Late Triassic (early Carnian) palynology of shallow stratigraphic core 7830/5-U-1, offshore Kong Karls Land, Norwegian Arctic

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SUMMARY

Palynostratigraphic and palynofacies data is presented from a stratigraphic core (7830/5-U-1) drilled in the northern Barents Sea, offshore Kong Karls Land. The core spans approximately 127m of the Snadd Formation (De Geerdalen Formation equivalent). The age of the core is constrained to the early Carnian (or younger) based on previously published Re – Os dates from the region. Samples yielded well-preserved and taxonomical diverse palynomorph assemblages consistent with an early Carnian (Julian) age. Taxa recorded include *Angustisulcites klausii*, *Aratrisporites laevigatus*, *Aulisporites astigmosus*, *Camarozonosporites rudis*, *Illinites chitinoides*, *Leschikisporis aduncus*, *Krauselisporites cooksonae*, *Podosporites amicus*, *Schizaeoisporites worsleyi*, *Staurosaccites quadrifidus*, *Striatella seebergensis*, *Triadispora verrucata* and *Zebrasporites fimbriatus*. Rare specimens of putative early angiosperm pollen assigned to *Afropollis* spp. were also observed. The results of the study indicate the potential for a more detailed regional palynological zonation for the Carnian and contribute to a growing body of knowledge concerning the Late Triassic palynofloras of the Barents Shelf. Palynofacies evidence indicates that deposition occurred in an increasingly proximal shelfal setting during the early Carnian. However, the occurrence of acritarchs and prasinophyte algae, coupled with rhythmic pulses in AOM content suggests episodic fluctuations along a nearshore - offshore trend.

1. Introduction

Middle to Late Triassic age strata are extensively exposed on the Svalbard Archipelago and subcrop close to the sea-floor in the adjacent Barents Sea where they contain proven hydrocarbon source and reservoir intervals (Henriksen et al., 2011; Ryseth, 2014; Lundschien et al., 2014). Precise dating and correlation of the Triassic succession in the region has long been problematic due to the overall scarcity of age-diagnostic macrofossil remains, this is particularly true of the paralic - deltaic Upper Triassic Series. However, such facies have proven to be favourable for palynology. Triassic palynological research in the region commenced in the early 1970s with a series of studies focusing mainly on the Kapp Toscana Group on the remote island of Hopen (Figure 1) (including Smith, 1974; Smith et al., 1975; Bjærke and Manum, 1977; Smith, 1982; Paterson and Mangerud, 2015; Paterson et al., submitted). A preliminary regional zonation for the Upper Permian to Late Triassic was outlined by Hochuli et al. (1989), consisting of 16 informal palynological assemblages. Recently, a formal zonation was presented by Vigran et al. (2014) comprised of 15 composite assemblage zones for the equivalent interval; however, the resolution for the Late Triassic epoch is relatively low with only 4 zones recognised for a time interval of approximately 36 m.y. Recent work on Upper Triassic exposures on Hopen (Paterson and Mangerud, 2015; Paterson et al., 2015) has demonstrated the potential for a more detailed palynozonation by describing 6 informal zones from the late Carnian – Rhaetian. However, further work is necessary to resolve the early Carnian palynofloral succession.

The current study is focused on a shallow stratigraphic core (7830/5-U-1), a Late Triassic (Carnian) age core drilled in an area east offshore Kong Karls Land in the north-east of the Svalbard Archipelago. The sequence stratigraphic context and the reservoir potential of the core was discussed by Riis et al. (2008) and Lundschien et al. (2014) respectively. A preliminary palynological study of 12 samples from the core was presented by Vigran et al. (2014) who assigned a Carnian age to the studied interval. Aside from preliminary studies by Bjærke and Manum (1977) and Bjærke (1977) on the younger, Rhaetian – early Jurassic exposures on Kong Karls Land, no other previous palynological studies have been conducted in the Kong Karls Land area. The present report provides a detailed quantitative palynostratigraphy of core 7830/5-U-1 and contributes to a more detailed palynozonation for the Upper Triassic Series in the Barents Sea region.

2. Geological setting

During the Triassic Period the Barents region was located on the northern shores of Pangaea at approximately 60° N and was a locus of deposition for large deltaic system, fed by sediment shed from the uplifting Uralides (Riis et al., 2008). During the Middle Triassic Epoch the Kong Karls Land area was situated offshore, in a restricted deep shelf setting. In the early Late Triassic (Carnian) the area became the site of prodeltaic and delta-front deposition as the rapidly advancing deltaic complex of the Snadd and De Geerdalen formations encroached upon the region (Riis et al., 2004; Lundschien et al., 2014; Klausen et al., 2015). Presently, the study area occupies a remote locality located offshore Kong Karls Land in the northern Barents Sea (78° 40' 53.8''N; 30° 40' 2.7''E). No commercial seismic acquisition or drilling has taken place in the area (Riis et al., 2008); however, the Norwegian Petroleum Directorate has been engaged in a programme of seismic acquisition in the region since 1973. This seismic dataset is so far unreleased but two seismic lines from eastern Kong Karls Land were presented by Riis et al. (2008, Fig. 4) showing a well-developed WSE – ENE trending clinoform belt in the study area. In 2005, the Norwegian Petroleum Directorate (with SINTEF as the operator) drilled 5 shallow stratigraphic cores in an area approximately 20km east of Kong Karls Land (Figure 1). The northern Barents Sea has been an area of net erosion since the Palaeogene (Riis et al., 2008) and Lower Triassic to Lower Cretaceous strata subcrop on the seabed over larger areas under a thin cover of Pleistocene tills. The cores were positioned along structural dip to obtain as much coverage of the sedimentary succession as possible (Riis et al., 2008)

The present report concerns only core 7830/5-U-1, which is the youngest of five cores drilled in the area (Figure 2). The cores 7831/2-U-2, 7831/2-U-1 and 7830/3-U-1 form the basis of two MSc. research projects at the University of Bergen and will be presented upon completion; analysis of 7830/6-U-1 is ongoing. Collectively the cores comprise an approximately 400 m thick composite section spanning the late Ladinian to Carnian age Botneheia, Tschermakfjellet and Snadd formations (Figures 2 and 3). As indicated by Lundschien et al. (2014, Figure 6.a) perhaps up to 300m of this intervening sedimentary succession is un-cored. Following the convention of previous workers (e.g. Vigran et al., 2014, p. 152) we use the Svalbard terminology for the lower two cores due to lithological similarities with exposures on eastern Svalbard. The Barents Sea nomenclature is used for the

upper three cores, including 7830/5-U-1, due to similarities with the Snadd Formation elsewhere in the Barents Sea.

Core 7830/5-U-1 penetrated 127m of the Snadd Formation (28.06 – 146.84m). The lower part of the core (146.9 – 65.3m) is composed of a claystone dominated unit which passes into a silty mudstone dominated interval in the upper part of the core (65.3 – 19.59m) (Figure 3). The claystone unit is dark grey in colour, laminated and contains abundant dispersed and nodular pyrite. Bioturbation is relatively sparse within the lower unit and is restricted to a few levels. The upper part of the core is characterised by numerous upwards coarsening packages, grading from shale to fine-grained sandstone. The uppermost part of the core (~30 – 19.59m) is intensely bioturbated by *Phycosiphon* traces and contains abundant coal fragments. Marine bivalves occur abundantly throughout the entirety of the core and consist mainly of the genera *Daonella* and *Halobia*. Occasional ammonoid remains are also present.

A preliminary palynological study of the core was conducted by Vigran et al. (2014) who assigned palynological assemblages from all 5 cores to their newly defined *Aulisporites astigmosus* Composite Assemblage Zone and proposed a Carnian age. This age interpretation is supported by Re – Os analysis of the two oldest cores (7831/2-U-2; 7831/2-U-1) by Xu et al. (2014) which places the Ladinian – Carnian boundary between the cores and constrains the age of the overlying cores, including 7830/5-U-1, as early Carnian or younger.

3. Materials and methods

3.1 Sampling

Stratigraphic core 7830/5-U-1 is curated at the Norwegian Petroleum Directorate core repository in Stavanger, Norway. Thirty-five palynological samples were collected from the core in 2013. Samples were collected primarily from mudrock and siltstone lithologies. Twelve samples studied previously by Vigran et al. (2014) were also incorporated into the study, giving a total of 47 samples from approximately 127m of core (Figure 2). Further details concerning the core is available at: www.factpages.npd.no.

3.2 Processing and analyses

Samples were processed by Palynological Laboratory Services Ltd. (PLS), Gwalchmai, United Kingdom. Approximately 10g of rock was processed per sample using standard palynological processing techniques (see Traverse 2008, pp.632-647). Coal samples were

processed using fuming nitric acid followed by a short immersion in 2% potassium hydroxide solution. Analyses were conducted at the Department of Earth Science, University of Bergen. Semi-quantitative abundance was determined by counting 300 palynomorph specimens per sample. The remainder of each slide was then scanned for rare taxa which were recorded as present outside of the count. Palynomorph abundances were plotted as a stratigraphic occurrence chart (Figure 4)

Palynomorphs were grouped according to inferred botanical affinity (Table 1), and assigned to Palynomorph Eco-Groups (PEGs) (Table 2) following the approach outlined by Abbink et al. (1998) and modified by Paterson et al. (submitted). Eco-Groups represent the following botanical and palaeoenvironmental associations: 1) marine, 2) brackish-freshwater, 3) pioneer, 4) coastal, 5) wet lowland, 6) dry lowland, 7) river, and 8) hinterland/ upland. Palynofacies analysis was performed by counting a minimum of 300 particles per sample in un-oxidised preparations; particulate organic matter (POM) was classified according to the scheme outlined by (Tyson 1995, p. 341-365). Palynofacies data was plotted both as a stratigraphic occurrence chart (Figure 5) and as a AOM-Phytoclast-Palynomorph ternary diagram (Figure 6). All palynological slides are currently curated at the Dept. of Earth Science, University of Bergen, Norway.

4. Results

4.1 Palynostratigraphy

Nearly all samples yielded well preserved and rich palynological assemblages. Assemblages are dominated mainly by terrestrial palynomorphs, consisting of fern, bryophyte and lycopsid spores, and conifer and cycad pollen (Figure 4; Table 1). Rare specimens of putative angiosperm pollen assigned to *Afropollis* spp. were recorded at 136.5 m and 79.8 m. The taxonomic association is remarkably consistent throughout the core with very few true first or last occurrences recorded. The quantitative data reveal some slight variations in the relative abundances of various taxa present in the core. In certain samples lycopsid spores were particularly abundant. For instance, *Krauselisporites* spp. is extremely abundant in the sample collected at 91.61m in which 114 specimens were observed in a count of 300 (Figure 4). Numerous tetrads of *Densoporites* spp. and *Krauselisporites* spp. were also noted throughout the core during the analysis. The coastal conifer pollen *Araucariacites australis* (Table 2) was particularly common in the upper 20 m of the core (40.50 – 19.72 m) where it constitutes

approximately one third of the total assemblage. However, no significant turnovers in the palynoflora were observed and the taxonomic association most likely represents a single palynological 'assemblage'.

Spore taxa recorded include *Annulispora folliculosa*, *Aratrisporites laevigatus*, *A. paenulatus*, *Calamospora tener*, *Camarozonosporites rudis*, *Carnisporites spiniger*, *Conbaculatisporites* spp., *Deltoidospora* spp., *Densosporites fissus*, *Densosporites* spp. (tetrads), *Dictyophyllidites mortonii*, *Krauselisporites cooksonae*, *Kyrtomisporis* sp. A, *Leschikisporis aduncus*, *Limatulasporites limatulus*, *Lycopodiacidites* spp., *Lycopodiumsporites semimuris*, *Neoraistrickia* spp., *Porcellispora longdonensis*, *Reticulatisporites bunteri*, *Striatella parva*, *S. seebergensis*, *Thomsonisporites toralis*, *Tigrisporites halleinis* and *Zebrasporites* spp.

