen is reduced, the crystals might be preserved in reduced oxygen conditions (personal communication with Tor Bjærke). Siderite nodules are also formed under restricted conditions. On Deltaneset, siderite nodules containing small bivalves are recognized at several levels (Appendix II). The marine component is modest, where *Veryhachium* spp., *Micrhystridium* spp., cf. *Rhaetigonyaulax rhaetica, Pareodinia* spp. or *Suessia swabiana* occur in sparse amount in all samples from Lyngefjellet, excluding samples LY-1-7 and LY-1-27A (Figure 5.2 and Appendix III). These two samples are continental and are recorded from the highest level in Assemblage L-1 and the lowest level in Assemblage L-2 (Figure 5.2). Samples LY-1-9, LY-1-10, LY-1-11, LY-1-12 and LY-1-14 in Assemblage L-2 (Figure 5.2) have all marine influence and are assumed belonging to the Hopen member (Solvi, 2013; Figure 5.9). The Hopen member is herein documented as equivalent to the Isfjorden Member on Spitsbergen (Figure 2.3). The Hopen member is described as a prominent black belt that is visible several places on Hopen (Solvi, 2013), and a clear transition can be seen from the underlying light coloured fluvial delta sediments over to the black interval indicative of a shallow marine environment (Solvi, 2013). The base of the Hopen member is placed at the same level as sample LY-1-27B (Figure 5.9). This sample has not been study in detail herein, but the slide is scanned for marine forms. The marine taxa *Veryhachium* spp. and *Rhaetigonyaulax* spp. are present in the slide. According to Solvi (2013) a shallow marine environment exist throughout the Hopen member section, which is supported by this study.

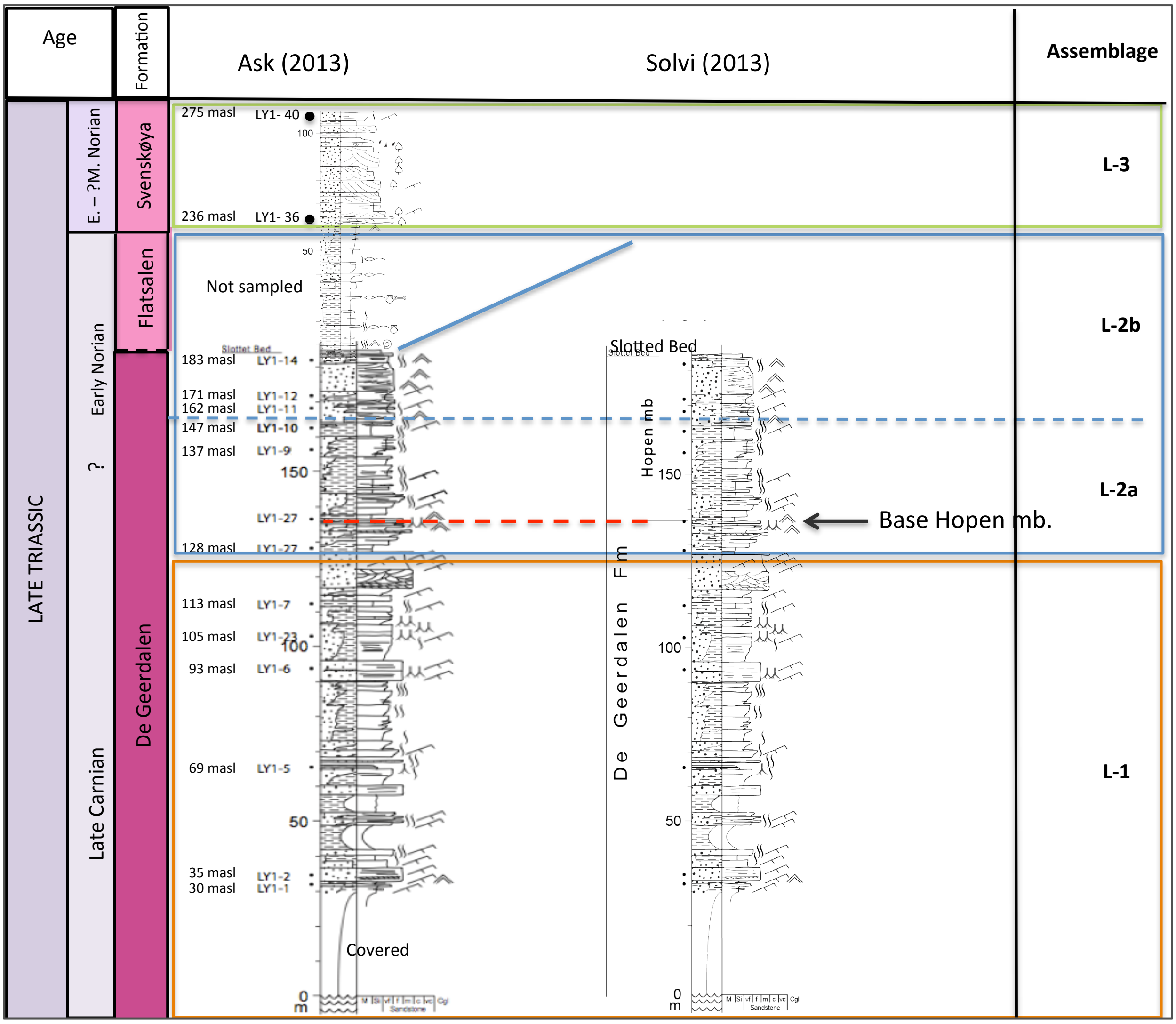


Figure 5.9 The base of the Hopen member is set at approximately the same level as the sample LY-1-27B. All the samples above this level in Assemblage L-2 contain marine taxa. A shallow marine environment is suggested for the Hopen member presented by Solvi (2013), which is supported in this study. The log (Solvi, 2013) was collected by Roger I. Johansen, Anne Mari Østvedt- Gahzi and Atle Mørk during the 1995 expedition to Hopen.

The marine content is higher in the Deltaneset section, where the acritarchs *Veryhachium* spp., *Micrhystridium* spp. and *Baltisphaeridium,* together with the dinocyst cf. *Rhaetigonyaulax rhatica* are present*.* The sample ASK-11-20 (Figure 5.7) is the only sample without marine taxa recorded.

Horizontal and vertical bioturbation was observed several places in the section on Deltaneset. The tracefossil *Diplocraterion* was recognised, which belongs to *Glossifungites* and *Skolithos* Ichnofacies (MacEachern et al., 2009). The former ichnofacies reflects a semi-consolidated substrate and the latter a sandy shore environment. Skolithos Ichnofacies often corresponds to high energy with shifting particulate substrates, generally in marine waters (MacEachern et al., 2009). The characteristics listed above together with observed plant material, paleosoils, shrink marks and wave- and current ripples on Deltaneset, reflects features of a near shore environment.

Dominance of terrestrial taxa of typical wet-land-spores is typical for coastal vegetation. The consistently high content of woody matter in association with few marine forms indicates marine influence in a near shore environment. A possibility might be a delta-plain or a coastal plain, associated with lagoons, barriers, levees and marshes where the access to saline conditions is restricted (Figure 5.10). In the Lyngefjellet section (Figure 2.8 and Appendix I) thicker sand-bodies was recorded, most likely deposited under higher energy conditions in the water, for example under storm conditions, probably as distributary bars or mouth bars, whereas the shale packages might represent interdistributary bays (Klausen et al., 2013). This is supported by the palynology reflecting a typical delta setting.

