



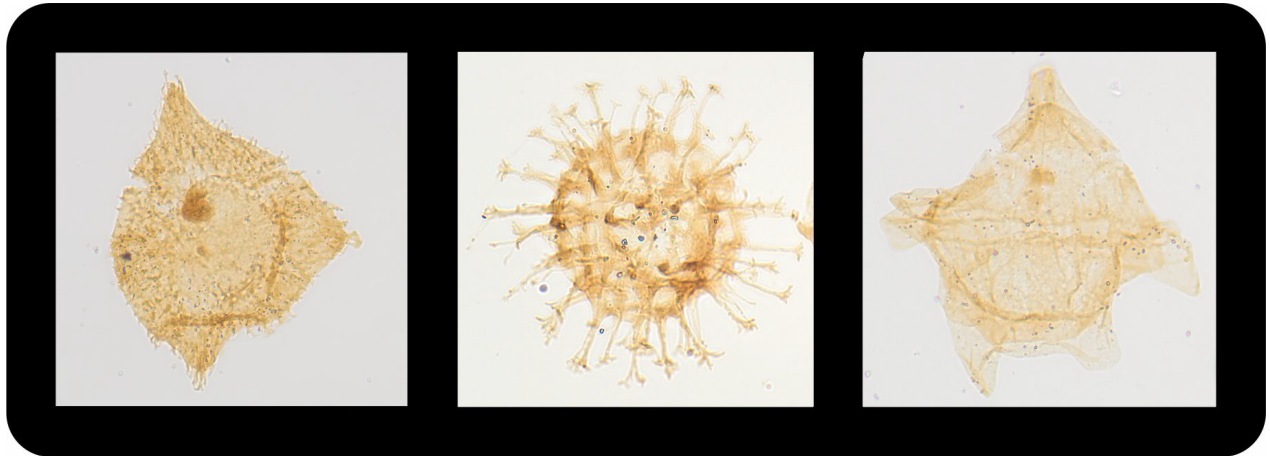
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**Mesozoic event-stratigraphy of the Scotian Margin,
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Upper Member of the Missisauga Formation in Panuke B-90**

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2023

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Permanent link: <https://doi.org/10.4095/331910>

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Recommended citation

Correia, V., Fensome, R.A., MacRae, R.A., Dafoe, L.T., and Williams, G.L., 2023. Mesozoic event-stratigraphy of the Scotian Margin, offshore Nova Scotia: preliminary palynological results from the Upper Member of the Missisauga Formation in Panuke B-90; Geological Survey of Canada, Open File 8981, 1 .zip file.
<https://doi.org/10.4095/331910>

Publications in this series have not been edited; they are released as submitted by the author.

ISSN 2816-7155
ISBN 978-0-660-48921-6
Catalogue No. M183-2/8981E-PDF

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Cover photo: Common Early Cretaceous dinoflagellate cysts from the Panuke B-90 conventional cores, Scotian Margin.

Abstract

Conceived as a continuation of the previous multidisciplinary event stratigraphy studies of the Late Cretaceous to Neogene of the Scotian Margin in the 2000s, the “Mesozoic event-stratigraphy of the Scotian Margin” project proposes a similar study for the Late Triassic to Early Cretaceous interval. The first stage of this project comprises a detailed multidisciplinary study of the composite Lower Cretaceous section from Panuke B-90 and Cohasset A-52 conventional cores. The present work reports initial palynologic data from the formal Upper Member of the Missisauga Formation in Panuke B-90. These data, combined with preliminary insights from sedimentary facies, macrofossil, and trace fossil analyses, suggest that from the base of the studied section upwards involves a transition from a neritic/shelfal to a mainly estuarine-brackish setting. This was followed by a transgressive cycle through the Upper Member of the Missisauga Formation, which culminated in a return of more fully marine environments near the base of the overlying Naskapi Member of the Logan Canyon Formation. It is apparent that this transgression is not continuous, but intercalated with smaller cycles, well documented by the fluctuations in dominance between terrestrial (pollen and spore abundance) versus marine (mainly dinoflagellate-cyst abundance and richness) palynomorph trends through this succession, presented here in three main intervals. The dinoflagellate-cyst assemblages and key bioevents recorded in this initial study indicate a Barremian age for the Upper Member of the Missisauga Formation in Panuke B-90. The overlying Naskapi Member is expected to be of early Aptian age based on previous reports of the presence of the age-diagnostic ammonite *Deshayesites* sp. Ongoing work on the conventional cores from Panuke B-90, and subsequently Cohasset A-52 and other wells, will contribute to a comprehensive Mesozoic event-stratigraphic framework for the Scotian Margin.

1. Scotian Margin palynostratigraphy: historical perspective and current status

The Scotian Shelf and the Scotian Slope are referred to together as the Scotian Margin, located off Nova Scotia, southeastern Canada. This margin is part of the eastern North America passive margin, which started to form following the initial breakup of Pangea and the beginning of seafloor spreading that opened the North Atlantic Ocean by 190 million years ago (Welsink et al. 1989; Sibuet et al. 2012). The Scotian Margin includes strata that accumulated within the Scotian Basin, a major sedimentary depocentre, which contains the Shelburne, Sable, Abenaki and Laurentian subbasins (Jansa and Wade 1975; Wade and MacLean 1990; Deptuck and Kendell 2017; Fig. 1).

Biostratigraphic studies of Mesozoic–Cenozoic strata along the Scotian Margin, and offshore eastern Canada in general, began in the early 1970s (see review in Williams et al. 1990). The aim was to develop an effective means of age control for the region, which would in turn promote an understanding of the geological history of the offshore sedimentary basins and thus their petroleum systems. The early phase of investigations at the Geological Survey of Canada–Atlantic (GSCA) involved palynological, micropaleontological (mainly foraminiferid and ostracod) and nannofossil studies, from which zonation schemes were developed separately for each discipline. In terms of palynological studies during the 1970s, a latest Triassic to Cenozoic zonation scheme based mainly on dinoflagellate-cyst (dinocyst) biozones was built from the study of five Scotian Margin wells and one Grand Banks well (Williams et al. 1974; Jenkins et al. 1974; Williams 1975; Bujak & Williams 1978). The culmination of this phase of study was the publication of analyses of 67 wells with this zonation scheme applied (Barss et al. 1979).