Pollen taxa include the following: *Afropollis* spp., *Alisporite*s spp., *Angustisulcites klausii*, *Araucariacites australis*, *Aulisporites astigmosus*, *Brachysaccus* spp., *Chasmatosporites apertus*, *C. hians*, *Chordasporites singulichorda*, *Classopollis* spp., *Dyupetalum vicentinense*, *Eucommiidites intrareticulatus*, *Granasporites magnus*, *Illinites chitinoides*, *Infernopollenites parvus*, *Institisporites crispus*, *Lunatisporites acutus*, *Lunatisporites noviaulensis*, *Ovalipollis ovalis*, *Podosporites amicus*, *Protodiploxypinus* spp., *Pseudoquadrisaccus irregularis*, *Retisulcites* spp., *Schizaeoisporites worsleyi*, *Striatoabieites* spp., *Staurosaccites quadrifidus*, *Triadispora* spp. and *Vitreisporites pallidus*.

Marine palynomorphs are relatively rare but are consistently present (Figure 4) and consist of acritarchs and prasinophyte algae. Taxa recorded include *Baltisphaeridium* spp., *Crassosphaera* spp., *Cymatiosphaera* spp., *Leiosphaeridium* spp., *Micrhystridium* spp., *Tasmanites* spp. and *Veryhachium* spp. Specimens of the alga *Crassosphaera* spp. are particularly abundant in samples at 82.67 and 56.72 m depth (Figure 4). Rare specimens tentatively assigned to the dinoflagellate cyst taxon *Heibergella asymmetrica* were also recorded in samples 93.50 m and 72.70 m. Freshwater palynomorphs *Botryococcus* spp. and *Plaesiodictyon mosellanum* were relatively rare but were consistently present in assemblages except in the uppermost 10 m of the core (32.25 – 22.82 m) where *Plaesiodictyon mosellanum* was common.

4.2 Palynofacies analysis and palynofloral affinities

Particulate organic matter (POM) assemblages from core 7830/5-U-1 are dominated by Amorphous Organic Matter (AOM), various phytoclast particles and sporomorphs (Figure 5).

Freshwater algae and marine microplankton constituted a very minor component of the palynofacies assemblages. The ratios of AOM to phytoclast fluctuate in a consistent and apparently cyclic manner (Figure 5 and 6). Four intervals of upwards increasing phytoclast abundance were noted (146.84 – 130.50m; 128.42 – 93.50m; 87.20 – 59.70m; 58.72 – 19.72m). These are bracketed by peaks in the relative abundance of AOM which were recorded in samples 128.42m, 87.20m and 58.72m; palynomorphs and phytoclasts were rare in such samples. The abundance of phytoclast is highest with the uppermost part of the core between 40.50 – 19.72m.

5. Discussion

5.1 Biostratigraphic correlation

Palynological assemblages from the stratigraphically older cores from Kong Karls Land (Vigran et al., 2014; Paterson et al., in prep) and from the younger outcrop sections on Hopen on Hopen (Paterson & Mangerud, 2015) contain many of the same taxa, indicating that the majority of species recorded in core 7830/5-U-1 are relatively long ranging. The core was previously dated to the mid - late Carnian by Vigran et al. (2014) who assigned the palynological assemblage to their *Aulisporites astigmosus* Zone (Figure 7). However, as currently defined the temporal resolution of the zone is relatively low, incorporating the entire Carnian Stage, a timespan of approximately 7 m.y. (according to Ogg, 2012).

In the Boreal Realm *A. astigmosus* is considered to have a first appearance datum during the early Carnian (Vigran et al., 2014). This taxon is also considered to appear in the early Carnian (Julian) in the Germanic (Visscher et al., 1994) and Alpine realms (Roghi et al., 2004; Cirilli et al., 2010; Roghi et al., 2010; Mueller et al., in press). However, as noted in previous works (Hochuli et al., 1989; Hochuli and Vigran, 2010; Paterson and Mangerud, 2015) there appear to be some clear differences in the composition of the palynofloras between these regions. In the Tethyan and Germanic realm early Carnian assemblages are characterised by the diversification of circumpolloid pollen such as *Camerosporites secatus*, *Duplicisporites granulatus*, *Paracirculina scurrilis*, *Praecirculina granifer*, and the monosaccate pollen *Patinasporites densus* (Cirilli et al., 2010). In contrast, these taxa are either rare or absent in the Boreal assemblages. These compositional differences most likely due to palaeoclimatic control and further underline the need to establish a regional palynozonation for the Barents Sea.

Recent work from the neighbouring island of Hopen (Paterson and Mangerud, 2015; Paterson et al., submitted) and from shallow stratigraphic core 7533/2-U-1 drilled in the Sentralbanken area of the Barents Sea (Paterson et al., in prep.) has demonstrated that the *A. astigmosus* Zone may be further subdivided (Figure 7). Two new informal zones were described from the De Geerdalen Formation on Hopen (Paterson and Mangerud, 2015); the '*Leschikisporis aduncus* assemblage', from the lower undifferentiated De Geerdalen Formation, and the '*Protodiploxypinus* spp. assemblage', corresponding with the overlying Hopen Member. The '*Leschikisporis aduncus* assemblage' is characterised by a dominance of fern spores including the nominate taxon, together with common specimens of *Apiculatisporis hirsutus*, *A. lativerrucosus*, *Aratrisporites fischeri*, *Clathroidites papulosus* and *Zebrasporites* spp. In contrast, the assemblage described in the current study from core 7830/5-U-1 is of relatively high taxonomic diversity. The assemblage is typified by an association consisting of pollen taxa *A. astigmosus*, *Podosporites amicus* and various striate bisaccate pollen, together with fern and lycopsid spores such as *Camarozonosporites rudis*, *Densosporites* spp. and *Krauselisporites* spp. *L. aduncus* is present in assemblages from core 7830/5-U-1 but never dominates as in the '*Leschikisporis aduncus* assemblage' on Hopen. Based on these fundamental differences we conclude that the palynofloral association from 7830/5-U-1 must predate the late Carnian (Tuvalian 2-3) '*Leschikisporis aduncus* assemblage' (Paterson and Mangerud, 2015).

The composition of the palynofloral association recorded in core 7830/5-U-1 is closely comparable to Assemblage F described by Hochuli et al. (1989) from the Tschermakfjellet and lower De Geerdalen formations on Spitsbergen. Assemblage F is characterised by striate bisaccate pollen, including *Infernopollenites*, *Lunatisporites* and *Striatoabieites* spp. According to those authors Assemblage F contains the last appearances of *Angustisulcites klausii* and *Podosporites amicus*, and the first stratigraphic occurrence of *Aulisporites astigmosus*, all of which are present in the assemblage recorded in the present study from core 7830/5-U-1. Hochuli et al. (1989) considered an early Carnian age for the assemblage based on ammonites from the Tschermakfjellet Formation assigned to the *Stolleites tenuis* Zone and the bivalve *Halobia zitteli* (Mørk et al., 1982; Weitschat and Lehmann, 1983).

This biostratigraphic evidence is consistent with absolute age determinations from the two oldest cores drilled offshore Kong Karls Land (Xu et al., 2014), which constrains the age of core 7830/5-U-1 to early Carnian (Julian) or older. Based on the available evidence we conclude that the assemblage described in this study from the core represents a further

subdivision of the *Aulisporites astigmosus* Zone of Vigran et al. (2014), which is older than the '*Leschikisporis aduncus* assemblage' (Paterson and Mangerud, 2015) but younger than *Echinitosporites iliacoides* Zone of Vigran et al. (2014) (Figure 7).

The palynological association documented in the current study is consistent with that reported in the preliminary study by Vigran et al. (2014). However, based on the current analysis it appears that the abundance of *Aulisporites astigmosus* in the core was perhaps overestimated in the previous study, where it was described as being common to abundant. In the current study, relatively few specimens conforming to the diagnosis of *A. astigmosus* (Leschik) Klaus (1960) were observed. This observation is significant because *A. astigmosus* is the nominate taxon of the *Aulisporites astigmosus* Composite Assemblage Zone of Vigran et al. (2014). However, numerous specimens of the species *Podosporites amicus* Scheuring (1970) with very small rudimentary sacci were observed and it is possible that there may be some degree of morphological overlap between the two taxa as currently defined; further taxonomic investigation is needed to clarify this issue.

Vigran et al. (2014) noted a dominance of *Krauselisporites* spp. from 91.61 upwards. This observation is confirmed by the present study. However, we have observed that particularly high abundance of *Krauselisporites* spp. is restricted to just a few samples, such as in sample 91.61m (Figure 4) where it accounts for more than one third of the total assemblage. Such high abundance of this taxon is unusual and has not been noted previously. Such discrete abundance peaks probably relate to palaeoenvironmental control but may prove to be of biostratigraphic significance. The common occurrence of *Densosporites* spp. and *Krauselisporites* spp. tetrads is also unique to this particular locality and stratigraphic interval and may suggest deposition very close to an area dominated by a lycopsid flora.

The occurrence of specimens assigned to *Afropollis* spp. confirms previous accounts of putative early angiosperm pollen in the Middle – Late Triassic of the Barents Sea region (Hochuli and Feist-Burkhardt, 2004; Hochuli and Feist-Burkhardt, 2013). Such specimens are rare; however, we anticipate that further specimens will be documented by future studies now that their presence has been established.

5.2 Palaeoenvironments

The composition of organic matter and palynological assemblages in core 7830/5-U-1 is consistent with deposition in a prevailing marine environment, in relatively close proximity to

a terrestrial organic matter source. This is consistent with the presence of marine bivalves and ammonoids throughout the core. The palynological assemblage consists of an in-situ marine component, which is overprinted by a local fern – lycopsid spore microflora derived from the adjacent coastal plain, and a conifer pollen association transported from the hinterland (Table 2).

The motif of repeated upwards increases in the relative abundance of phytoclast particles suggests increasing proximity to the terrestrial kerogen source over four distinct phases (Figure 5), herein termed 'palynofacies cycles'. The high abundance of AOM between these phases, in samples 128.42m, 87.20m and 58.72m, suggests significantly decreased terrestrial organic matter input and the establishment of dysoxic-anoxic conditions at the site of deposition, and is consistent with the presence of dispersed and nodular pyrite in the core, particularly in the lower unit.

Such recurrent changes in the particulate organic matter assemblage may be the result of autocyclic switching of deltaic lobes. Alternatively, these changes could reflect successive phases of out-building and flooding of the deltaic front in response to changes in accommodation space and sediment supply (i.e. progradational parasequences). The peaks in AOM abundance may represent minor flooding surfaces delineating the parasequence boundaries. Fluctuations in the proximity of the deltaic front are supported by the AOM-Phytoclast-Palynomorph ternary plot which suggests deposition along a nearshore – offshore trend (Figure 6). Due to the fluctuation between samples dominated by AOM and phytoclast, samples plot along the left side of the figure. According to Tyson (1995) such assemblages correspond with 'highly proximal shelf' to 'distal suboxic – anoxic' palaeoenvironments.