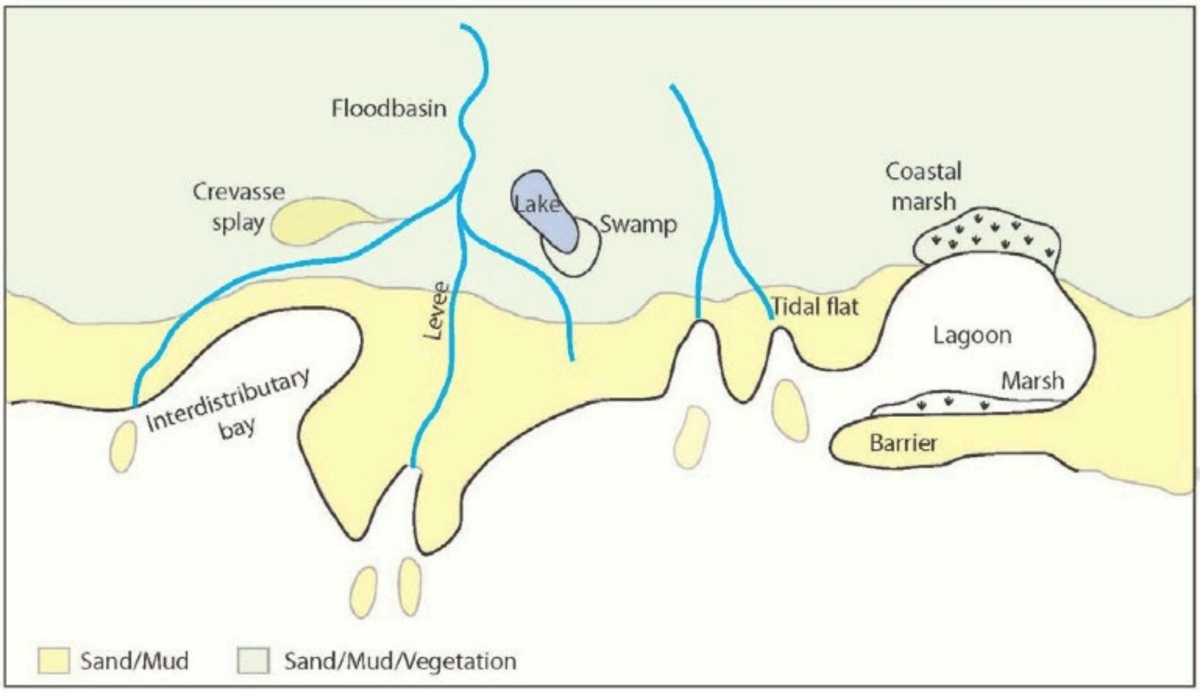


Figure 5.10 An environment with delta-plains or coastal plains, associated with lagoons, barriers, levees and marshes, where the access to saline conditions were restricted is suggested for the studied locations on Lyngefjellet, northeastern Hopen (Figure 2.5) and on Deltaneset, Central Spitsbergen (Figure 2.10). Figure from Hynne (2010).

The Svenskøya Formation; Near-shore delta environment

Terrestrial forms dominate the palynoflora in the uppermost section. Sample LY-1-36 (Figure 2.8 and Appendix III) from Lyngefjellet is dominated by abundant *Deltoidospora* spp., cf. *Araucariascidites australis, Conbaculatisporites* spp., and *Baculatisporites* spp. Pollen is sparse, and the marine taxa *Veryhachium* spp., *Mircrhystridium* spp. and *Pareodinia evetti* are present in very low numbers (Appendix III). Sample LY-1-40 is dominated by *Deltoidospora* spp., *Protodiploxipinus* spp., *Calamospora nathorstii* and *Kyrtomisporis* spp. Approximately 10% of the counted specimens are pollen grains, and no marine taxa is recorded from sample LY-1-40.
The palynoflora reflects a near-shore delta environment, dominated by terrestrial forms with marine influence in the base of the formation.

In such depositional environments as suggested for the De Geerdalen and Svenskøya formations, erosion due to transgression, and changes in accommodation in sediment supply is expected to result in unconformities within the strata package. Reworking from layers just below can therefore not be excluded.

6 Conclusion

Palynological samples from two sections of the upper De Geerdalen Formation on Central Spitsbergen and Hopen where studied. In addition samples from the Svenskøya Formation on Hopen was included. Many of the samples, especially from Deltaneset, yielded poorly preserved palynomorphs, but the overall assemblages yielded rich diversity of palynomorphs enabling determined to genera or species level. The most important features are as follows:

- No significant changes in the overall palynofloral transitions are observed.
- The lower 100 meters of the De Geerdalen succession on Hopen has been assigned a Late Carnian age, while the upper part of De Geerdalen Formation is assigned an Early Norian age. The Flatsalen Formation has been dated to Early Norian based on dated ammonites (Korchinskaya, 1982). An Early to possibly Middle Norian age has been suggested for the Svenskøya Formation.
- The palynoflora is dominated by terrestrial taxa throughout the successions, however, low abundances of marine species are recorded in 20 out of 24 samples. Most of the taxa are long ranging and the occurrence of stratigraphically important taxa is sparse.
- The lower part of the De Geerdalen Formation on Hopen was deposited in a near-shore environment, probably on a delta-plain, reflected in a palynoflora from typical wetland plants.
- The upper part of the De Geerdalen Formation on Hopen has marine influence, supporting correlation of the Hopen member (Solvi 2013) with the Isfjorden Member, and a near-shore delta setting is suggested for the environment.
- According to Klausen et al. (2013) the Flatsalen Formation represent a general transgression to fully marine conditions, which is supported by several ammonite finds (Korchinskaya, 1982).
- The Svenskøya Formation is interpreted to have been deposited in a near-shore environment, possibly in a delta setting, reflected in a palynoflora from typical wetland plants.
- Correlation between the studied sections on Hopen and on Deltaneset suggests that the Deltaneset section is equivalent to the Assemblage L-2 recorded from the upper part of the De Geerdalen Formation from Lyngefjellet, Hopen.

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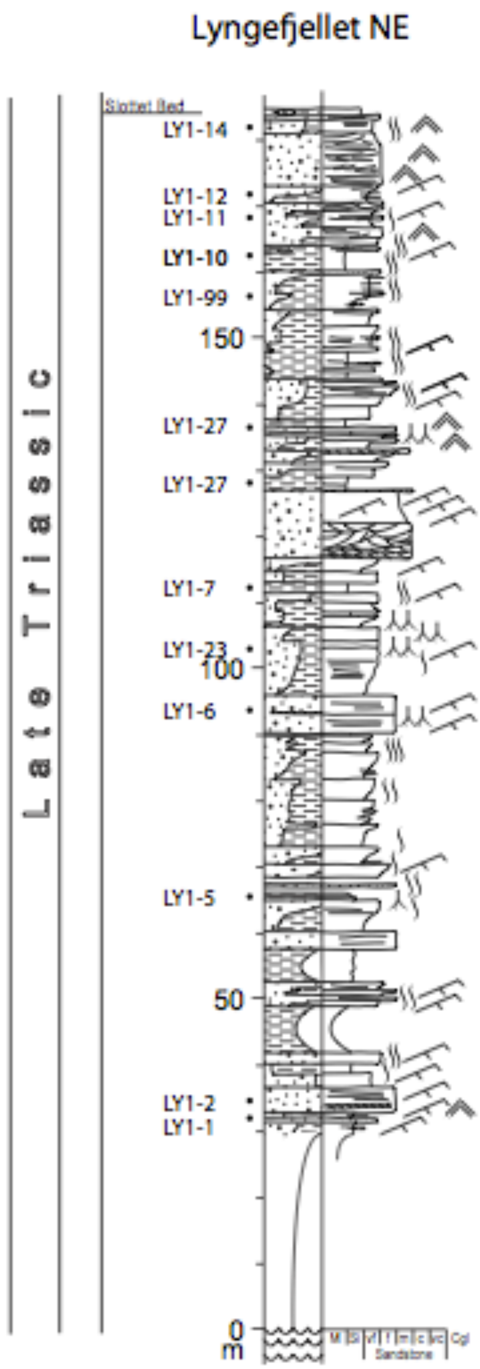
Appendix

Appendix I	Log Lyngefjellet
Appendix II	Log Deltaneset
Appendix III	Range chart Lyngefjellet
Appendix IV	Range chart Deltaneset
Appendix V	Species list with references