A new phase of study of Scotian Margin biostratigraphy occurred in the 2000s, with the application of an event-stratigraphic approach rather than the implementation of a zonation scheme. The advantage of an event-stratigraphic methodology is that it leads to the clearer use and documentation of basic data (origins, extinctions and acmes) and doesn't rely on the varying and somewhat subjective zonation schemes that may be modified frequently and thus make consistent correlations difficult. To develop a comprehensive event-palynostratigraphic scheme, integrated with micropaleontological and nannofossil data for the Late Cretaceous and Cenozoic of the Scotian Margin, seven wells were analyzed, and the study culminated in publication of a new scheme (Fensome et al. 2008). The study also spawned an extensive formal review of the taxonomy of the palynomorphs for this interval on the Scotian Margin (Fensome et al. 2009). As noted by Gravendyck et al. (2021), detailed taxonomy is fundamental to quality control, good

scientific communication and consistency, and it is a dynamic discipline (e.g. Fensome and Williams 2005, 2019; Williams et al. 2015; Fensome et al. 2019; Riding et al. 2022).

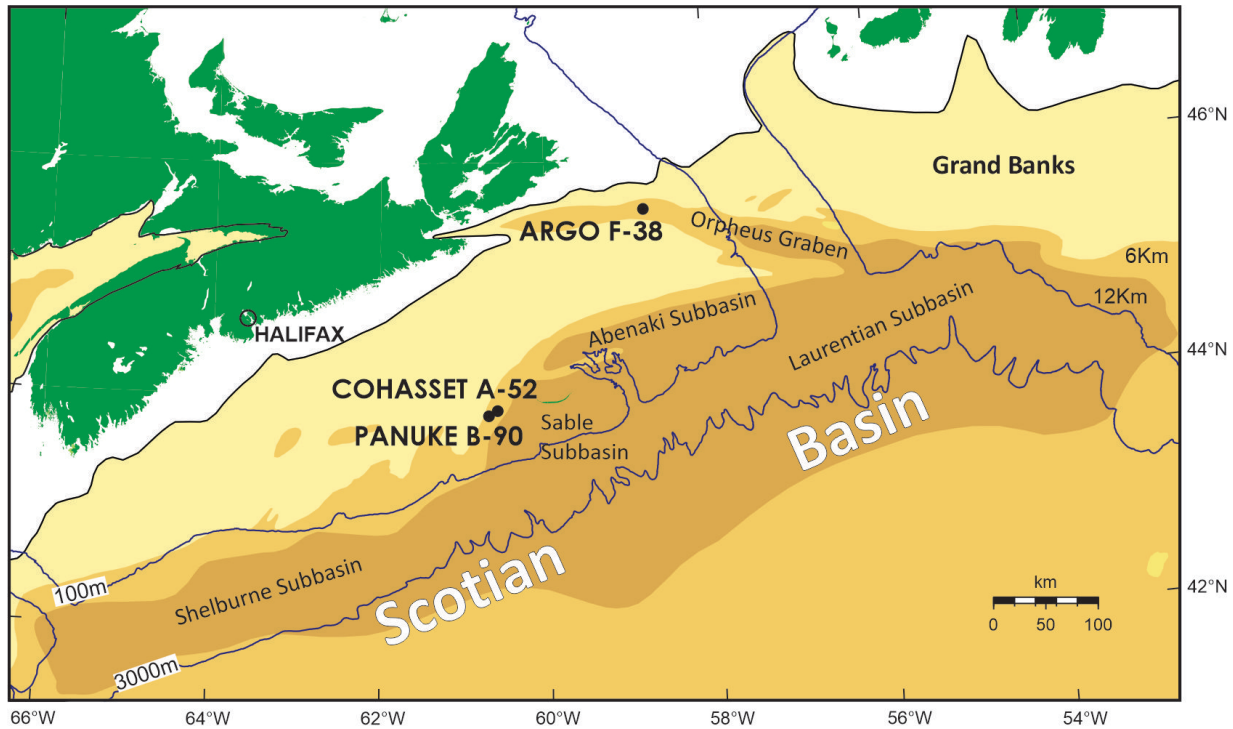


Figure 1. Location map of the Scotian Basin showing bathymetry (dark blue lines) and the location of the three wells currently under study: Panuke B-90 and Cohasset A-52 in the Sable Subbasin, and Argo F-38 in the Orpheus Graben. The yellow-brown shading represents the basement depths, indicated in kilometres (adapted from Williams and Grant 1998).

The next key biostratigraphic development was the Scotian Margin Play Fairway Analysis (PFA) project, a multidisciplinary study (under the auspices of the Offshore Energy Technology Research Association of Nova Scotia; OERA 2011) that examined the petroleum potential and exploration risk of the Mesozoic–Cenozoic Scotian Basin of offshore Nova Scotia. Biostratigraphy was a significant part of the PFA project and resulting Atlas (OERA 2011). The PFA project’s biostratigraphy activity involved an extensive study by industrial, academic and GSCA researchers on the Mesozoic to Neogene interval on the Scotian Margin. As well as being reported in the PFA Atlas, the biostratigraphic results were detailed in a major publication combining palynological, microfossil and nannofossil events that were tied to unconformities and maximum flooding surfaces that were correlated with seismic horizons (Weston et al. 2012). As valuable and innovative as the PFA study was, no taxonomic component in concert with the detailed event scheme was developed, as was done for the Late Cretaceous and Cenozoic interval

of the Scotia Margin by Fensome et al. (2008, 2009). We have designed the present project to develop detailed taxonomic and event-stratigraphic results for the Late Triassic to Early Cretaceous part of the section, based mainly on palynology and sequence stratigraphy. In addition, we also aim to investigate the impact of varying paleoenvironmental conditions, including regional marine to estuarine depositional settings and global stress events (e.g. oceanic anoxic events). We focus on conventional cores (e.g. Shell PCI et al. Panuke B-90 well, and Petro-Canada et al. Cohasset A-52 well) to avoid problems with down-hole sample contamination (caving). We are also investigating cuttings from some selected wells (e.g. Shell Argo F-38 well) to provide a broader context. Initially we are concentrating on the Lower Cretaceous interval (a composite Panuke B-90–Cohasset A-52 core section; Fig. 2). The present report is the first palynological results from the Upper Member of the Missisauga Formation in Panuke B-90 (Figs 3, 4, 5).