The highest abundance of phytoclasts was recorded between 40.50 – 19.72m and corresponds to the high abundance of coal debris noted in the core. This trend corresponds with the interval of intense bioturbation (Figure 2), which suggests that the upper layers of sediment were sufficiently oxic to permit colonisation by infauna. The almost total absence of AOM in this interval is consistent with this interpretation. The occurrence of the fresh – brackish water algae *Plaesiodictyon mosellanum* between 32.25 and 22.82 m suggests increased proximity to a freshwater source.

6. Conclusions

Shallow stratigraphic core 7830/5-U-1 yielded an exceptionally well-preserved and diverse palynoflora which is confidently assigned an early Carnian (Julian) age based on the available absolute and relative age constraints. The palynological assemblage described herein represents a new subdivision of the previously described *Aulisporites astigmosus* Composite Assemblage Zone, which is younger than the Ladinian age *Echinitosporites iliacoides* Zone, and older than the late Carnian (Tuvalian) '*Leschikisporis aduncus* assemblage'. The palynofloral association is surprisingly consistent over the 127 m thick sampled interval, with few first or last stratigraphic appearances recorded, suggesting the assemblages documented in the core comprise a single 'palynozone'. The rare occurrence of putative early angiosperm pollen is noted, confirming previous reported occurrences in the region. Palynofacies evidence is indicative of an overall upward shallowing sedimentary succession deposited along a fluctuating onshore – offshore trend. Palaeoenvironments are considered to range from offshore pro-deltaic to nearshore settings. The evidence is consistent with the arrival of the prograding Snadd/ De Geerdalen Formation deltaic system in the Kong Karls Land area during the early Carnian.

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Appendices

Appendix 1. List of palynomorph taxa

Spores

Annulispora folliculosa (Rogalska) de Jersey, 1959 Pl. 1, 16.

Annulispora cf. *folliculosa*

Annulispora microannulata de Jersey, 1962

Apiculatasporites hirsutus Leschik, 1955 Pl. 2, 8-9.

Apiculatasporites lativerrucosus Leschik, 1955 Pl. 2, 10-11.

Apiculatisporis parvispinosus (Leschik) Playford and Dettman, 1965

Aratrisporites fischeri (Klaus) Playford and Dettman, 1965

Aratrisporites cf. *fischeri*

Aratrisporites granulatus Orlowska-Zwolinska, 1976

Aratrisporites laevigatus Bjærke and Manum, 1977 Pl. 2, 16.

Aratrisporites cf. *macrocavatus*

Aratrisporites palletae (Klaus) Schulz, 1967 Pl. 2, 19.

Aratrisporites cf. *palletae*

Aratrisporites paenulatus Playford and Dettman, 1965 Pl. 2, 18.

Aratrisporites scabratus Klaus, 1960

Aratrisporites sp. A Pl. 2, 20.

Aratrisporites spp.

Baculatisporites spp. Pl. 1, 5.

Calamospora tener (Leschik) Mädler, 1964

Camarozonosporites laevigatus Schulz, 1967 Pl. 1, 14.

Camarozonosporites rudis (Leschik) Klaus, 1960 Pl. 1, 13.

Carnisporites spiniger (Leschik) Morbey, 1975 Pl. 1, 6.

Carnisporites sp.

Cingulizonates rhaeticus (Reinhardt) Schulz, 1967

Clathroidites papulosus Bai in Bai et al., 1983 Pl. 1, 9.

Conbaculatisporites hopensis Bjærke and Manum, 1977 Pl. 1, 10.

Conbaculatisporites sp. A

Conbaculatisporites spp.

Concavisporites crassexinus Nilsson, 1958

Concavisporites scabratus Bjærke and Manum, 1977 Pl. 1, 3.

Concavisporites sp. B

Converrucosisporites spp.

Converrucosisporites sp. A

Cyclotriletes pustulatus (Kosanke) Potonié and Kremp, 1955

Deltoidospora spp.

Densoisporites sp. A (*Cingutriletes infrapunctus*) Pl. 1, 11.

Densosporites fissus (Reinhardt) Schulz, 1967 Pl. 2, 2.

Densosporites 'verrucosus' Pl. 2, 1

Densoporites sp. A

Densosporites spp.

Densosporites spp. tetrad

Dictyophyllidites mortonii (de Jersey) Playford and Dettman, 1965 Pl. 1, 2.

Gordonispora spp. Pl. 1, 15.

Jerseyiaspora punctispinosa Kar et al., 1972

Krauselisporites apiculatus Jansonius, 1962 Pl. 2, 4.

Krauselisporites cooksonae (Klaus) Dettman, 1963 Pl. 2, 3.

Krauselisporites dentatus Leschik 1956 Pl. 2, 5.

Krauselisporites sp. A

Krauselisporites sp. B

Krauselisporites sp. C

Krauselisporites spp.

Krauselisporites spp. tetrad Pl. 2, 6.

Kyrtomisporis sp. A Pl. 2, 12-15.

Kyrtomisporis cf. *laevigatus*

Kyrtomisporis spp.

Lapposisporites sp. A

Leptolepidites bossus Tralau, 1968

Leptolepidites spp.

Leschikisporis aduncus (Leschik) Potonié, 1958 Pl. 1, 1.

Limatulasporites limatulus (Playford) Helby and Foster, 1979 Pl. 1, 18.

Lophotriletes novicus Singh, 1964 Pl. 1, 7.

Lycopodiacidites rugulatus (Couper) Schulz, 1967 Pl. 1, 25.

Lycopodiacidites keuperi Klaus 1960

Lycopodiumsporites semimuris (Danzé-Corsin and Laveine) Reiser and Williams, 1968

Megaspore sp. A Pl. 2, 7 (50% scale)

Megaspore sp. B

Naumovaspora striata Jansonius 1962

Neoraistrickia taylorii Playford and Dettman, 1965 Pl. 1, 8.

Neoraistrickia spp.

Nevesisporites bigranulatus (Levet-Carette) Morbey 1975 Pl. 1, 12.

Osmundacidites spp.

Perotriletes spp.

Polycingulatisporites bicollateralis (Rogalska) Morbey, 1975 Pl. 1, 17.

Porcellispora longdonensis (Clarke) Scheuring, 1970 emend. Morbey, 1975

Punctatisporites fungosus Balme, 1963

Punctatisporites spp.

Raistrickia spp.

Reticulatisporites bunteri Mädler, 1964 Pl. 1, 30.

Retitriletes sp. A

Retusotriletes spp.

Rewanispora foveolata (de Jersey) de Jersey and Raine, 1990

Rewanispora vermiculatus Antonescu and Taugourdaeu-Lantz, 1973

Rogalskaisporites cicatricosus Pl. 1, 19.

Semiretisporis sp. A

Spinotriletes spp.

*Stereisporite*s *perforatus* Leschik, 1955 Pl. 1, 20.

*Stereisporite*s spp.

Striatella parva (Li and Shang) Filatoff and Price, 1988 Pl. 1, 23.

Striatella seebergensis Mädler, 1964 Pl. 1, 24.

Thomsonisporites toralis Leschik, 1955 Pl. 1, 22.

Tigrisporites halleinis Klaus 1960 Pl. 1, 21.

Uvaesporites argentaeformis (Bolkhovitina) Schulz, 1967

Uvaesporites sp. A

Velosporites sp. A

Verrucosisporites remyanus Mädler, 1964 Pl. 1, 4.

Zebrasporites interscriptus (Thiergart) Klaus, 1960 Pl. 1, 27.

Zebrasporites fimbriatus Klaus 1960 Pl. 1, 29.

Zebrasporites kahleri Klaus 1960

Zebrasporites laevigatus (Schulz) Schulz, 1967

Zebrasporites sp. A Pl. 1, 28.

Pollen

Afropollis spp. Pl. 4, 1-3.

Alisporites spp. Pl. 3, 6.

Angustisulcites klausii (Freudenthal) Visscher, 1966 Pl. 3, 15.

Araucariacites australis Cookson, 1947

Aulisporites astigmosus (Leschik) Klaus, 1960 Pl.3, 22.

Bisaccate spp.

Brachysaccus neomundanus (Leschik) Mädler, 1964

Brachysaccus spp.

Camerozonosporites pseudoverrucatus Scheuring, 1970

Chasmatosporites apertus (Rogalska) Nilsson, 1958

Chasmatosporites hians Nilsson, 1958

Chasmatosporites cf. *hians*

Chasmatosporites spp.

Chordasporites singulichorda Klaus, 1966

Chordasporites spp.

Classopollis spp. Pl. 4, 5.

Clavatispollenites spp. Pl. 4, 4.

Cordaitina gunyalensis (Pant and Srivastava) Balme, 1970

Cycadopites spp.

Duplicisporites spp.

Dyupetalum vicentinense Brugman, 1983 Pl. 3, 21.

Echinitosporites sp. A

Echinitosporites spp.

Ellipsovelatisporites plicatus Pl. 3, 19.

Enzonalasporites tenuis Leschik, 1955

Eucommiidites intrareticulatus Bjærke and Manum, 1977

Eucommiidites sp. A

Eucommiidites sp. B

Eucommiidites spp.

Falcisporites spp.

Granasporites magnus Lijun et al., 1983 Pl. 3, 24.

Haberkornia gudati Scheuring, 1978

Haberkornia parva Scheuring, 1978

Illinites chitinoides Klaus, 1964 Pl. 3, 16.

Infernopollenites parvus Scheuring, 1970

Infernopollenites sp. A

Infernopollenites spp.

Institisporites crispus Pautsch, 1971 Pl. 3, 20.

Kuglerina meieri Scheuring, 1978

Lueckisporites virkkiae (Potonié and Klaus) Clarke, 1965

Lunatisporites acutus (Leschik) Scheuring, 1970 Pl. 3, 10.

Lunatisporites noviaulensis (Leschik) Scheuring, 1970 Pl. 3, 11.

Lunatisporites noviaulensis var. *mollis* Scheuring, 1970

Lunatisporites rhaeticus (Schulz) Warrington, 1974

Lunatisporites spp.

Ovalipollis breviformis Krutsch, 1955

Ovalipollis brutus Scheuring emend. Scheuring, 1978

Ovalipollis cultus Scheuring, 1970

Ovalipollis minimus Scheuring, 1970

Ovalipollis ovalis (Krutsch) Scheuring, 1970 Pl. 3, 13.

Ovalipollis pseudoalatus (Thiergart) Schuurmann, 1976

Ovalipollis septimus Scheuring emend. Scheuring, 1978

Ovalipollis spp.

Patinasporites densus Leschik, 1955

Platysaccus spp.

Podosporites amicus Scheuring, 1970 Pl. 3, 23.

Podosporites spp.

Pretricolpipollenites spp.

Protodiploxypinus decus Scheuring, 1970 Pl. 3, 17.

Protodiploxypinus minor Bjærke and Manum, 1977 Pl. 3, 18.

Protodiploxypinus spp.

Protohaploxypinus spp.

Pseudoquadrisaccus irregularis Liu 1981

Retisulcites perforatus (Mädler) Scheuring, 1970

Retisulcites sp. 1

Retisulcites sp. 2

Ricciisporites umbonatus Felix and Burbridge, 1977

Schizaeoisporites worsleyi Bjærke and Manum, 1977 Pl. 3, 12.

Schizosaccus keuperi Mädler, 1964

Staurosaccites quadrifidus Dolby in Dolby and Balme, 1976 Pl. 3, 14.

Steevesipollenites spp.

Striatoabieites aytugii (Visscher) Scheuring, 1970 Pl. 3, 7.

Striatoabieites balmei (Klaus) Scheuring, 1978 Pl. 3, 8.

Striatoabieites multistriatus (Balme and Hennelly) Hart, 1964 Pl. 3, 9.

Striatoabieites spp.