Appendix I

Log Lyngefjellet

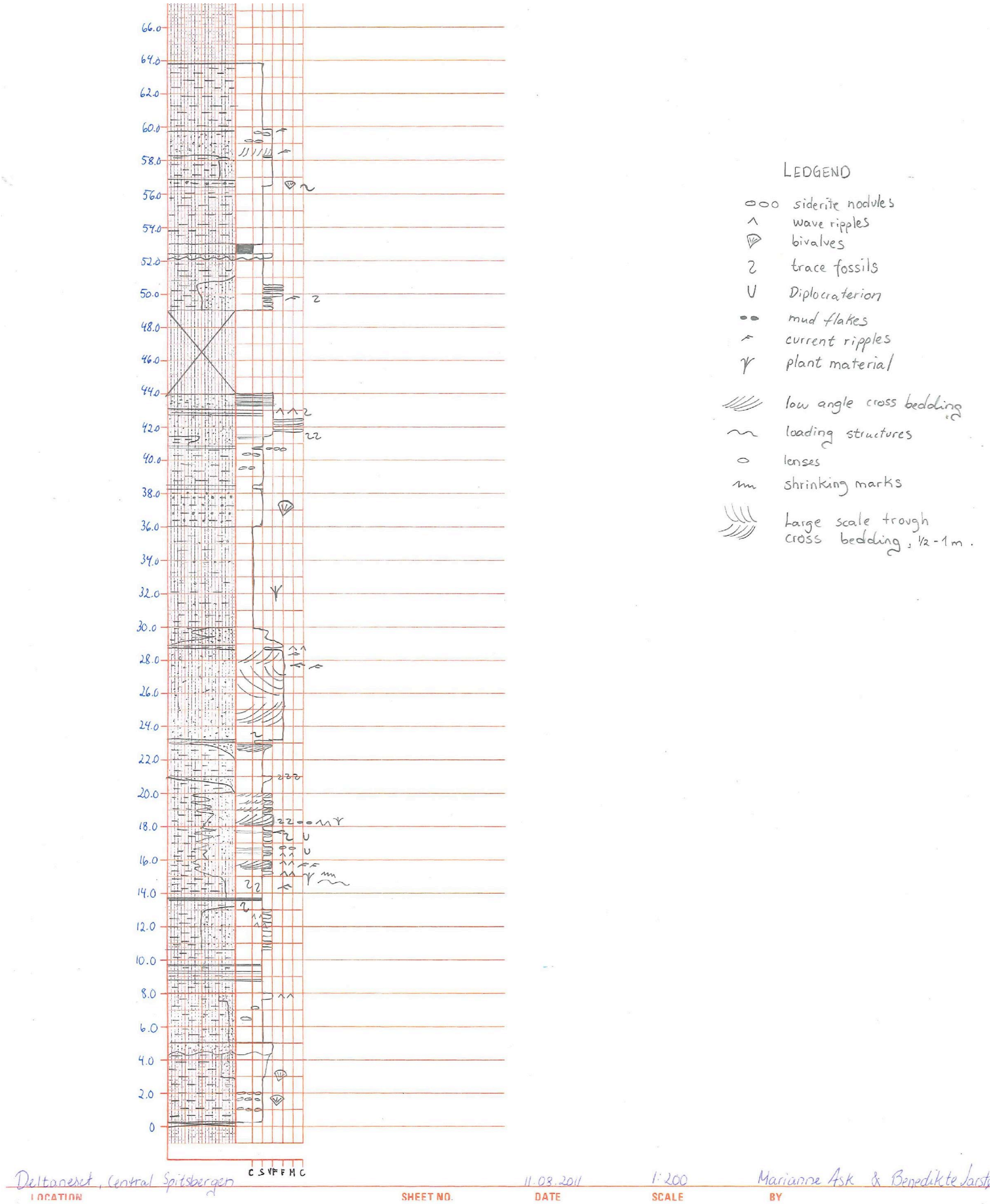


Logged in 1995 by G.B. Larssen and others

Appendix II

Log Deltaneset, scale 1: 200

During fieldwork, Marianne Ask and Benedikte Jarstø logged the log in scale 1: 20.



Appendix III

LYNGEFJELLET, HOPEN (all species)

Sample no:	Hight (mabp)	Spores	Annulispora spp.	Aratrisporites macrocavatus	Araucariacidites cf. australis	Aulisporites spp.	Calamospora nathorstii	Camarozonosporites rudis	Conbaculatisporites hopensis	Conbaculatisporites mesozoicus	Deltoidospora auritora	Deltoidospora spp.	Deltoidospora toralis	Duplexisporites problematicus	Guthoerlisporites cancellosus	Kyrtomisporis speciosus	Leschikisporis aduncus	Lycopodiacidites rugulatus	Lycopodiumsporites spp.	Monosulcites punctatus	Anapiculatisporites spiniger	Apiculatisporites spp.	Aratrisporites laevigatus	Densosporites spp.	Neoraistrickia taylorii	Retusotriletes spp.	Todisporites spp.	Trachysporites spp.	Aratrisporites spp.	Converrucosisporites cameroni
LY-1-40	275	65		p	5		8		p			35	6	p	p	p	3			3					1		3			
LY-1-36	236	75	2	1	22		2					30	p	p	p		1		p			p	p		2		1			1
LY-1-14	183	129	p	2			4					7	2				p													
LY-1-12	171	66	p	2	2		3				4	45	5					2		1	p	p	p		p		1			
LY-1-11	162	72	p	p		2	7		p			51	16	p	p	p		1		2										p
LY-1-10	147	61	p	p	p		6		1	p		55	16				p	p		13	2	2	p	p						
LY-1-9	137	67	2	p			14		3	2	p	44	17	p	p		9		p		p		1		p					1
LY-1-27A	128	68	p	1		1			5		2	14	4	1			44						p		1					4
LY-1-7	113	38																											p	
LY-1-23	105	102		5			12		5		1	1								1	15	16	1		12					
LY-1-6	93	36	1	4	1	4	14		7	6	p	18	8	p			82							3	1					
LY-1-5	69	39	p			12	16		2	2	4	42	12	1			22	1		p					p				2	p
LY-1-2	35	93	1	2	2	1	7		8	1	1	35	10				4				p	p	3	p	p	1	3	1		
LY-1-1	30	26	p	5	20	1	15	1	3	1	2	65	28	p	p	p	8	1	p	p										

Sample no:	Hight (mabp)	Duplexisporites spp.	Eucommiidites spp.	Punctatisporites spp.	Zebrasporites laevigatus	Rugulatisporites mesozoicus	Spinotriletes echinoides	Conbaculatisporites spp.	Dictyophyllidites mortonii	Velosporites cavatus	Cingulizonates rhaeticus	Eucommiidites intrareticulatus	Monosulcites spp.	Retusotriletes mesozoicus	Apiculatisporites parvispinosus	Baculatisporites spp.	Kyrtomisporis spp.	Cavatoretisporis obvius	Lycopodiumsporites austroclavatidites	Polycingulatisporis spp.	Schizaeoisporites worsleyi	Verrucosisporites klukiformis	Camarozonosporites spp.	Globulisporis primus	Rugulatisporites spp.	Semiretisporis gothae	Verrucatosporites scabratus	Kyrtomisporis gracilis	Leptolepidites rotundus	Raistrickia spp.	Zebrasporites interscriptus
LY-1-40	275							3	7	1					3	8	p												1		
LY-1-36	236		p	p				10	10	p			5		12	p	4									2		2	1	p	p
LY-1-14	183	3						2					6		3		6	1	2							4					
LY-1-12	171	p						3	1	p			9		4		1	1	p			p	1	1	p	1	p				
LY-1-11	162	1						4					1		1		3	1	p		p	p									
LY-1-10	147	p						p							1		p	p	p	p											
LY-1-9	137									p			4		1	p	p														
LY-1-27A	128		p					20			p	p	8	1																	
LY-1-7	113																														
LY-1-23	105							2	7	2																					
LY-1-6	93		3			p	p																								
LY-1-5	69	p	11	1	p																										
LY-1-2	35																														
LY-1-1	30																														