2. Objectives

The overall goal of the project is to establish a detailed Late Triassic–Early Cretaceous event-stratigraphic framework for the Scotian Margin. To achieve this, we have five main objectives:

- 1) To document in detail the **palynology** of the Late Triassic to Early Cretaceous succession, focusing on biostratigraphy, though identification of key bioevents, and taxonomy.
- 2) To assess **paleoenvironments** through qualitative and quantitative analyses of palynomorph assemblages.
- 3) To analyze facies in detail using sedimentology, ichnology and macrofossil data to delineate depositional paleoenvironments and their changes through time to build a **sequence stratigraphic model**.
- 4) To integrate **nannofossil** and **seismic** studies with the palynoevents and sequence stratigraphy to develop a comprehensive and multidisciplinary event-stratigraphic scheme.
- 5) To integrate **paleoenvironmental assessments with stable isotope results (e.g. $\delta^{13}\text{C}$)**, including identification of possible major global changes such as the early Aptian Oceanic Anoxic Event 1a (OAE1a), also known as “Selli event” (Luciani et al. 2001; Weston et al. 2012), and interpret their impact on the marine communities, especially on dinoflagellates.

3. Material and Methods

The first stage of the project involves the study of an almost complete Barremian–Albian succession: a composite section of Panuke B-90 and Cohasset A-52 conventional cores (Fig. 2). We are also analyzing cuttings from Argo F-38, a Late Jurassic–Cenozoic succession which provides a longer temporal context. We collected samples from the conventional cores with assistance of staff from the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) Data Management Centre in Dartmouth, Nova Scotia. From the 13 cores of Panuke B-90, we collected 113 samples for palynology, 64 for carbon isotopes analysis, and 20 for nannofossil study; and from the 22 cores of Cohasset A-52, we collected 75 samples for palynology and carbon isotopes analyses, and 10 for nannofossil analyses. For Argo F-38, we are analyzing 110 cuttings samples from the GSCA palynological legacy collections.

The palynological samples from Panuke B-90 were processed at GSC-Calgary (2011–2012) using standard techniques (Barss and Williams 1973; Riding 2021) and Argo F-38 samples were reprocessed at GSCA in the 2000s from pre-existing residues. Panuke B-90 slides were made for unsieved, -20 μ m, +20 μ m, +45 μ m and kerogen (unoxidized) fractions. The sieved slides were scanned and well-preserved specimens were photographed in our initial taxonomic and palynological analysis of the various marine and terrestrial groups. The samples from Cohasset-A52 are currently being processed in the Palynology Laboratory at GSCA. The isotopic analysis are being done at the Department of Earth Sciences, University of Manitoba, by Dr. Ricardo Silva, and the nannofossil study developed by Dr. Kevin Cooper (UK).

In the present study, we report on the qualitative palynological analysis of 51 samples from core 13 (base at 2438.2 m) up to core 7 (at 2303.95 m) from Panuke B-90 (GSCA P41396–P41445), all from the formal Upper Member of the Missisauga Formation (Fig. 3). The results are fully documented in Table 1 with all taxa recorded, as well the depths from all samples. The depths are expressed in metres (m) measured depth (MD) below the Kelly Bushing (KB). We also identified preliminary bioevents, including first occurrences (FOs), last occurrences (LOs) and acmes. We illustrate selected specimens from Panuke B-90 in Plates I–VII. The palynological study was carried out using an Olympus BX53 microscope with an SC180 incorporated camera for both plain transmitted light and differential interference contrast (DIC) photographs.