Succinctisporites grandior Leschik, 1955

Tetrasaccus spp.

Triadispora aurea Scheuring, 1970

Triadispora crassa Klaus, 1964 Pl. 3, 3.

Triadispora obscura Scheuring, 1970

Triadispora plicata Klaus, 1964 Pl. 3, 2.

Triadispora sulcata Scheuring, 1978 Pl. 3, 4.

Triadispora verrucata (Schulz) Scheuring, 1970 Pl. 3, 1.

Triadispora sp. A Pl. 3, 5.

Triadispora cf. *verrucata*

Triadispora spp.

Vitreisporites pallidus (Reissinger) Nilsson, 1958

Acritarchs and prasinophytes

Baltisphaeridium spp.

Crassosphaera spp.

Cymatiosphaera spp.

Leiosphaeridium spp.

Micrhystridium spp.

Tasmanites spp.

Veryhachium spp.

Dinocysts

? *Heibergella asymmetrica*

Freshwater algae

Botryococcus spp.

Plaesiodictyon mosellaneum Willie, 1970

Fungal

Fungal hyphae undiff.

Reduviasporonites chalastus (Foster) Elsik, 1999

Microforaminiferal linings

Microforaminiferal linings undiff.

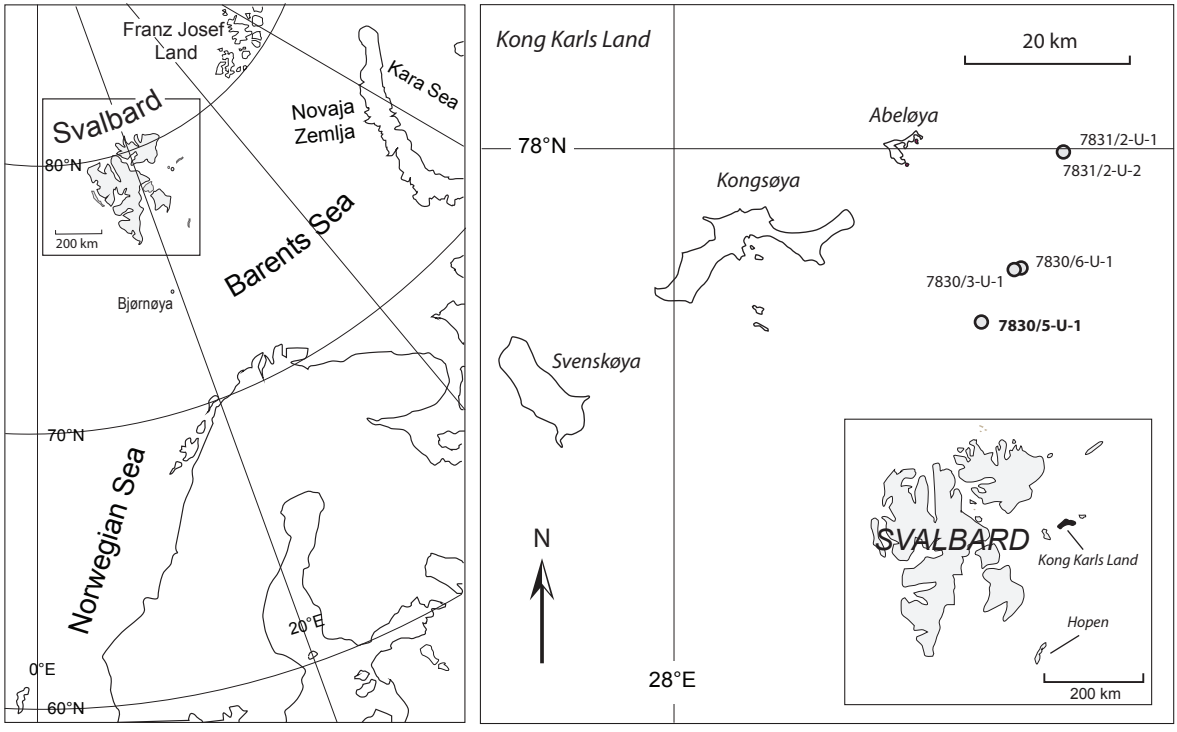

Figure 1. Location map of shallow stratigraphic core 7830/5-U-1, offshore Kong Karls Land, northern Barents Sea.

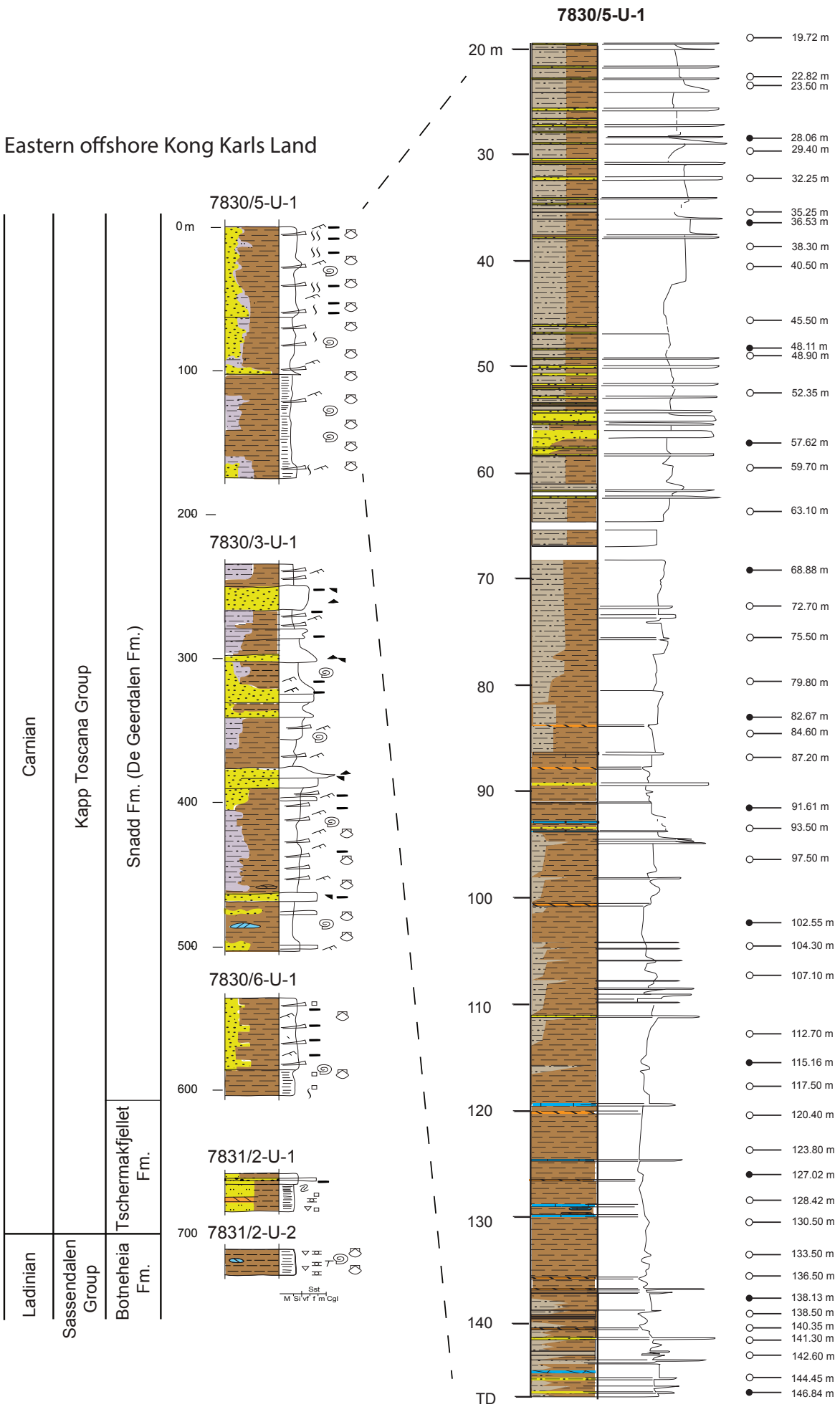

Figure 2. Summary of Middle to Late Triassic stratigraphic cores drilled offshore Kong Karls Land (core logs modified from Lundschien et al, 2014); sample depths from core 7830/5-U-1. Filled black circles represent samples previously studied by Vigran et al. (2014); open circles denote samples collected for this study.

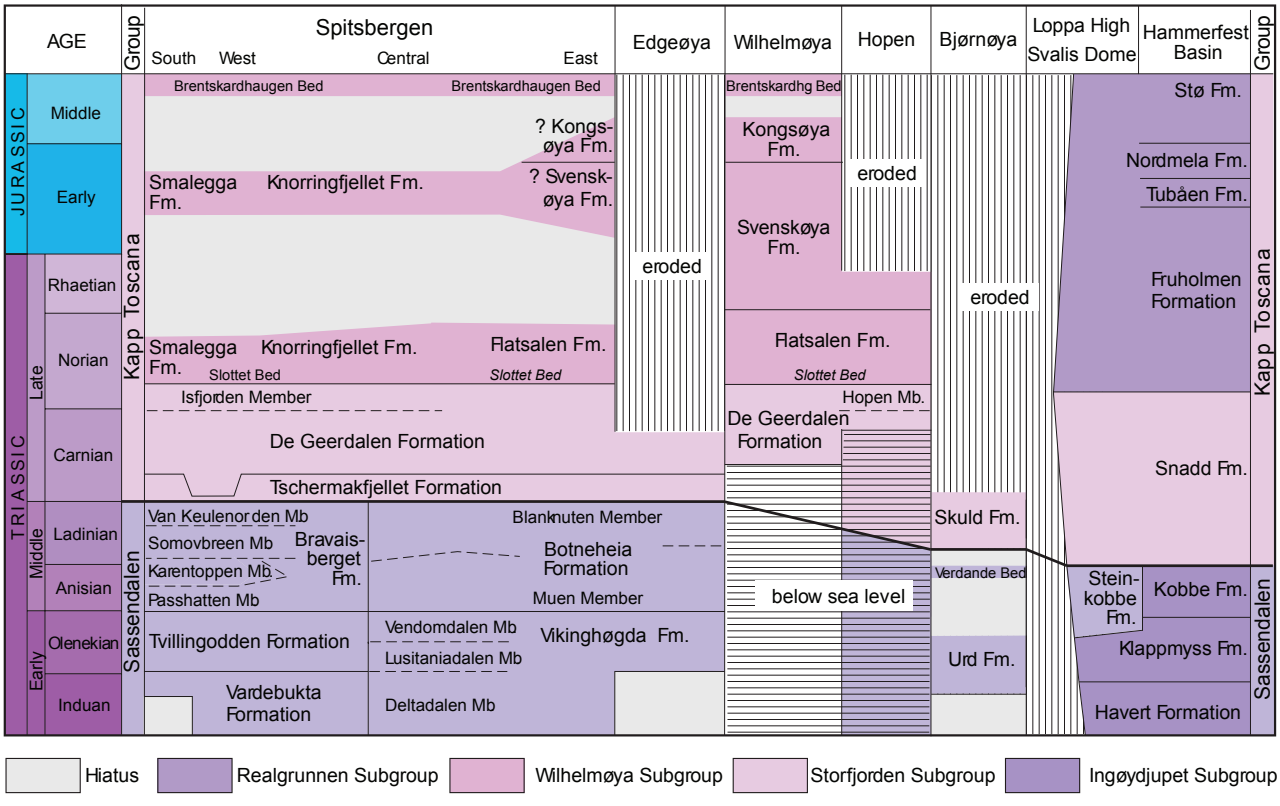

Figure 3. Stratigraphic subdivisions for the Triassic to Middle Jurassic succession of Svalbard & the Barents Sea (after Mørk et al. 2013).