Sample no:	Hight (mabp)	Conbaculatisporites spinosus	Illinites spp.	Limbosporites lundbladii	cf. Schizosporis spp.	Bisaccate pollen	Chasmatosporites spp.	Lunatisporites spp.	Ovalipollis ovalis	Protodiploxipinus spp.	Labiipollis mesozoicus	Ovalipollis breviformis	Ovalipollis spp.	Striate bisaccate pollen	Triadispora spp.	Ricciisporites cf. tuberculatus	Chasmatosporites apertus	Klaussipollenites spp.	Ricciisporites tuberculatus	cf. Rhaetigonyaulax rhaetica	Pareodinia ceratophora	Veryhachium spp.	Micrystridium spp.	Pareodinia spp.	Suessia swabiana	Pareodinia evetti	Quantity
LY-1-40	275	3	p	5	1	22	4			8			2	3													200
LY-1-36	236					5	5			2								1	1			2	p			1	200
LY-1-14	183					16	2			10												p			1		200
LY-1-12	171					20				24							3					p					200
LY-1-11	162					22			1	11					1	p						2	1				200
LY-1-10	147					11		1		26						p				1		2	2				200
LY-1-9	137					21		1		10			p	1	p					2			p				200
LY-1-27A	128					4	16			6																	200
LY-1-7	113					15																					53
LY-1-23	105					8				9			1							p							200
LY-1-6	93					4	3			p	1	3								1		p			p		200
LY-1-5	69					5	20			7														1			200
LY-1-2	35					15	p	1		10										p		p	p	p	1		200
LY-1-1	30					9	1	p	1	9										p	4	p					200

Appendix IV

DELTANESET, SPITSBERGEN (all species)

Sample no.	Hight	Spores	Annulispora spp.	Apiculatisporites parvispinosus	Apiculatisporites spp.	Aratrisporites macrocavatus	Calamospora nathorstii	Camarozonosporites rudis	Cavatoretisporites obvius	Conbaculatisporites spp.	Deltoidospora auritora	Deltoidospora spp.	Densosporites spp.	Dictyophyllidites mortonii	Duplexisporites problematicus	Kraeuselisporites spp.	Leptolepidites rotundus	Lycopodiumsporites austroclavatidites	Monosulcites punctatus	Neoraistrickia taylorii	Punctatisporites spp.	Raistrickia spp.	Retusotriletes spp.	Stereisporites punctatus	Ukjent 51	Ukjent 52	Zebresporites interscriptus
ASK-11-20	56.60m	79	p	4	3	p	2	p		6	1	37	p	13					5	1		p	p				
ASK-11-18	53.80m	69	p							2	1	56	p		p				1	1		p	p				p
ASK-11-17	52.40m	93	p	3	1	p	p		p	2		10	p	1	p	p		p	8			p	p	p			
ASK-11-14	48.80m	89	p	5	1	p	5			5		31		7	p				p	3			p				p
ASK-11-11	20.60m	91	p		5		2			2	1	34		5						p			1				
ASK-11-9	13.45m	90	p	4		1	2		1	1	p	46		1	p	1				3	6	1					
ASK-11-7	8.32m	96		2			p		p	3		34	p	2		1			6			1					p
ASK-11-6	6.40m	132			1	p	p	p		1		14		12	p	p			1	p		p					
ASK-11-2	2.60m	98				1	p			2		33		14		p			5	p		1		1			p
ASK-11-1	1.20m	124	p	3	10	p	1	p	p	1	1	29	p	13	p	p	1	p	4	p	p	p	p	p	p	p	p

Sample no.	Hight	Baculatisporites spp.	Conbaculatisporites hopensis	Deltoidospora toralis	Duplexisporites spp.	Eucommiidites spp.	Lycopodiacidites rugulatus	Monosulcites spp.	Naiditaspora harrisi	Semiretisporis gothae	Thomsonisporites toralis	Ukjent 54	Aratrisporites centratus	Guthoerlisporites cancellosus	Leschikisporis aduncus	Lycopodiumsporites spp.	cf. Pterospermella spp.	Todisporites spp.	Aratrisporites laevigatus	Araucariacidites cf. australis	Aulisporites spp.	Converrucosisporites cameroni	Perotriletes spp.	Schizaeoisporites worsleyi	cf. Schizosporis spp.	Ukjent 58	Aratrisporites paenulatus	Ephedripites spp	Velosporites cavatus
ASK-11-20	56.60m	10				4								p	5				1		11	p							p
ASK-11-18	53.80m	15		7		p		4							6	p		p						p				1	p
ASK-11-17	52.40m	8		p	p	p									9				1		3	1					p	p	
ASK-11-14	48.80m	13		7											15						3								2
ASK-11-11	20.60m	9	p	7	3	1		1							9			p			1							1	p
ASK-11-9	13.45m	6	p	6						4					2	p			1			p					p		
ASK-11-7	8.32m	8	p	2									p		p		2	1	3	3	p	p	p	p	1	p			
ASK-11-6	6.40m	3		2				6		p	p		1	p	p	p	p	p											
ASK-11-2	2.60m	3	p	2	2	1	2	1	p	p	2	2																	
ASK-11-1	1.20m																												

Sample no.	Hight	Kraeuselisporites dentatus	Kyrtomisporis spp.	Osmundacidites wellmanii	Camarozonosporites spp.	Kraeuselisporites cooksonae	Pollen	Chasmatosporites spp.	Striatobieites spp.	Lunatisporites spp.	Striatites spp.	Protodiploxioinus spp.	Striatites spp.	Taeniasporites rhaeticus	Labiipollis mesozoicus	Ovalipollis ovalis	Ricciisporites umbonatus	Ricciisporites spp.	Baltisphaeridium spp.	cf. Rhaetigonyaulax rhaetia	Veryhachium spp.	Micrystridium spp.	*Quantity*
ASK-11-20	56.60m		p			1	13	1	p			3						p					200
ASK-11-18	53.80m		p	p	p		28		1			6				2	p		p		p	p	200
ASK-11-17	52.40m	p	2	p			35	1	1	p		13			p	p	p				p	8	200
ASK-11-14	48.80m						14		p										p	p	p	p	200
ASK-11-11	20.60m						13		1			6			1	p			3		3	p	200
ASK-11-9	13.45m						16		1	p		6									1		200
ASK-11-7	8.32m						15	3	2	p		8							1	p	6	p	200
ASK-11-6	6.40m						15		1			6		1						p	3	1	200
ASK-11-2	2.60m						23	p		p	1	4	1								p	1	200
ASK-11-1	1.20m						9	2	p	1									p	p	1		200

Appendix V

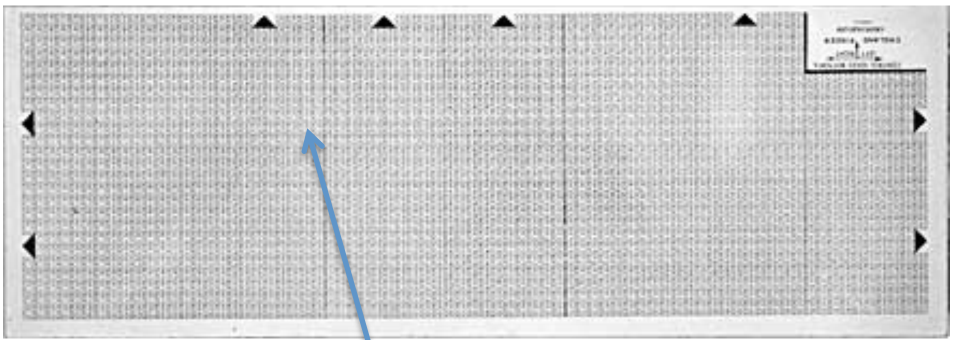
List of species recorded from Lyngefjellet and Deltaneset