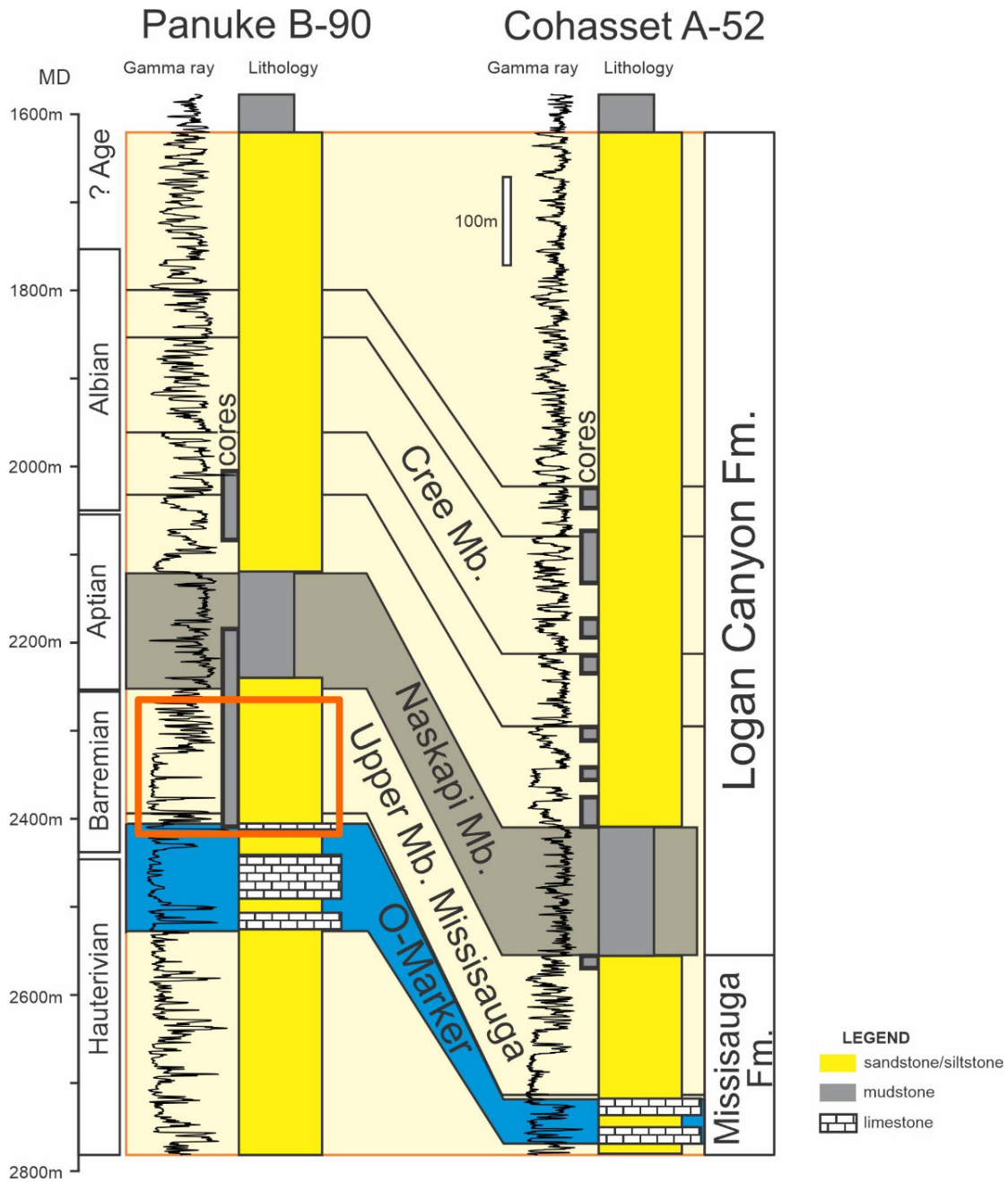


Figure 2. Simplified stratigraphy and correlation of conventional core intervals in the Panuke B-90 and Cohasset A-52 wells. The section studied is in the Upper Member of the Missisauga Formation and the Naskapi and Cree members of the Logan Canyon Formation. The O-Marker unit (in blue) corresponds to a carbonate rich interval. Gamma-ray log is digitized from paper logs from CNSOPB. Cohasset A-52 is significantly deviated, resulting in measured depths (MD) that are exaggerated versus true vertical depth. For detailed correlation of individual sand units, see Gould et al. (2012). The cored succession studied for palynology in this work is delineated by the orange rectangle in Panuke B-90. The ages shown are approximate, based on regional correlations.

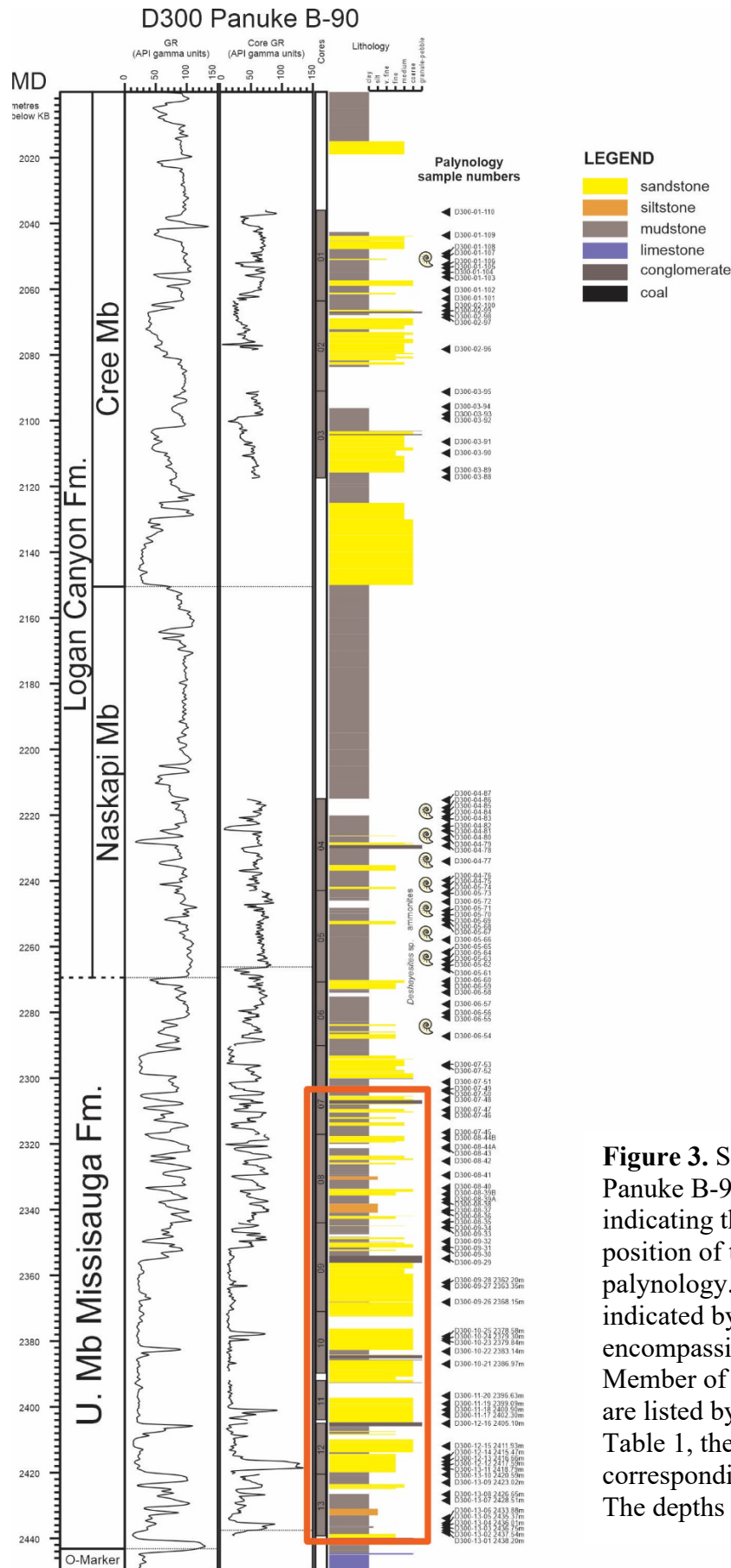


Figure 3. Simplified stratigraphic log for the Panuke B-90 well (based on MacRae 2011), indicating the 13 conventional cores and the position of the 113 samples collected for palynology. The section documented here is indicated by the orange rectangle, encompassing 51 samples from the Upper Member of Missisauga Formation. Here they are listed by the sample numbers (D#), and in Table 1, they are also listed by the corresponding slide numbers (P#) and depths. The depths correspond to MD below KB.

4. Results and Discussion

We document the palynological assemblages from the 51 studied samples in Panuke B-90, comprising the Upper Member of the Missisauga Formation, together with biostratigraphical, paleoenvironmental and paleobiological interpretations. Five samples, P41399, P41401, P41410, P41414 and P41421, were barren of palynomorphs. The overall preliminary palynomorph dataset is presented in Table 1. Figure 4 shows the general marine (largely dinocysts) and terrestrial (spores and pollen = miospores) palynomorph trends, and Figure 5 charts significant dinocyst occurrences. Based on the relative dominance of marine versus terrestrial palynomorphs (Fig. 4) we distinguished three intervals that are described and discussed below. Plates I–IV document general views with various palynological components present, and Plates V–VII show selected palynomorph specimens.