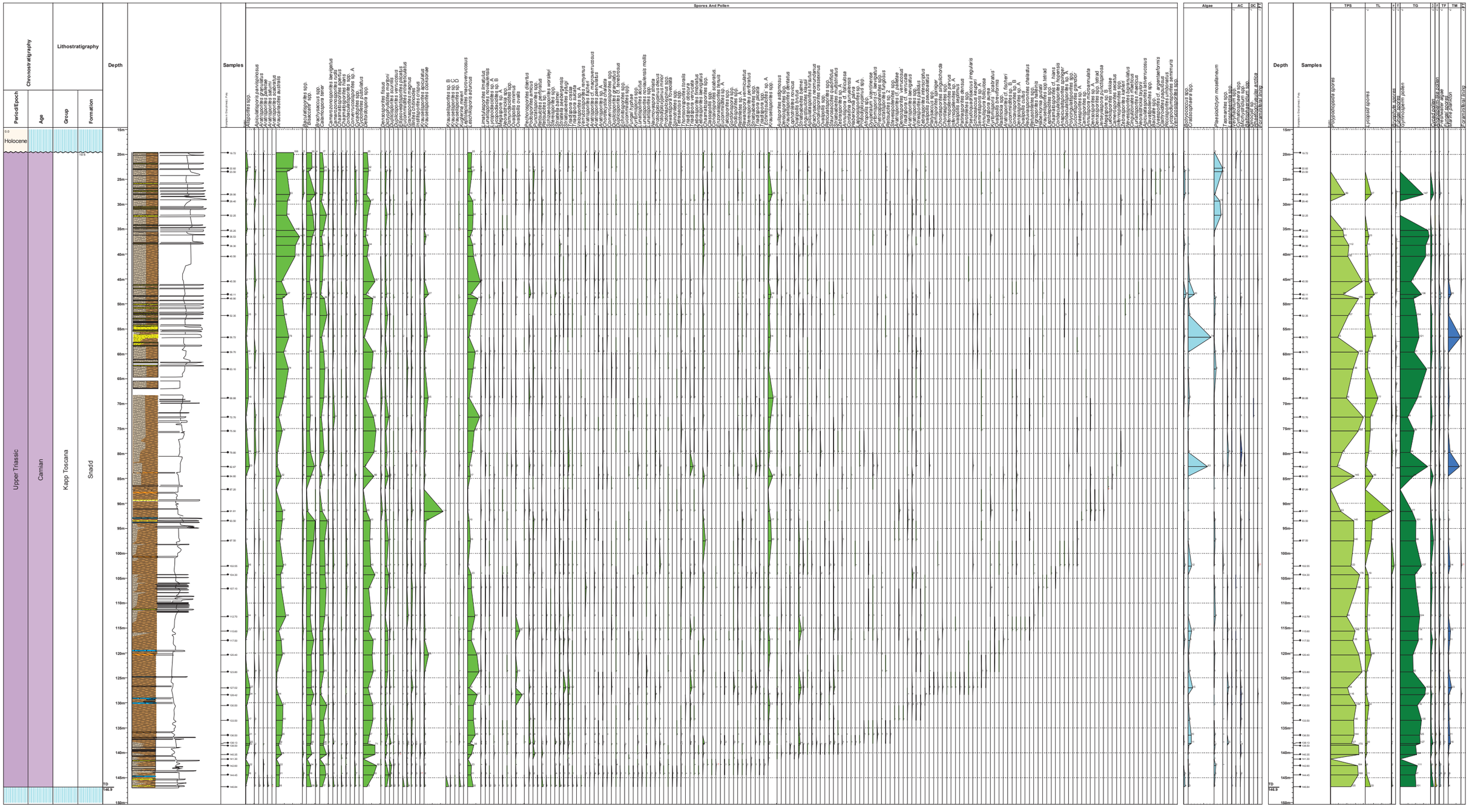

Figure 4. Relative abundance of palynomorphs from core 7830/5-U-1.

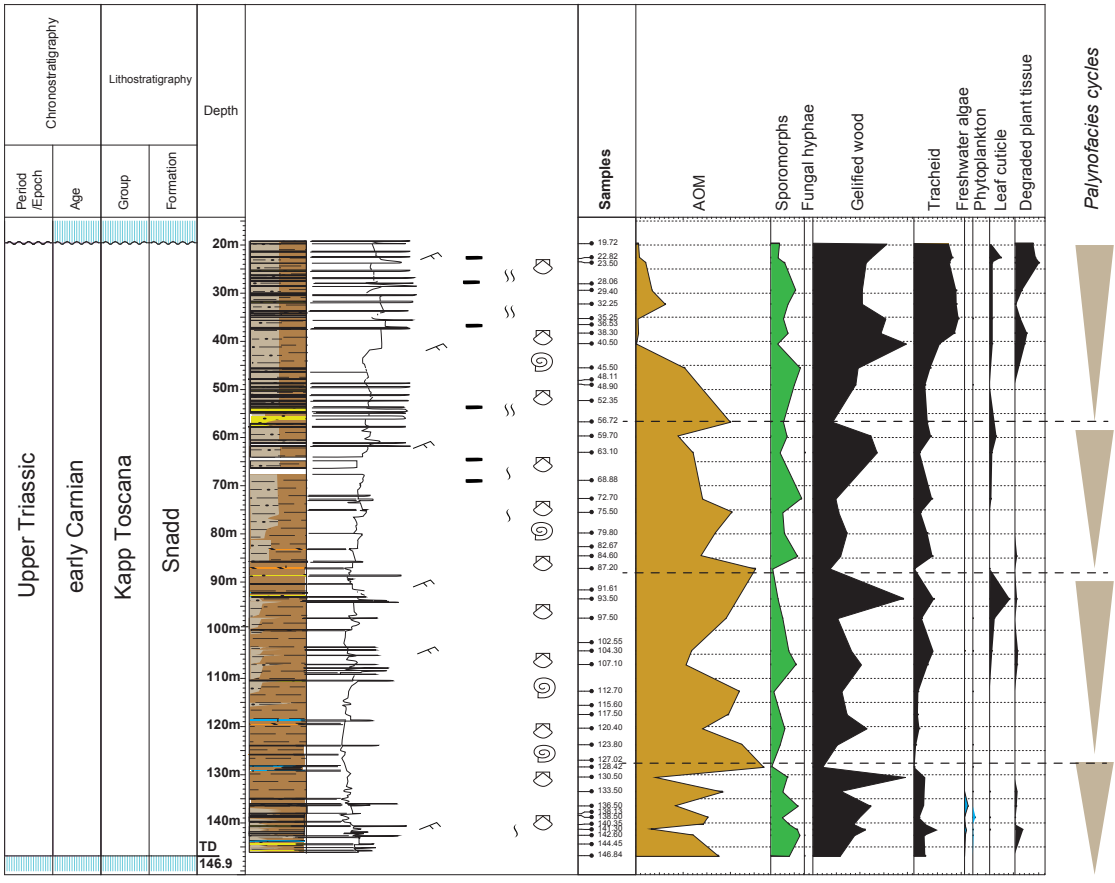

Figure 5. Relative percentages of particulate organic matter (POM) from core 7830/5-U-1

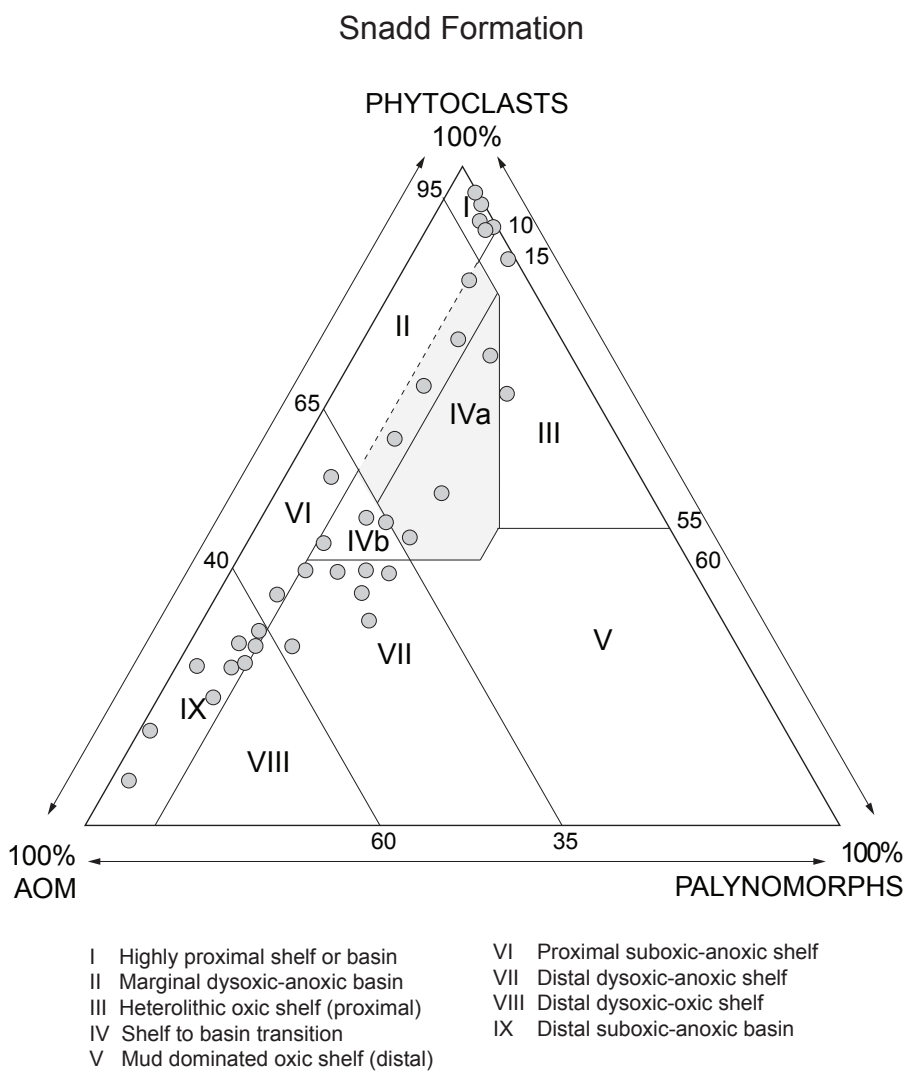

Figure 6. 'AOM'- Palynomorph - Phytoclast (APP) ternary plots for core 7830/5-U-1 (after Tyson 1985, 1989, 1993). Grey circle represent the ratio of AOM - Palynomorphs - Phytoclast present in samples from the core.