SPECIES	REFERENCES
Anapiculatisporites spiniger	SMITH ET AL. 1975
Annulispora folliculosa	SMITH ET AL. 1975
Apiculatisporites parvispinosus	LESCHIK/BASEL 1955
Aratrisporites centratus	LESCHIK 1955
Aratrisporites laevigatus	BJÆRKE & MANUM 1977
Aratrisporites macrocavatus	BJÆRKE 1976
Aratrisporites paenulatus	PLAYFORD & DETTMANN 1965
cf. *Araucariacidites australis*	COOKSON 1947
Calamospora nathorstii	(HALLE) KLAUS 1960
Camarozonosporites rudis	(LESCHIK) KLAUS 1960
Cavatoretisporites obvius	BJÆRKE & MANUM 1977
Chasmatosporites apertus	NILSSON 1958, SMITH ET AL. 1975
Cingulizonates rhaeticus	SCHULTZ 1967
Conbaculatisporites hopensis	BJÆRKE & MANUM 1977
Conbaculatisporites mesozoicus	KLAUS 1960
Conbaculatisporites spinosus	MÄDLER 1964
Converrucosisporites cameroni	DEJERSEY 1964
Deltoidospora auritora	REINHARDT 1961
Deltoidospora minor	(COUPER 1953) POCOCK 1970
Deltoidospora toralis	LESCHIK 1955
Dictyopyllidites mortonii	PLAYFORD & DETTMANN 1965
Duplexisporites problematicus	PLAYFORD & DETTMANN 1965
Eucommiidites intrareticulatus	BJÆRKE & MANUM 1977
Globulisporis primus	MÄDLER 1964
Guthoerlisporites cancellosus	PLAYFORD & DETTMANN 1965
Kraeuselisporites cooksonae	(KLAUS) DETTMANN 1963
Kraeuselisporites dentatus	LESCHIK 1955
Kyrtomisporis gracilis	BJÆRKE & MANUM 1977
Kyrtomisporis speciosus	SMITH ET AL. 1975
Labiipollis mesozoicus	MÄDLER 1964
Leptolepidites rotundus	GUY 1971
Leschikisporis aduncus	MÄDLER 1964
Limbosporites lundbladii	NILSSON 1958
Lycopodiacidites rugulatus	(COUPER 1958) SCHULTZ 1967
Lycopodiumsporites austroclavatidites	(COOKSON 1953) POTONIÉ 1957
Monosulcites punctatus	ORLOWSKA-ZWOL 1966
Naiditaspora harrisi	ORBELL 1973
Neoraistrickia taylorii	PLAYFORD & DETTMANN 1965
Osmundacidites wellmanii	COUPER 1953
Ovalipollis breviformis	KRUTZSCH 1955

Ovalipollis ovalis	Schultz 1967
Pareodinia ceratophora	deFlandre 1947, Gocht 1970
Protodiploxipinus gracilis	Scheuring 1970
Protodiploxipinus minor	Bjærke & Manum 1977
Retusotriletes mesozoicus	Klaus 1960
cf. *Rhaetigonyaulax rhaeticus*	(Sarjeant) Loeblich & Loeblich 1968
Riccisporites tuberculatus	Lundblad 1954
Riccisporites umbonatus	Felix and Burbridge 1977
Rugulatisporites mesozoicus	Mädler 1964
Schizaeoisporites worsleyi	Bjærke & Manum 1977
Semiretisporis gothae	Reinhardt 1962
Spinotriletes echinoides	Mädler 1964
Stereisporites punctus	(Klaus 1960) Krutzsch 1963
Suessia swabiana	Morbey 1975
Taeniasporites rhaeticus	Schultz 1967
Thomsonisporites toralis	Leschik 1956
Velsosporites cavatus	Bjærke 1976
Verrucatosporites scabratus	Bjærke & Manum 1977
Verrucosisporites klukiformis	Nilsson 1958
Veryhachium reductum	(Deunff) Jechowsky 1961
Zebrasporites interscriptus	Smith et al. 1975
Zebrasporites laevigatus	Schultz 1967

Plates

The positions of the taxa are found in the slides by the use of England Finder. The "square" in one of the corners on the England Finder is placed to the right furthers away from me, and the position is noted as for example: the letter J at position 29 = J29, and J29,3 if the taxa is placed outside the ring:



England Finder

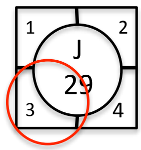


PLATE 1

Fig. 1: *Aratrisporites macrocavatus,* LY-1-2, N32
Fig. 2: *Zebrasporites laevigatus,* LY-1-5, J47,4
Fig. 3: *Conbaculatisporites hopensis,* LY-1-27A, F48, 2
Fig. 4: *Cingulizonates rhaeticus,* LY-1-27A, L48,2
Fig. 5: *Eucommiidites intrareticulatus,* LY-1-27A, F39
Fig. 6: *Deltoidospora auritora,* LY-1-9, C39,1
Fig.7: *Deltoidospora toralis,* LY-1-9, M54
Fig. 8: ?*Guthoerlisporites cancellosus,* LY-1-9, O52,2
Fig. 9: *Lycopodiacidites rugulatus,* LY-1-10, H48,1
Fig. 10: *Converrucosisporites cameronii,* LY-1-11, J60
Fig. 11: *Schizaeoisporites worsleyi*, LY-1-11, F35,1
Fig. 12: *Annulispora* spp., LY-1-12, H36
Fig. 13: *Annulispora folliculosa,* LY-1-12, L54
Fig. 14: *Aratrisporites laevigatus,* LY-1-12, B27,2
Fig. 15a: *Kyrtomisporis* spp. proximal side, LY-1-12, B39
Fig. 15b: *Kyrtomisporis* spp. distal side, LY-1-12, B39
Fig. 16: *Semiretispors gothae,* LY-1-36, Y37,4
Fig. 17: *Kyrtomisporis spesiosus,* LY-1-36, O36