4.1. Interval 1: base of core 13 to middle of core 11 (P41396–P41413; 2438.2–2400.9 m)

At the base of the section studied (core 13, sample P41396 at 2438.2 m) is a bioclastic (bivalve-dominated) and oolitic limestone. The palynological assemblage from this sample is dominated by foraminiferal test linings, the prasinophyte *Pterospermella australiensis*, and acritarchs, including *Leiosphaeridia* and *Nummus*; the freshwater alga *Schizosporis reticulatus* (Plate VII) is also present, but dinocysts are relatively sparse (*Cribroperidinium* spp., *Kiokansium* spp., *Oligosphaeridium* spp., and *Spiniferites* sp.). The assemblage suggests a marine environment, probably inner neritic/inner shelf. By contrast, the following two samples from grey shale or mudstone intervals, P41397 (2437.54 m) and P41398 (2436.76 m), are characterized by high species richness (number of species) and abundance of dinocysts, which indicate a more distal marine (neritic) depositional setting (Fig. 4). Common in these samples are *Cribroperidinium* spp., *Kiokansium unituberculatum*, *Tenua hystrix*, *Gardodinium trabeculosom*, *Druggidium rhabdoreticulatum* and *Oligosphaeridium* spp. Also present are *Spiniferites ramosus*, *Subtilisphaera perlucida*, *Tenua anaphrissa* (after Fensome et al. 2019), *Circulodinium distinctum*, *Exochosphaeridium phragmites*, *Florentinia* sp., *Hystrichosphaerina schindewolfii*, *Kleithriasphaeridium* spp., *Odontochitina operculata*, *Pseudoceratium pelliferum*, and *Aptea* sp. Rare specimens of *Achomosphaera neptuni*, *Apteodinium* spp., *Callaiosphaeridium asymmetricum*, *Coronifera oceanica*, *Hystrichodinium pulchrum*, *Bourkidinium granulatum*, *Canningia* spp. *Cometodinium? comatum* and *Muderongia* spp. were also identified (Plates V; VI; Table 1). The FO of *Odontochitina operculata* (Plate V, 15) is within the early to middle

Barremian according to De Reneville and Raynaud (1981), Stover et al. (1996) and Duxbury (2001). *Tenua anaphrissa* (Plate V, 9) has a short stratigraphic range of early Barremian (Sarjeant 1966; Harding 1990a; and Costa and Davey 1992). The presence of these two species in samples P41397 and P41398 indicate an age no older than Barremian for this section of the conventional core, and their ranges are likely truncated at the base of the sampled section.

Overall, remaining strata up-section in Interval 1 are dominated by medium- to coarse-grained, trough cross-bedded sandstones, but the palynological samples are mainly from interbedded grey mudstones/fissile shales that yield assemblages dominated by marine forms (Fig. 4). With the exception of four barren samples—P41399 (2436.01 m), P41401 (2433.88 m), P41410 (2411.93 m) and P41414 (2399.09 m)—and sample P41400 (2435.37 m), which has more terrestrial content, the samples yielded relatively high abundances of dinocysts, especially P41403 (2426.65 m), P41404 (2423.02 m) and P41406 (2418.79 m) (Table 1). In the samples with abundant dinocysts, several specimens of the ceratiacean *Pseudoceratium retusum* were recorded, together with common occurrences of the areoligeracean *Circulodinium distinctum* (Plates I; V). Intermediate morphotypes between these two species (e.g. Plate V, 4) clearly show that the families Ceratiaceae and Areoligeraceae are closely related (Fensome et al. 2019). Another ceratiacean, *Muderongia microperforata* (FO and common occurrences in P41403; Plate VI, 13) was recorded, and this form continues to occur frequently up-section, and in abundance in some strata (see 4.3. Interval 3; Plates I, 2; II; VI, 14; Table 1). Furthermore, different forms of *Kleithriasphaeridium*, including *Kleithriasphaeridium cooksoniae*, *Kleithriasphaeridium eoinodes* (the taxonomic senior synonym of *Kleithriasphaeridium simplicispinum*), *Kleithriasphaeridium fasciatum* and *Kleithriasphaeridium mantellii*, as well as *Muderongia staurota*, *Odontochitina costata*, *Oligosphaeridium* cf. *diluculum*, and forms of *Subtilisphaera scabrata/senegalensis* have their FOs in these three samples.

In this interval, terrestrial palynomorphs are also very common, including the spores *Appendicisporites* spp., *Cicatricosisporites* spp., *Concavissimisporites* spp., *Deltoidospora* spp., *Dictyophyllidites* spp. *Gleicheniidites senonicus* and *Ruffordiaspora* spp., and the pollen *Araucariacites* spp., *Callialasporites* spp., *Cerebropollenites macroverrucosus*, *Perinopollenites elatoides* and abundant bisaccates. We also recorded grains of the early angiosperm pollen genus *Clavatipollenites*, with common occurrences in samples P41398 (2436.76 m) and P41411 (2405.1 m) (Plate VII; Table 1). The oldest reliable records of *Clavatipollenites* are documented

in the late Barremian (e.g. Heimhofer et al. 2007; Archangelsky et al. 2009) but the earliest occurrence of such pollen is still debated (Boukhamsin et al. 2022; Gravendyck et al. 2022). Other miospores occur more sparsely here, such as *Auritulinasporites* spp., *Biretisporites potoniaei*, *Cibotiumspora jurienensis*, *Distaltriangulisporites perplexus*, *Rotverrusporites* spp., *Stereisporites* sp., *Todisporires* spp., *Zlivisporis* sp., *Balmeiopsis limbatus* and *Ephedripites* spp. (Table 1).

4.2.Interval 2: middle of core 11 to middle of core 9 (P41415–P41425; 2396.63–2352.64 m)

The predominant lithology in this interval consists of medium- to coarse-grained, usually trough cross-stratified sandstones, which we interpret as channel fills, likely in an estuarine setting. Within these channels there are intermittent thin intervals of laminated and interbedded mudstones from which the palynological samples were mainly collected, as well as finer-grained sandstones. These samples are dominated by terrestrial palynomorphs, with only sparse occurrences of dinocysts (mostly *Cribroperidinium* spp. and *Kiokansium* spp.), acritarchs (mainly *Leiosphaeridia* spp.) and freshwater algae such as *Schizosporis reticulatus*, *Chomotriletes* sp. and *Botryococcus* (Fig. 4; Plate VII). The sample P41421 (2368.15 m), representing allochthonous coal fragments in the cross-stratified sandstones, was devoid of palynomorphs (Table 1).