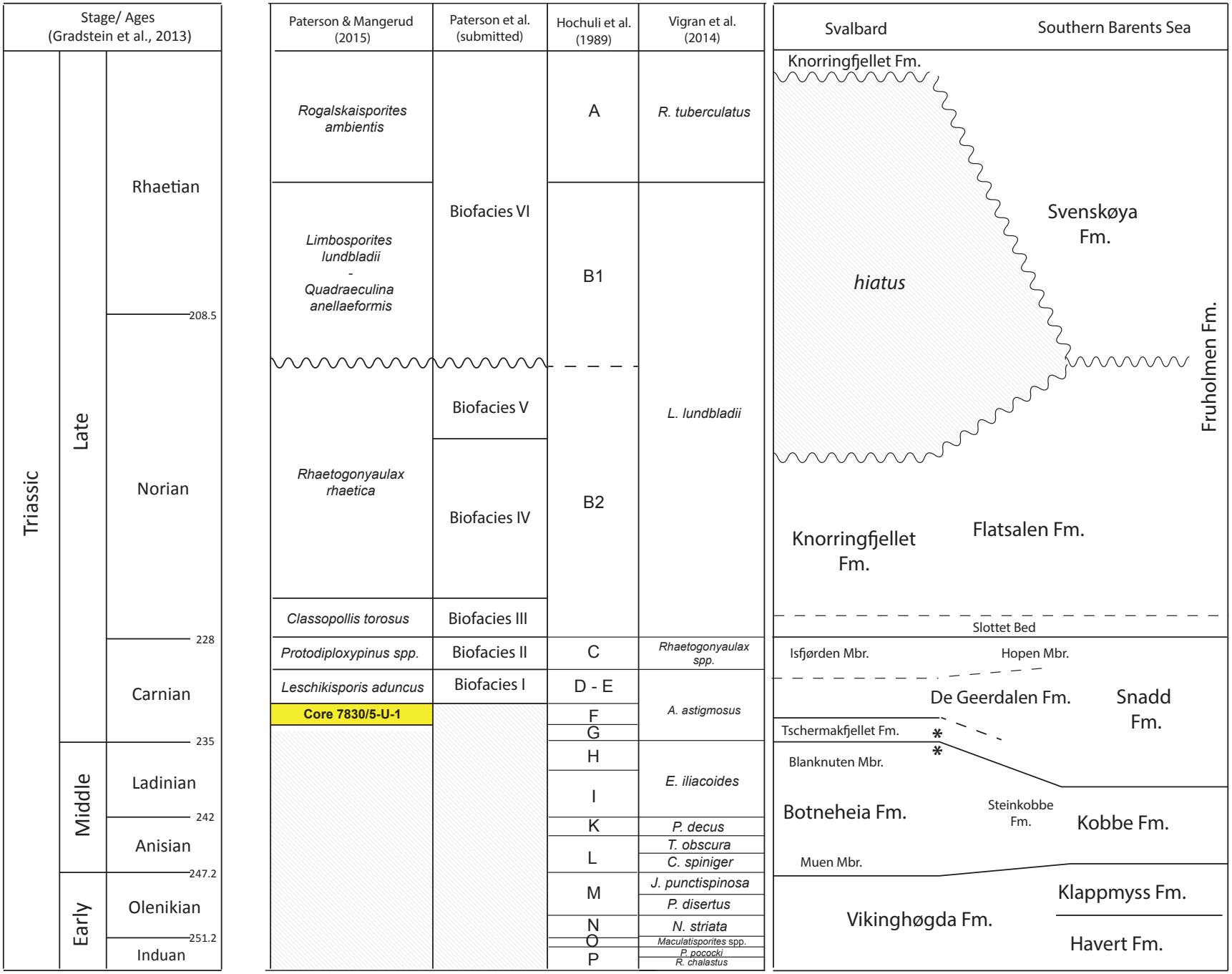

Figure 7. Outline of revised palynological zonation for the Late Triassic of Svalbard and the Barents Sea (modified from Paterson and Mangerud, 2015) with comparison to palynological zonations of Hochuli et al. (1989) and Vigran et al. (2014). * Re-Os dating (Xu et al., 2014)

Table 1. Botanical affinity of selected Late Triassic spore and pollen taxa from core 7830/5-U-1.

Spore taxon	Botanical affinity
Annulispora folliculosa	Bryophyta; Sphagnales (Koppelhus 1991; Martin et al. 2013)
Apiculatasporites spp.	Pteridophyta; Filicopsida (Balme 1995)
Apiculatisporis spp.	Pteridophyta; Filicopsida (Balme 1995)
Aratrisporites spp.	Lycopodiophyta; Pleuromeiaceae; Isoetaceae (Balme 1995); *Cyclostrobus, Lycostrobus* (Helby & Martin 1965) & *Annalepsis zeilleri* (Grauvogel-Stamm & Duringer 1983)
Baculatisporites spp.	Pteridophyta; Filicopsida (Polypodiopsida); Filicales (Van Konijnenburg - Van Cittert 2000)
Calamospora spp.	Sphenopsida (Equisetopsida); Equisetales (Balme 1995; Mander et al. 2010)
Camarozonosporites spp.	Lycopodiophyta; Lycopsida; Lycopodiaceae (Scholtz 1985; Bonis 2010)
Carnisporites spiniger (=*Anapiculatisporites spiniger)*	Lycopodiophyta; *Carinostrobus* spp. (Balme 1995; Kustatscher et al. 2012)
Conbaculatisporites spp.	Pteridophyta; Filicopsida; Filicales (Mander et al. 2010)
Concavisporites spp.	Pteridophyta; Filicopsida; Filicales (Mander et al. 2010)
Deltoidospora spp.	Pteridophyta; Filicopsida; Filicales (Balme 1995; Mander et al. 2010)
Densosporites spp.	Lycopodiophyta; Lycopsida
Dictyophyllidites mortonii	Filicopsida; Dipteridaceae & Matoniaceae (Balme 1995)
Gordonispora spp.	Bryophyta (Petersen & Lindström, 2012)
Krauselisporites spp.	Lycopodiophyta; Lycopsida; Lycopodiales (Balme 1995)
Kyrtomisporis spp.	Pteridophyta (Bonis 2010)
Leschikisporis aduncus	Pteridophyta; Marattiopsida; Marattiales; *Asterotheca meriani* (Balme 1995; Kustatscher & Van Konijnenburg-Van Cittert 2011)
Limatulasporites limatulus	Bryophyta (McLoughlin et al., 1997)
Lycopodiacidites rugulatus	Pteridophyta; Filicopsida; Filicales (Balme 1995; Mander et al. 2010)
Lycopodiumsporites semimuris	Lycopodiophyta; Lycopsida (Mander et al. 2010)
Neoraistrickia spp.	Lycopodiophyta; Lycopsida; Lycopodiales (Gary et al., 2010)
Polycingulatisporites spp.	Bryophyta; Sphagnales (Koppelhus 1991)
Porcellispora longdonensis	Hepatophyta (Bonis & Kürschner 2012)
Raistrickia spp.	Filicopsida; Botryoptreidales, Zygopteridales (Balme 1995)
Retitriletes spp.	Lycopodiophyta; Lycopsida ?
Stereisporites spp.	Bryophyta; Sphagnopsida; Sphagnales (Filatoff 1975; Boulter & Windle 1993; Martin et al. 2013)
Thomsonisporites spp.	Lycopodiophyta; Lycopsida ?
Zebrasporites spp.	Pteridophyta; Filicopsida; Filicales; Cyatheaceae (Bonis 2010; Bonis & Kürschner 2012)

Pollen taxon	Botanical affinity
Afropollis spp.	possible angiosperm (Hochuli & Feist-Burkhart, 2004; (Hochuli & Feist-Burkhart, 2013)
Alisporites spp.	Coniferopsida; Coniferales (Mander et al. 2010)
Angustisulcites klausii	?
Araucariacites australis	Coniferopsida; Coniferales; Araucariaceae (Mander et al. 2010)
Aulisporites astigmosus	Cycadophyta; Spermatopsida; Bennettitales; found *in situ* in *Williamsonianthus keuperianus* (Kräusel & Schaarschmidt 1966; Balme 1995)
Brachysaccus spp.	?
Cerebropollenites macroverrucosus	Coniferopsida; Coniferales; Taxodiaceae (Mander et al. 2010; Bonis 2010)
Chasmatosporites spp.	Cycadopsida; Cycalades (Mander et al. 2010)
	Ginkgopsida; Ginkgoales (Mander et al. 2010)
Chordasporites spp.	?
Cycadopites spp.	Cycadopsida; Cycalades (Mander et al. 2010)
	Ginkgopsida; Ginkgoales (Mander et al. 2010)
	Pteridospermopsida; Peltaspermales (Mander et al. 2010)
	Bennetitopsida; Bennettitales (Mander et al. 2010)
Dyupetulum vicentinense	?
Eucommiidites spp.	Cycadopsida; ? Cycalades (Balme 1995)
Granasporites magnus	?

Illinites chitinoides	Coniferopsida; Voltziales; *Willsiostrobus acuminatus* (*Aethophyllum*, Grauvogel-Stamm 1978; Balme 1995)
Infernopollenitis spp.	?
Institisporites crispus	?
Lunatisporites spp.	Coniferopsida; Coniferales; Voltziaceae (Bonis 2010)
Ovalipollis spp.	? Coniferopsida (Petersen & Lindström, 2012)
Protodiploxypinus spp.	Conifer (Samoilovich 1953); Pinaceae or Podocarpaceae (Scheuring 1970); *in situ* in *Sertostrobus laxus*, *Darneya peltata* & *D. mougeoutii* (Grauvogel-Stamm 1978)
Retisulcites spp.	?
Schizaeoisporites worsleyi	?
Staurosaccites quadrifidus	?
Striatoabieites spp.	Pteridospermatophyta (Bonis 2010)
Triadispora spp.	Coniferopsida; Coniferales; Voltziaceae (Balme 1995); *in situ* in *Sertostrobus*, *Darneya* (Grauvogel-Stamm 1978)
Vitreisporites pallidus	Pteridospermatophyta; Caytoniales (Bonis 2010)

Table 1. Botanical affinity of selected Late Triassic spore and pollen taxa from core 7830/5-U-1.

Table 2. Ecological grouping of selected Late Triassic palynomorph taxa from core 7830/5-U-1. Fern spores attributed to the Wet Lowland SEG may also be attributed to the River SEG; bryophyte spores placed in the River SEG may also be attributed to the Lowland SEG. Groupings based on Abbink (1998), Kustatscher et al. (2012) and Peterson and Lindström (2012).

Palynomorph ecogroup	Taxon	Environmental remarks
Marine	*Baltisphaeridium* spp.	
	Crassosphaera spp.	
	Cymatiosphaera spp.	
	Leiosphaeridium spp.	
	Micrhystridium spp.	
	Microforaminiferal linings undiff.	
	Rhaetogonyaulax spp.	
	Tasmanites spp.	
	Veryhachium spp.	
Brackish-freshwater	*Botryococcus* spp.	
	Plaesiodictyon mosellanum	
Pioneer	*Protodiploxypinus* spp.	Xerophytic - tidal flats (Brugman 1986)
Coastal	*Aratrisporites* spp.	Kustatscher et al. 2012; Petersen & Lindström, 2012
	Araucariacites australis	Kustatscher et al. 2012
	Carnisporites spiniger	Kustatscher et al. 2012
	Densosporites spp.	
	Illinites chitinoides	Conifer forming reed-like vegetation on delta plain (Brugman et al. 1994)
	Krauselisporites spp.	Kustatscher et al. 2012
	Retitriletes spp.	
	Striatella spp. (=*Asseretospora* spp.)	Kustatscher et al. 2012
	Thomsonisporites spp.	
Wet lowland	*Apiculatasporites* spp.	
	Apiculatisporis spp.	
	Baculatisporites spp.	Mire (Petersen & Lindström, 2012)
	Clathroidites papulosus	
	Conbaculatisporites spp.	
	Concavisporites spp.	
	** Leschikisporis aduncus*	
	Ricciisporites spp.	? Mire (Petersen & Lindström, 2012)
	Trachysporites spp.	
	Vitreisporites pallidus	Deltaplains & swamps (Ref)
	Zebrasporites spp.	Mire (Petersen & Lindström, 2012)
Dry lowland	*Aulisporites astigmosus*	Kustatscher et al. 2012
	Chasmatosporites spp.	
	Cycadopites spp.	Kustatscher et al. 2012
	Deltoidospora spp.	Kustatscher et al. 2012
	Dictyophyllidites mortonii	
	Eucommiidites spp.	