PLATE 1

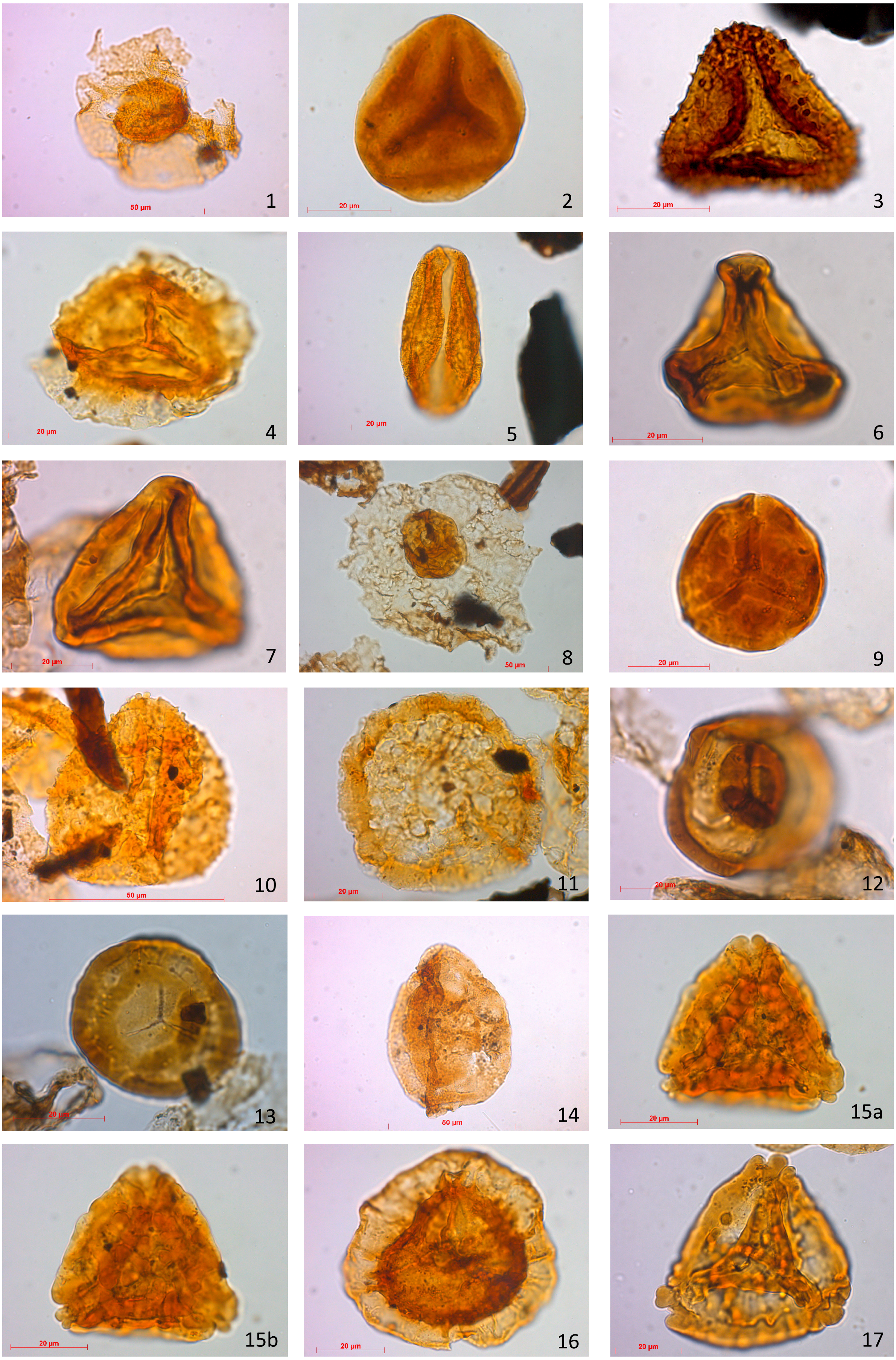


PLATE 2

Fig. 1: *Zebrasporites interscriptus,* LY-1-36, L34,2
Fig. 2: *Duplexisporites problematicus,* LY-1-40, B52,2
Fig. 3: *Leptolepidites rotundus,* LY-1-40, B49,2
Fig. 4a: *Limbosporites lundbladii,* LY-1-40, P26
Fig. 4b: *Limbosporites lundbladii,* LY-1-40, P26
Fig. 5: cf. *Schizosporis* spp., LY-1-40, N28
Fig. 6: Overview picture, LY-1-10, O53

PLATE 2

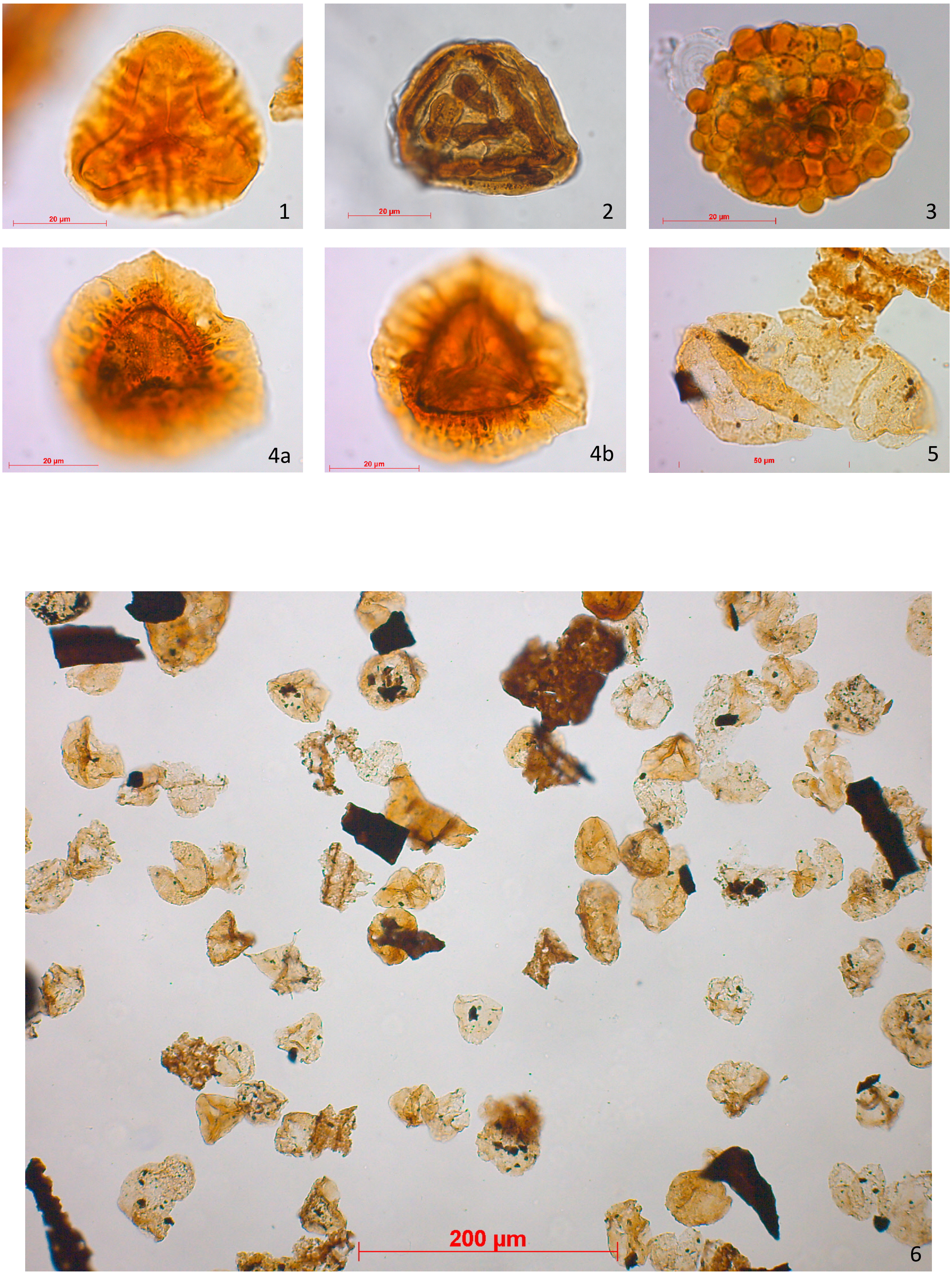


PLATE 3

Fig. 1: *Ovalipollis ovalis,* LY-1-1, N30
Fig. 2: *Corollina* spp. LY-1-2, Q39,2
Fig. 3: Bisaccate pollen grain, LY-1-6, E56
Fig. 4: *Ovalipollis breviformis,* LY-1-6, P35,2
Fig. 5: *Protodiploxipinus* spp. LY-1-9, C31,2
Fig. 6: *Lunatisporites* spp. LY-1-9, O40,4
Fig. 7: *Chasmatosporites apertus,* LY-1-12, M31,1
Fig. 8: *Riccisporites tuberculatus,* LY-1-36, O33
Fig. 9: *Illinites* spp. LY-1-40, B39
Fig. 10: Overview picture. (a) *Protodiploxipinus minor (b) Protodiploxipinus verrucosis* 40x magnification.