Typical Early Cretaceous spores, frequently recorded in this interval, are *Aequitriradites* spp., *Appendicisporites* spp., *Cicatricosisporites* spp., *Concavissimisporites* spp., *Costatoperforosporites* spp., *Impardecispora* spp., *Pilosisporites* spp., *Plicatella* spp. and *Ruffordiaspora* spp., as well others with longer stratigraphic ranges, including *Deltoidospora* spp., *Gleicheniidites senonicus*, *Ischyosporites* spp., *Osmundacidites wellmanii*, *Retitriletes* spp. and *Staplinisporites caminus*. Bisaccate pollen are the most abundant palynomorph group in this interval and throughout the studied section. Other common pollen are: *Cerebropollenites macroverrucosus*, *Classopollis torosus* (the taxonomic senior synonym of *Classopollis classoides*), Cupressaceae-Taxaceae forms, *Perinopollenites elatoides*, *Exesipollenites tumulus* and the araucariaceans *Araucariacites australis*, *Araucariacites* sp. and *Callialasporites* spp., including *Callialasporites turbatus* (Fig. 4; Plates III; IV; VII). Sporadic occurrences of other miospores, such as *Baculatisporites comaumensis*, *Densoisporites* spp., *Foveotriletes* spp., *Stoverisporites* sp., *Cycadopites* spp. and *Eucommiidites* spp., are also recognized in this interval (Table 1).

Panuke B-90: cores 13 to 4 (studied 13-7)

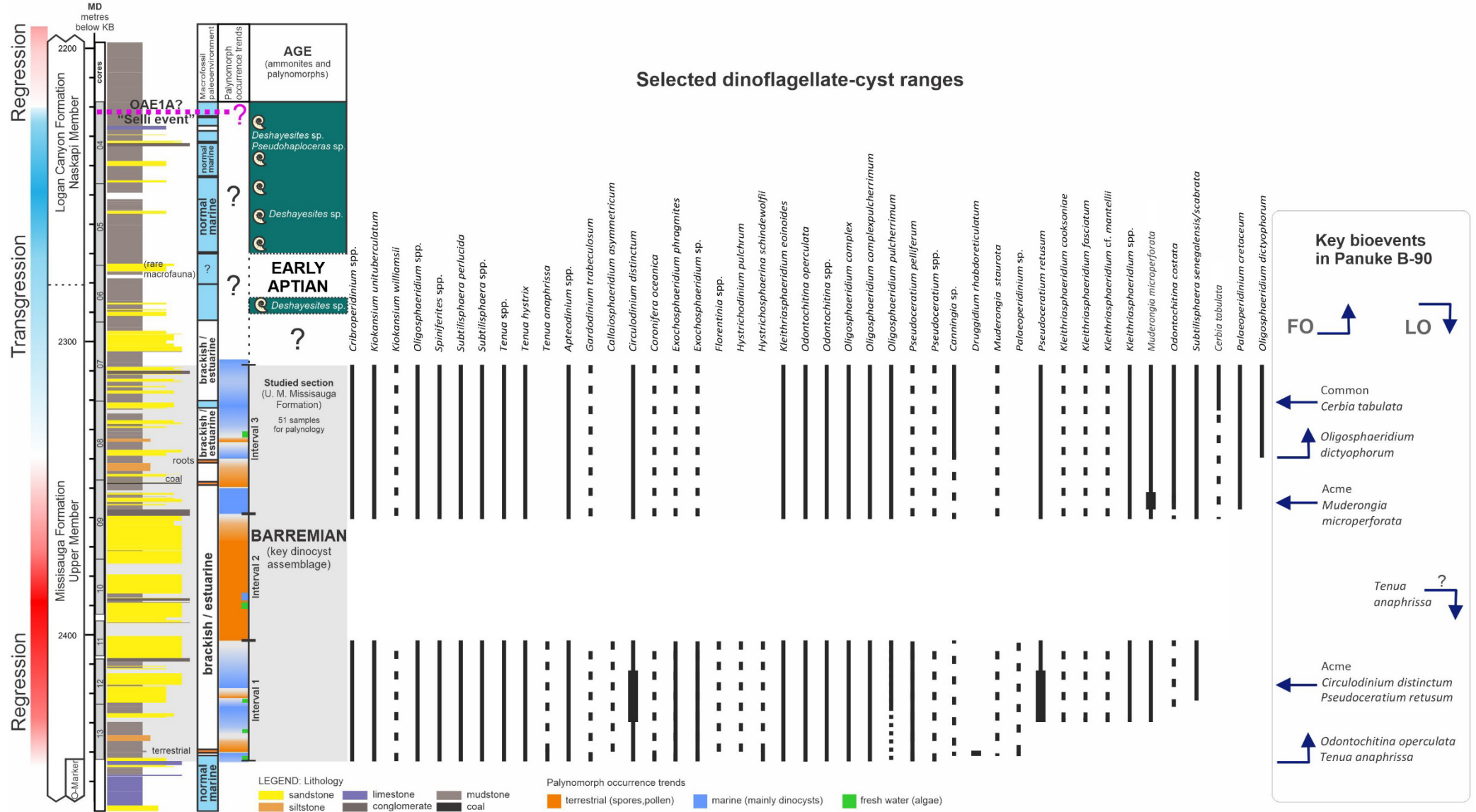


Figure 5. Selected dinoflagellate-cyst ranges and significant bioevents from the Upper Member of the Missisauga Formation in Panuke B-90 (conventional cores 13 to 7). The blank interval corresponds to thick sandstone units (channel-fill deposits) dominated by terrestrial palynomorphs and almost completely lacking dinoflagellate cysts. Dotted lines indicate scarcity; thick lines represent abundant occurrences (acmes). FO=first occurrence, LO=last occurrence.

4.3. Interval 3: middle of core 9 to middle of core 7 (P41426–P41445; 2351.48–2303.95 m)

Towards the top of core 9, fine-grained sandstones and mudstones become more common, succeeding the thick succession of channel deposits. In samples P41426 (2351.48 m) and P41427 (2349.7 m) we recorded an abundance event (acme) of *Muderongia microperforata* (Plates I, 2; II), together with another ceratiacean, *Pseudoceratium retusum*, the areoligeracean *Circulodinium distinctum*, and the peridiniacean *Palaeoperidinium cretaceum* (Plate V). The earliest reliable occurrence in this succession of *Palaeoperidinium cretaceum* in sample P41426 indicates a possible middle to late Barremian age (Davey 1982; Duxbury 2001) and a possible brackish-water environment (Harding 1990a,b). Harding (1986) also established that *Muderongia simplex* subsp. *microperforata* (= *Muderongia microperforata* after Monteil 1991) is tolerant of low-salinity environments.