	Granasporites magnus	
	Podosporites amicus	
	Retisulcites spp.	
River	*Annulispora folliculosa*	
	Calamospora spp.	River banks (Petersen & Lindström, 2012)
	***Camarozonosporites* spp.**	
	Gordonispora spp.	
	Limatulasporites limatulus	
	Lycopodiacidites rugulatus	
	Lycopodiumsporites semimuris	
	Neoraistrickia taylori	
	Osmundacidites spp.	
	Polycingulatisporites spp.	
	Porcellispora longdonensis	
	Rogalskaisporites spp.	
	Stereisporites spp.	
	Uvaesporites argentaeformis	
Hinterland/ Upland	*Angustisulcites klausii*	
	Brachysaccus spp.	
	Infernopollenites spp.	
	Institisporites crispus	
	Lunatisporites spp.	Well-drained (Petersen & Lindström, 2012)
	Ovalipollis spp.	Well-drained, habitat unknown (Petersen & Lindström, 2012)
	Parvisaccites radiatus	
	Quadraeculina anellaeformis	Habitat unknown (Petersen & Lindström, 2012)
	Striatoabieites spp.	Kustatscher et al. 2012
	Staurosaccites quadrifidus	
	Triadispora verrucata	Kustatscher et al. 2012
	Vesicaspora fuscus	

Table 2. Ecological grouping of selected Late Triassic palynomorph taxa from core 7830/5-U-1. Fern spores attributed to the Wet Lowland SEG may also be attributed to the River SEG; bryophyte spores placed in the River SEG may also be attributed to the Lowland SEG. Groupings based on Abbink (1998), Kustatscher et al. (2012) and Peterson and Lindström (2012).

Plate Captions

Plate 1. Following the taxon name is the sample number, England Finder coordinates. Scale bars equal 10 µm:

1. *Leschikisporis aduncus* 115.16m, H56
2. *Dictyophyllidites mortonii* 138.06m, F46
3. *Concavisporites crassexinus* 102.49m, F53-3
4. *Verrucosisporites* spp. 126.94m, G51
5. *Baculatisporites* spp. 115.16m, N49-2
6. *Carnisporites spiniger* 126.94m, E55-3
7. *Lophotriletes novicus* 138.06m, F56-2
8. *Neoraistrickia* spp. 115.16m, L59-2
9. *Clathroidites papulosus* 91.57m, G47-4
10. *Conbaculatisporites hopensis* 104.3m, W54-1
11. *Densoisporites* spp. 91.57m, V52-1
12. *Nevesisporites bigranulatus* 91.57m, U45-3
13. *Camarozonosporites rudis* 138.06m, P54-2
14. *Camarozonosporites laevigatus* 146.83m, J45-2
15. *Gordonispora* spp. 32.25m, G36-2
16. *Annulispora folliculosa* 97.5m, E44-4
17. *Polycingulatisporites bicollateralis* 102.49m, H49-4
18. *Limatulasporites limatulus* 97.5m, P47-4
19. *Rogalskaisporites cicatricosus* 126.94m, N46
20. *Stereisporites cicatricosus* 23.50m, P46-2
21. *Tigrisporites halleinis* 91.57m, Q56
22. *Thomsonisporites toralis* 59.7m, C42-3
23. *Striatella parva* 138.06m, P53-2
24. *Striatella seebergensis* 126.94m, C52-3
25. *Lycopodiacidites rugulatus* 102.49m G54-2
26. *Lycopodiacidites keuperi* 91.57m N42
27. *Zebrasporites interscriptus* 68.82m, H45-3
28. *Zebrasporites* sp. A 136.5m, R60-4 b
29. *Zebrasporites fimbriatus* 36.7m, P47-2
30. *Reticulatisporites bunteri* 112.7m, F42-4

Plate 2. Following the taxon name is the sample number, England Finder coordinates. Scale bars equal 10 µm:

1. *Densosporites* sp. A 91.57m, V40-1
2. *Densosporites fissus* 117.5m, D38
3. *Krauselisporites cooksonae* 115.16m, F55-3
4. *Krauselisporites apiculatus* 146.83m, P39-2
5. *Krauselisporites dentatus* 91.57m, N45
6. *Krauselisporites* spp. tetrad 68.82m, T45
7. Megaspore sp. A 102.49m, H46-3
8. *Apiculatasporites hirsutus* 146.2m E62-29

Apiculatasporites hirsutus 45.5m D49-2

10. *Apiculatasporites lativerrucosus*
11. *Apiculatasporites lativerrucosus*

12 – 14. *Kyrtomisporis* sp. A 68.82m, M44-1; 68.82m, Q57-4; 102.49m, V55-4

15. *Kyrtomisporis* sp. A tetrad 68.82m, Q40-1
16. *Aratrisporites laevigatus* 117.5m, D34-3
17. *Aratrisporites* sp. 146.83m, Q41
18. *Aratrisporites paenulatus* 126.94m, K59
19. *Aratrisporites palettae* 104.3m, W45-2
20. *Aratrisporites* sp. A 126.94m, P57-2

Plate 3. Following the taxon name is the sample number, England Finder coordinates. Scale bars equal 10 µm:

1. *Triadispora verrucata* 102.49m, G49-4
2. *Triadispora plicata* 126.94m, J56-3
3. *Triadispora crassa* 126.94m, C49-2
4. *Triadispora sulcata* 117.5m, H42-4
5. *Triadispora* spp. 126.94m, G50-3
6. *Alisporites* spp. 115.16m, G58-2
7. *Striatoabieites aytugii* 138.06m, V50-2
8. *Striatoabieites balmei* 138.06m, T57-2
9. *Striatoabieites multistriatus* 79.8m, R37
10. *Lunatisporites acutus* 146.83m, T44

11. *Lunatisporites noviaulensis* 126.94m, C56-2
12. *Schizaeoisporites worsleyi* 126.94m, D51-2
13. *Ovalipollis ovalis* 104.3m, X52-3
14. *Staurosaccites quadrifidus* 138.06m, P42-2
15. *Angustisulcites klausii* 102.49m, C53
16. *Illinites chitinoides* 84.6m, R54-4
17. *Protodiploxypinus decus* 82.62m, D41-4
18. *Protodiploxypinus minor* 82.62m, P48-1
19. *Ellipsovelatisporites plicatus* 126.94m, L42-1
20. *Institisporites crispus* 82.62m, L54-3
21. *Dyupetalum vicentinense* 136.5m, D43-1
22. *Aulisporites astigmosus* 117.5m, B54
23. *Podosporites amicus* 117.5m, B54
24. *Granasporites magnus* 138.06m, M46-2

Plate 4. Following the taxon name is the sample number, England Finder coordinates. Scale bars equal 10 µm:

1 - 3. *Afropollis* spp. 48.9m H55-1, 48m G52-4, 79.8m H43
4. ? *Clavatipollenites* spp. 102.49m, D41-2
5. *Classopollis* spp. 79.8m
6 - 8. *Chasmatosporites* spp. 7830 5-U-1 146.83m Y57-1; 102.49m E49-3; 115.16m L56-1
9. *Eucommiidites intrareticulatus* 126.94m K56-2
10. *Retisulcite*s sp. 82.62m M55-2
11. *Leiosphaeridia* spp. 126.94m R60
12. *Tasmanites* spp.
13. *Crassosphaera* spp.
14. *Tithodiscus* spp. 115.16m O47 (33% scale)
15. *Heibergella asymmetrica* 93.5m H53-1
16. *Baltisphaeridium* spp. 82.62m J54-3
17 – 20. *Micrhystridium* spp. 82.62m E45; 82.62m L42-4; 126.94m R61-1; 117.5m D36-4
21 - 22. *Cymatiosphaera* spp. 126.94m R49-1; 68.82m V50-1
23. *Dorsennidium* spp. 126.94m H61
24. *Veryhachium* spp.
25. Cyst sp. A 117.5m D42-1