PLATE 3

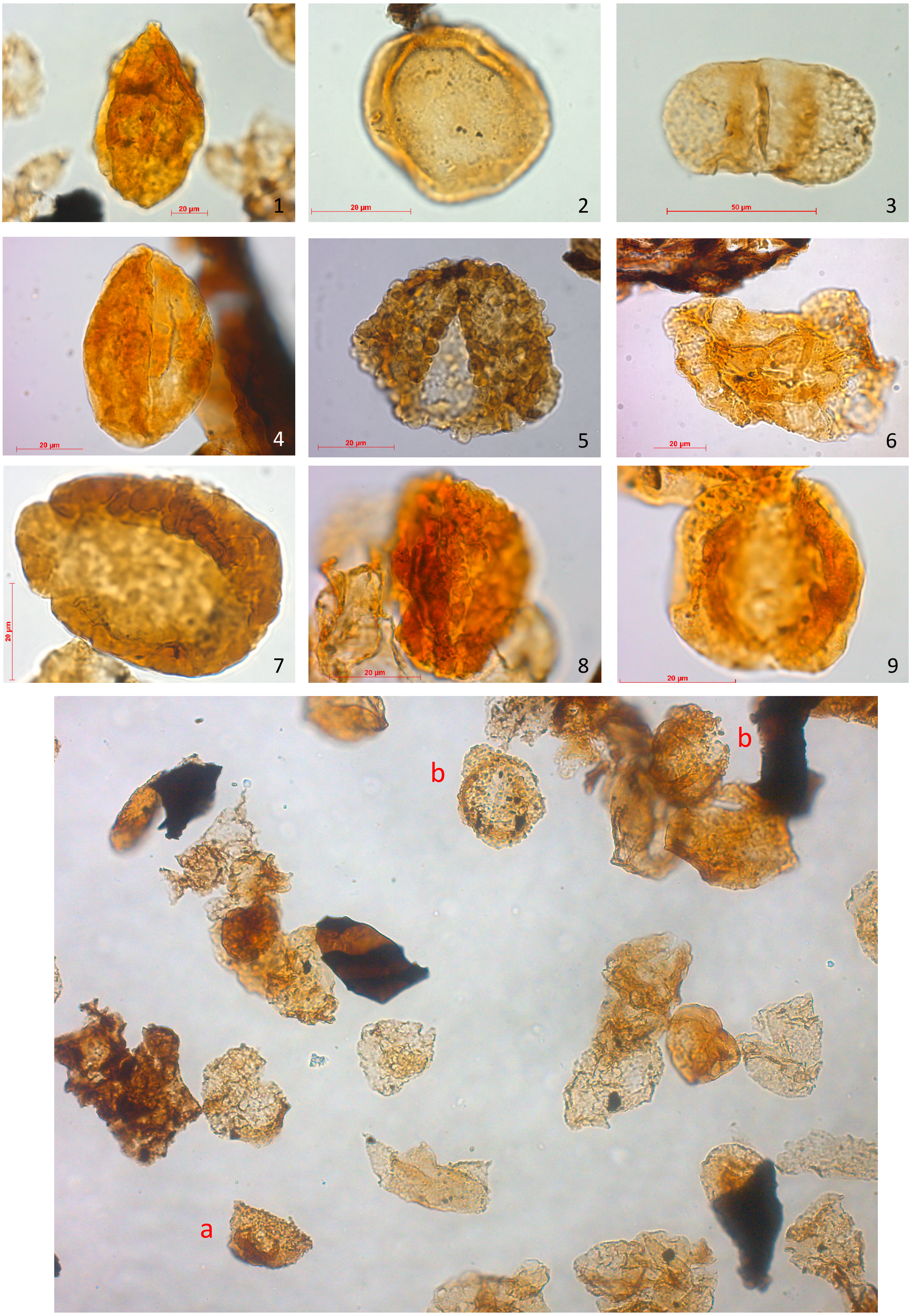


PLATE 4

Fig. 1: cf. *Rhaetigonyaulax rhaetica,* LY-1-1, F36,4
Fig. 2: *Pareodinia ceratophora,* LY-1-1, M24,4
Fig. 3: *Micrhystridium* spp. LY-1-2, N66
Fig. 4: *Suessia swabiana,* LY-1-2, O64,4
Fig. 5: cf. *Rhaetigonyaulax rhaetica,* LY-1-23, T36
Fig. 6: *Veryhachium* spp. LY-1-10, N57,4
Fig. 7: *Micrhystridium* spp. LY-1-10, F36,1

PLATE 4

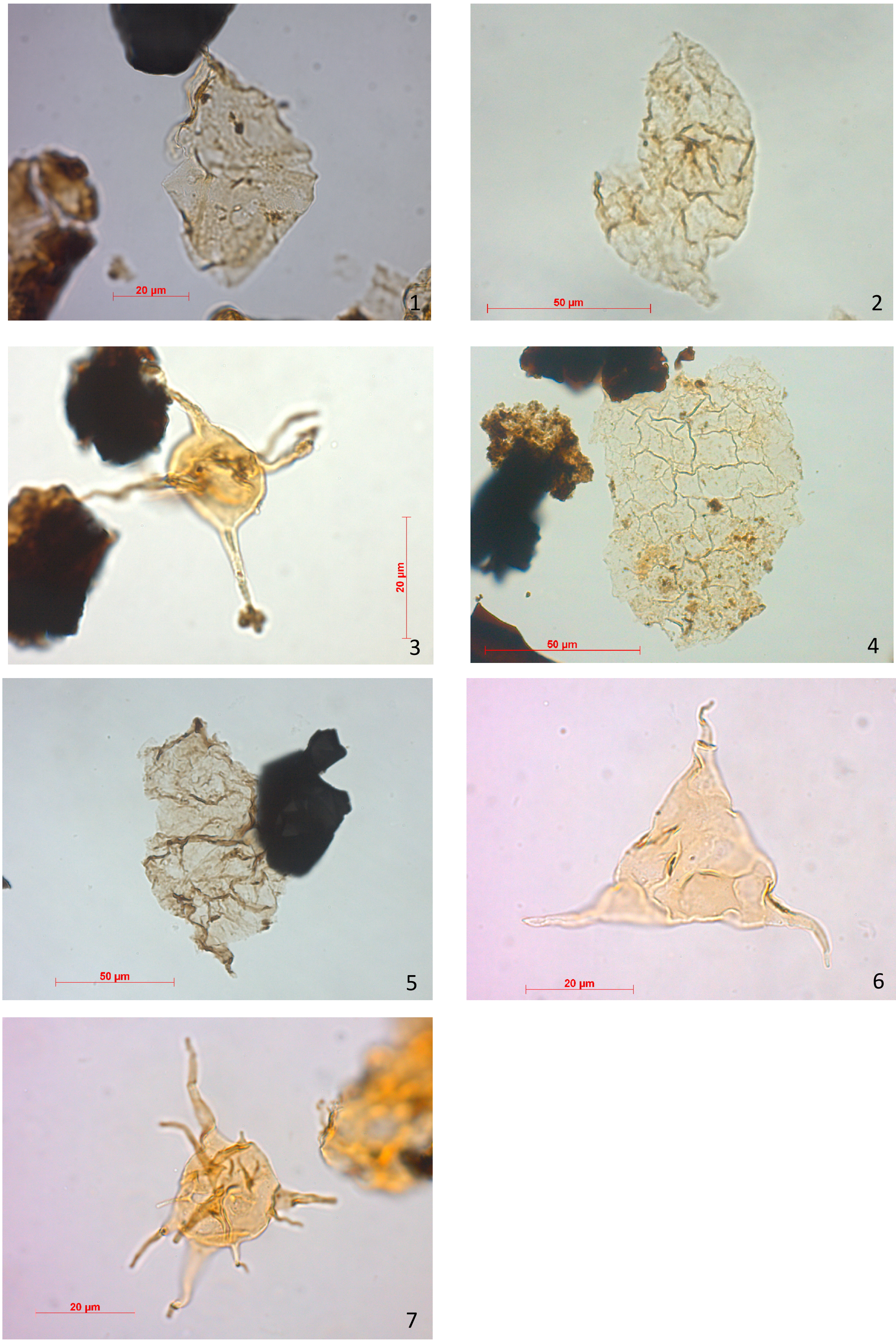


PLATE 5

Fig. 1: *Leptolepidites rotundus,* Ask-11-1, K46,4
Fig. 2: *Naiditaspora harrisi,* ASK-11-2, D49
Fig. 3: *Thomsonisporites toralis,* ASK-11-2, U44
Fig. 4: *Schizaeoisporites worsleyi,* ASK-11-7, S49
Fig. 5: *Converrucosisporites cameroni,* ASK-11-9, G35
Fig. 6: *Semretisporis gothae,* ASK-11-9, T54
Fig. 7: *Zebrasporites interscriptus,* ASK-11-14, F62
Fig. 8: *Kreauselisporites dentatus,* ASK-11-17, R51,4
Fig. 9: *Aratrisporites laevigatus,* ASK-11-20, Q31,4
Fig. 10: *Conbaculatisporites hopensis,* ASK-11-2, J49,3
Fig. 11: *Leschikisporis aduncus,* Ask-11-14, C40
Fig. 12: *Camarozonosporites rudis,* ASK-11-20, D32,3