The dominant lithologies in the remaining units of this interval consist of weakly to highly bioturbated, interbedded sandstone and mudstone that, based on lithology and trace fossil occurrences, suggest an increasingly transgressive trend. This interpretation is supported at the top of core 8 (sample P41467, at 2318.24 m) by the first occurrence of mudstones with occasional echinoids, indicative of normal marine salinities. This general transgressive cycle is further supported by the increasing trend of dinocyst richness and abundance, from the top of core 8 (samples P41439, at 2320.99 m, and P41467, at 2318.24 m) to the top of the studied section (middle of core 7; Fig. 4). Together with *Muderongia microperforata*, *Pseudoceratium retusum*, *Circulodinium distinctum*, and *Palaeoperidinium cretaceum*, dinocysts include *Apteodinium* spp., *Cribroperidinium* spp., *Kiokansium unituberculatum*, *Kleithriasphaeridium* spp., *Oligosphaeridium* spp., *Spiniferites ramosus* and *Subtilisphaera* spp. as the most common taxa in this interval. *Canningia* spp., *Cerbia tabulata* and *Odontochitina costata* are also present (Plates V; VI). The FO of *Cerbia tabulata* (Plate VI, 16–20) has been established in the early Barremian to earliest middle Barremian (Costa and Davey 1992; Duxbury 2001, as *Canninginopsis tabulata*), but is more common in the late Barremian (Harding, 1990a). The FO of *Oligosphaeridium dictyophorum* was also identified in this interval (Fig. 5; Plate VI, 4; Table 1). We think is possible that the common to abundant presence of *Muderongia microperforata* and *Palaeoperidinium cretaceum* in this interval supports a general brackish-estuarine environment, consistent with the occurrence of abundant in-situ oysters in some cores. However,

based on this relatively rich dinocyst assemblage, neritic pulses occur as shown in the dinocyst trends (Fig. 4).

4.4. Overview of the studied section

Based on initial palynological results described here, the base of our studied section in Panuke B-90 is characterized by a transition from neritic to mainly estuarine-brackish environment (Interval 1). Above the estuarine channel-fill sandstones, dominated by miospores (Interval 2), a more evident transgressive cycle is recognized, with intermittent neritic influxes as suggested by the dinocyst abundance and richness trends (Interval 3; Fig. 4; Table 1). Terrestrial palynomorphs are abundant throughout the succession and support a relatively proximal setting.

In general, the most common dinocyst taxa recorded are *Apteodinium* spp., *Circulodinium distinctum*, *Cribooperidinium* spp., *Kiokansium unituberculatum*, *Kleithriasphaeridium* spp., *Muderongia microperforata*, *Oligosphaeridium* spp., *Palaeoperidinium cretaceum*, *Pseudoceratium retusum*, *Spiniferites* spp., *Subtilisphaera* spp. and *Tenua hystrix* and, in the upper part of the section, *Cerbia tabulata* (Fig. 5; Table 1). This assemblage, in addition to the key species *Odontochitina operculata* and *Tenua anaphrissa* that have FOs within the early-middle Barremian, strongly suggests a Barremian age for the Upper Member of the Missisauga Formation. Less frequent species such as *Achomosphaera neptuni*, *Callaiosphaeridium asymmetricum*, *Coronifera oceanica*, *Druggidium rhabdoreticulatum*, *Exochosphaeridium phragmites*, *Gardodinium trabeculosum*, *Hystrichodinium pulchrum*, *Hystrichosphaerina schindewolfii*, *Muderongia staurota* and *Odontochitina costata* are also typical of the Barremian (Duxbury 1980; De Reneville and Raynaud 1981; Srivastava 1984; Harding 1986, 1990a; Mendes et al. 2023). A probable presence of the early Aptian marker ammonite *Deshayesites* sp. in core 6 (~2283.5m), above the section reported here, indicates an early Aptian age for the overlying part of the Naskapi Member of the Logan Canyon Formation and likely continuation of the transgressive trend (MacRae 2011; Weston et al. 2012; Figs. 4, 5).

5. Conclusions

A palynological study of conventional cores in Panuke B-90, in combination with ichnological, macrofossil, and sequence-stratigraphic analyses, is proving effective in understanding the details of the various depositional environments of the Lower Cretaceous on the Scotian Margin. The presence of the dinocyst species *Muderongia microperforata* and

Palaeoperidinium cretaceum, considered tolerant to low-salinity waters, may confirm a brackish-estuarine setting in a large part of the studied section. However, the relatively abundant and rich dinocyst assemblages in Intervals 1 and 3 also indicate a frequent direct connection with a fully marine environment. In addition to paleoenvironmental interpretations, palynomorphs, especially dinocyst, are a reliable biostratigraphic tool, confirming a Barremian age for the Upper Member of the Missisauga Formation in Panuke B-90, using key dinocyst bioevents (co-occurrence *Odontochitina operculata* and *Tenua anaphrissa*) and assemblages.

These interpretations will be refined in continuing studies involving quantitative palynological analysis of all conventional cores from Panuke B-90 and Cohasset A-52, providing an almost continuous Barremian–Albian succession. The integration of palynology, sedimentology, ichnology, nannofossils, stable isotopes and seismic analysis will contribute to a comprehensive Mesozoic event-stratigraphic scheme for the Scotian Margin.

Acknowledgements

The authors thank Anita Nicoll at the C-NSOPB for providing access to the cores and assisting with obtaining core samples used in this project and to Linda Dancey formerly of the palynology laboratory at GSC-Calgary, for processing the samples for this study. We are also grateful to Bill MacMillan for help with graphics and to Carla Skinner, who reviewed the manuscript, with resulting improvements to this report.

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Plate I. General views

General views of slides from the Upper Member of the Missisauga Formation in the Panuke B-90 conventional cores, Scotian Basin.

1. View showing a group of specimens of *Circulodinium distinctum* and *Pseudoceratium retusum* (acmes), sample P41403 (plain transmitted light).
2. View showing specimens of *Pseudoceratium retusum* (at centre) and *Muderongia microperforata* (acme), sample P41427 (plain transmitted light).