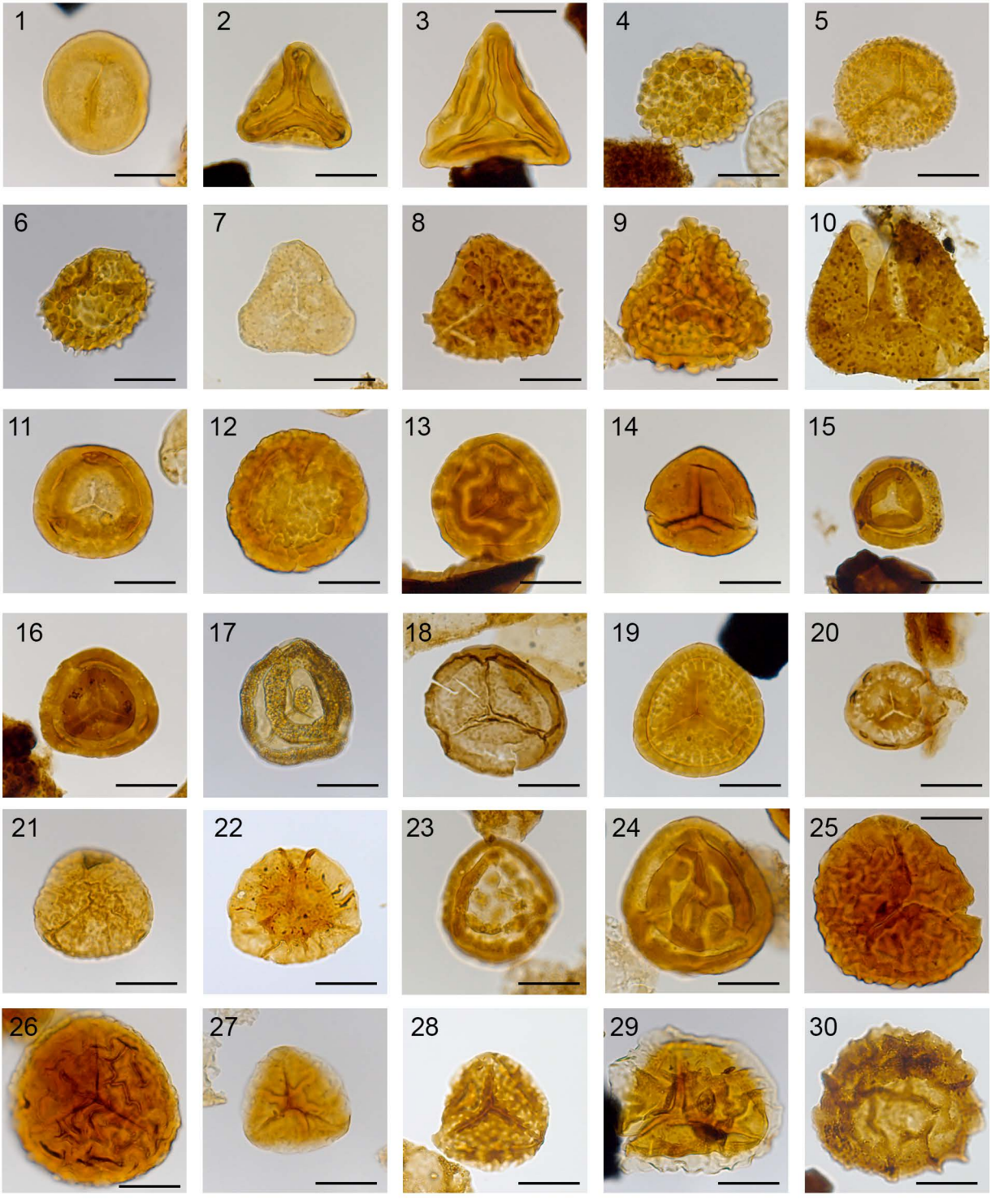
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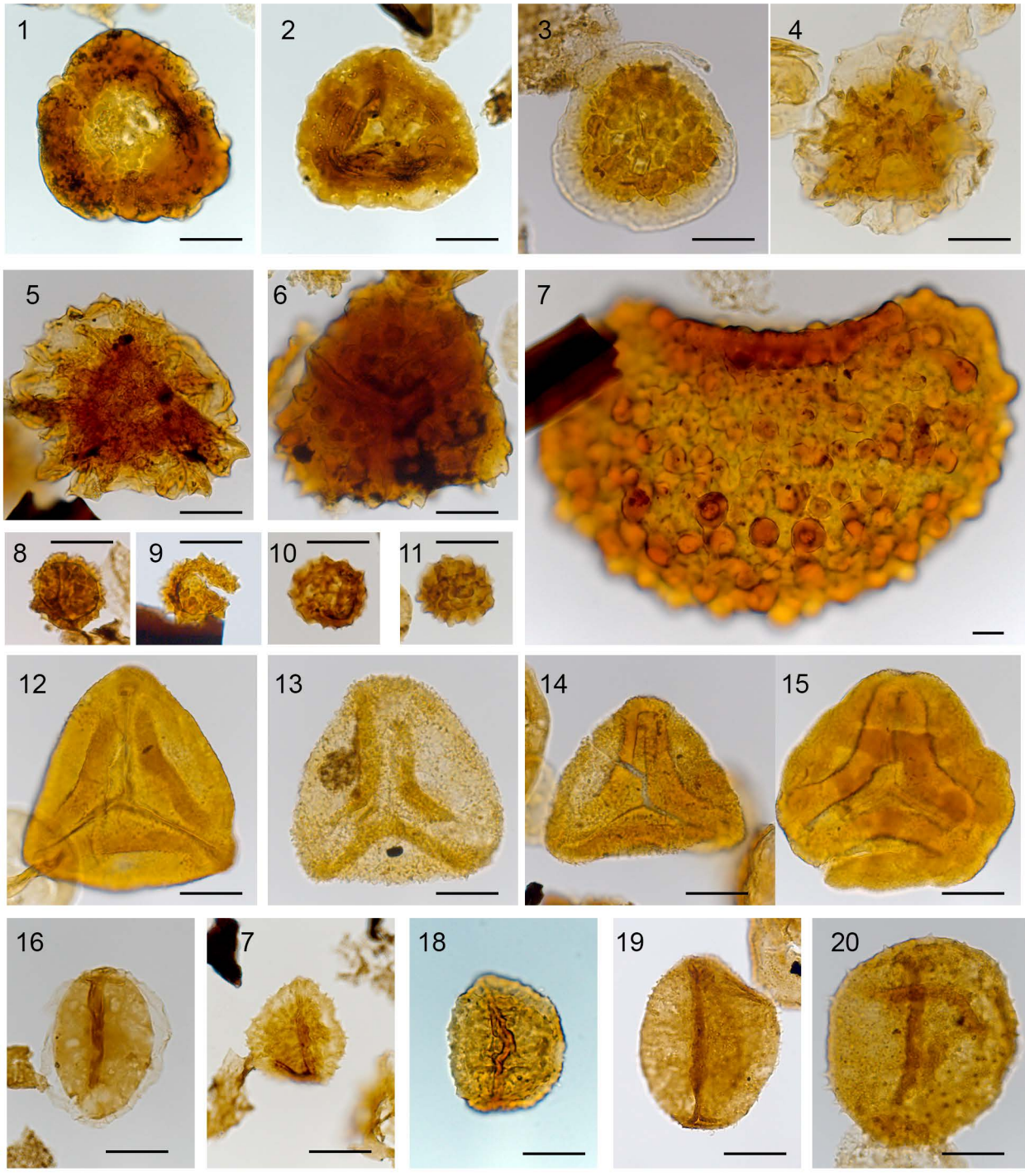
Plate 1



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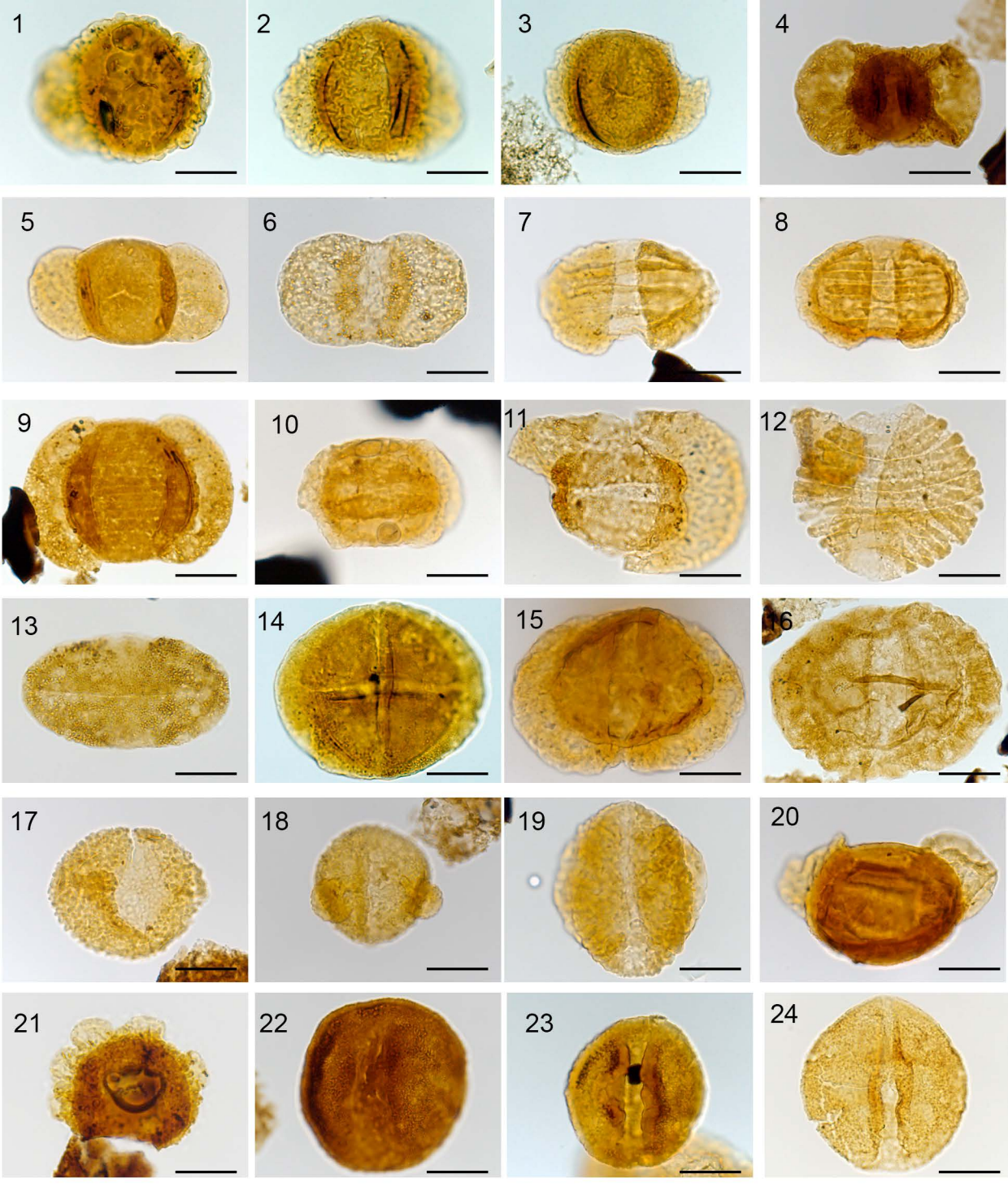

Plate 3

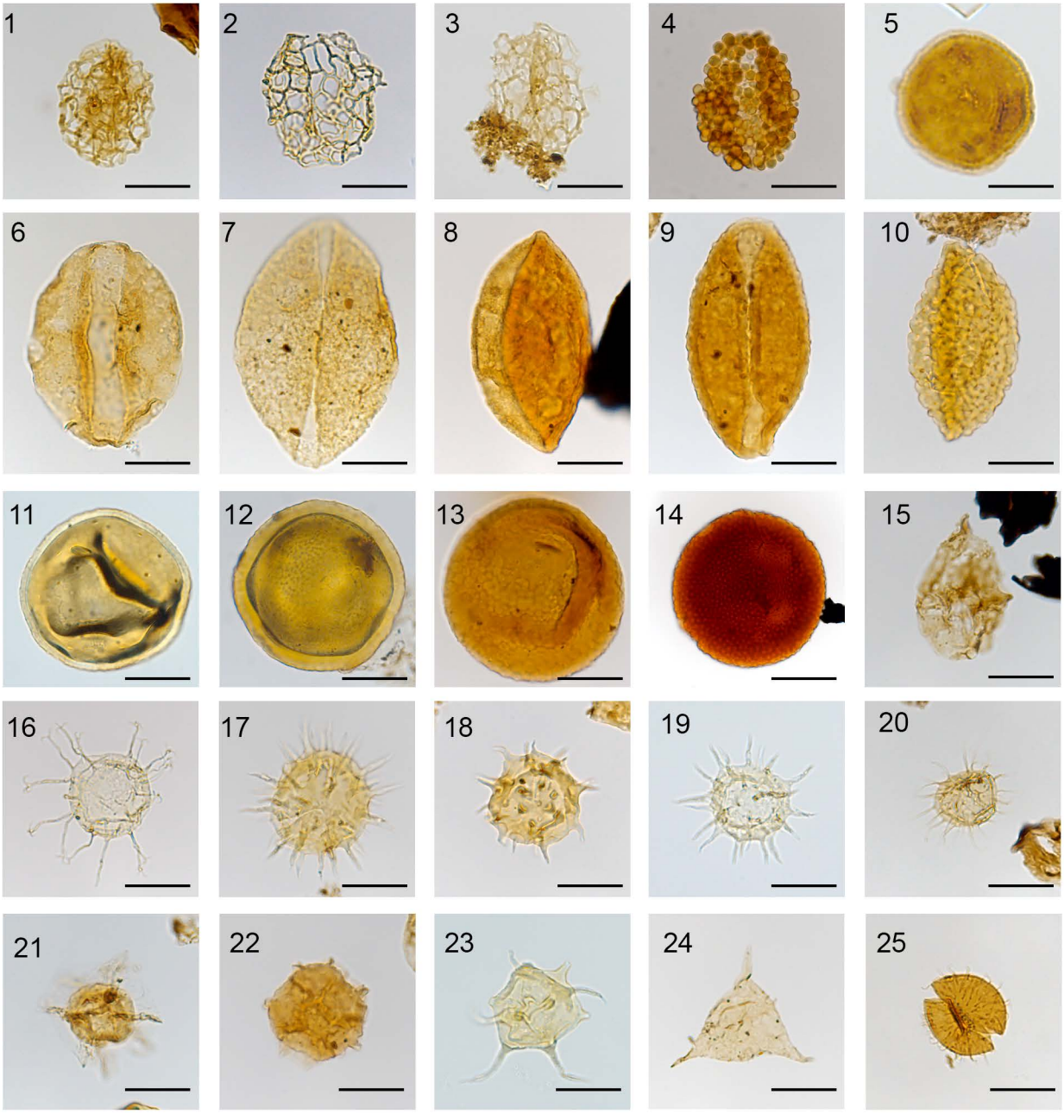

Plate 4