PLATE 5

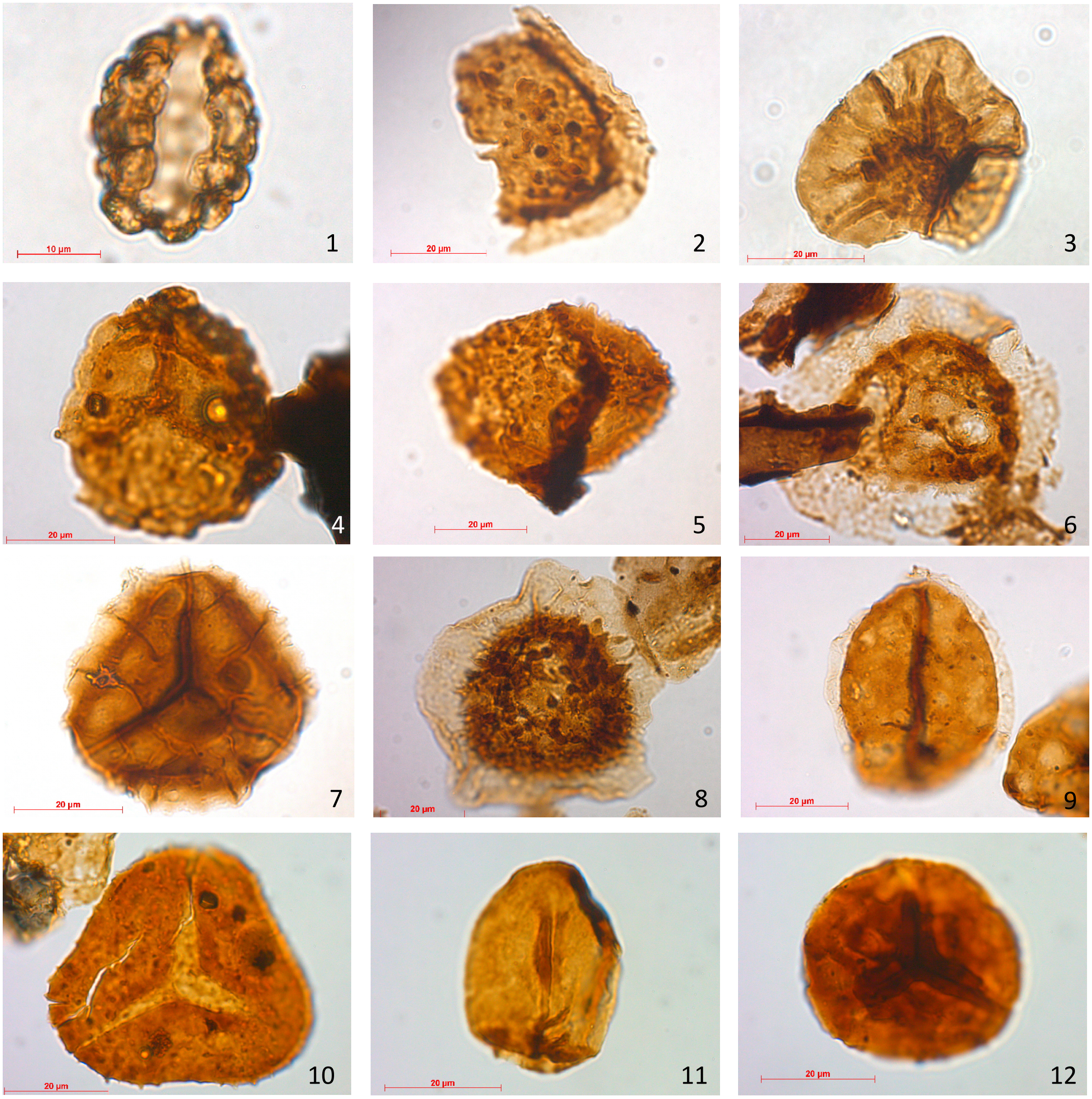


PLATE 6

Fig. 1: *Ovalipollis ovalis,* ASK-11-11, C40
Fig. 2: *Striatoabieites* spp. ASK-11-11, T36. 40x magnification
Fig. 3: *Riccisporites umbonatus,* ASK-11-17, C53,2
Fig. 4: *Riccisporites umbonatus,* ASK-11-17, F34
Fig. 5: *Riccisporites umbonatus,* ASK-11-11, L50

PLATE 6

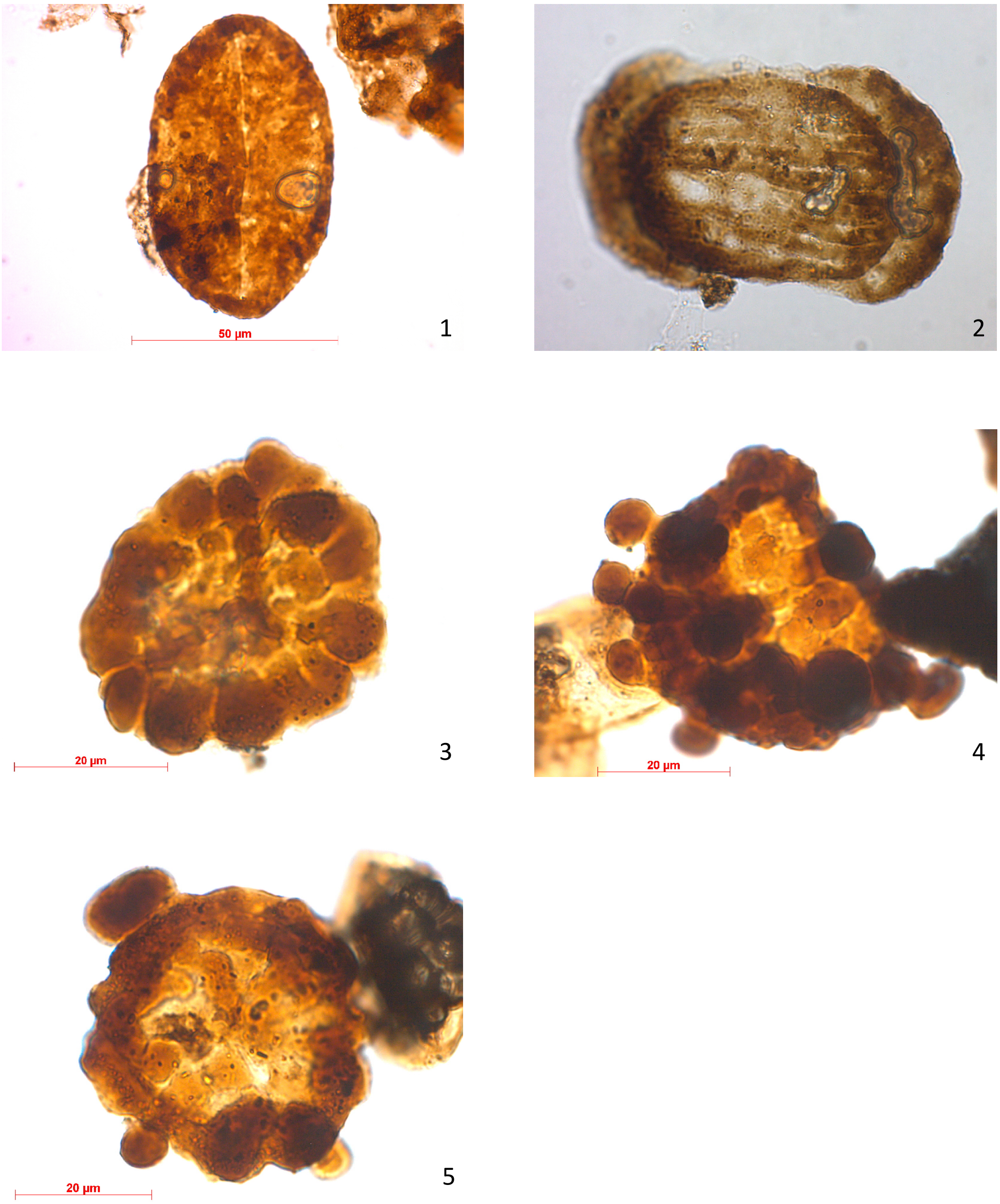


PLATE 7

Fig. 1: *Baltisphaeridium* spp. ASK-11-1, H54
Fig. 2: cf. *Rhaetigonyaulax rhaetica,* ASK-11-7, S49
Fig. 3: *Veryhachium* spp. ASK-11-11, C40
Fig. 4: *Baltisphaeridium* spp. ASK-11-14, L46,4

PLATE 7