Plate I

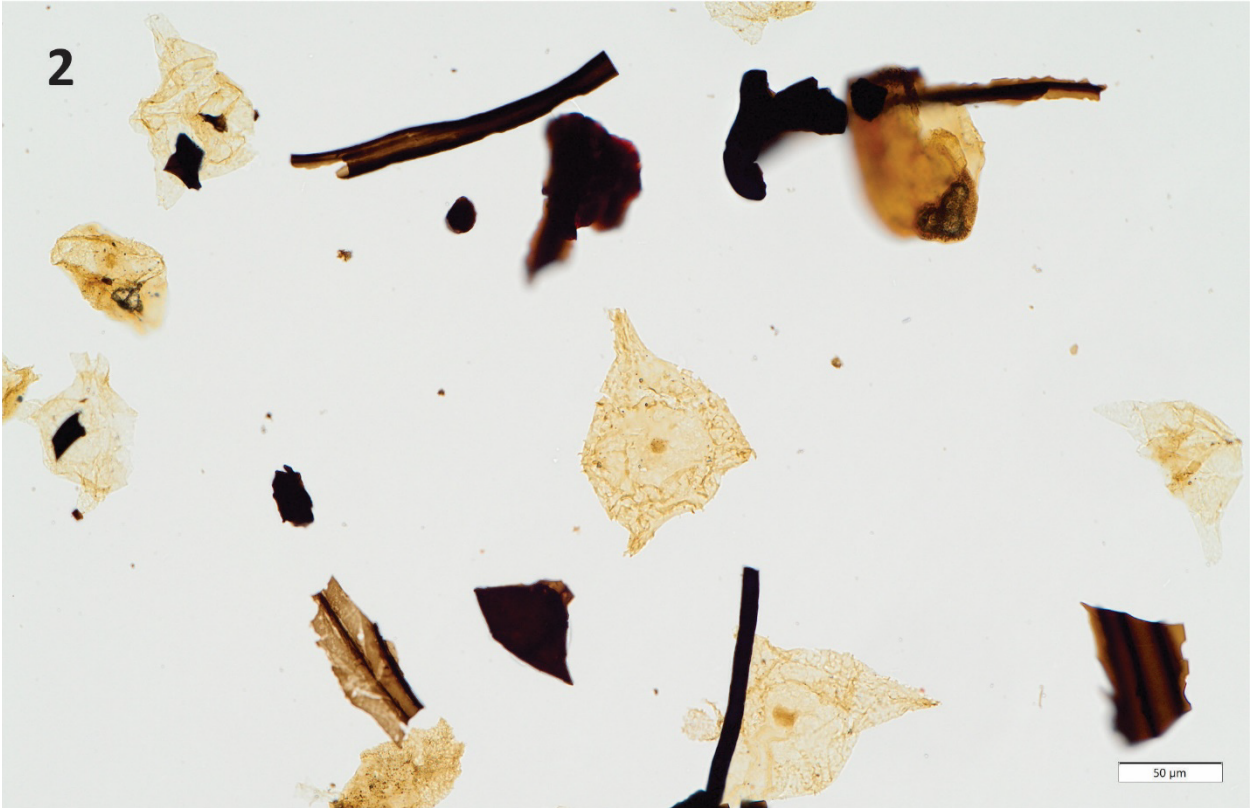
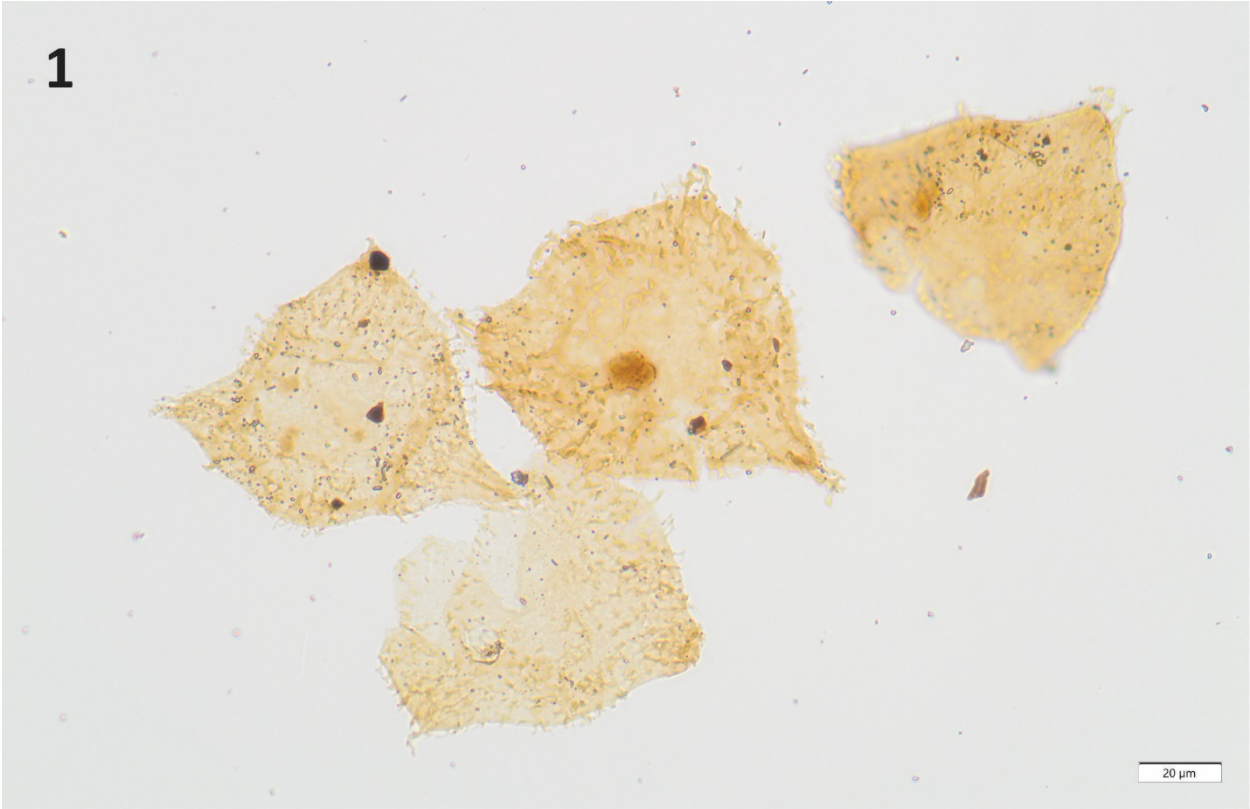


Plate II. General views

General views of slides from the Upper Member of the Missisauga Formation in the Panuke B-90 conventional cores, Scotian Basin.

1, 2. View showing a group of specimens of *Muderongia microperforata* (acme), sample P41426 (plain transmitted light) **1.** Note the damaged periphragm in most specimens. **2.** Note the abundance of this species in this sample.

Plate II

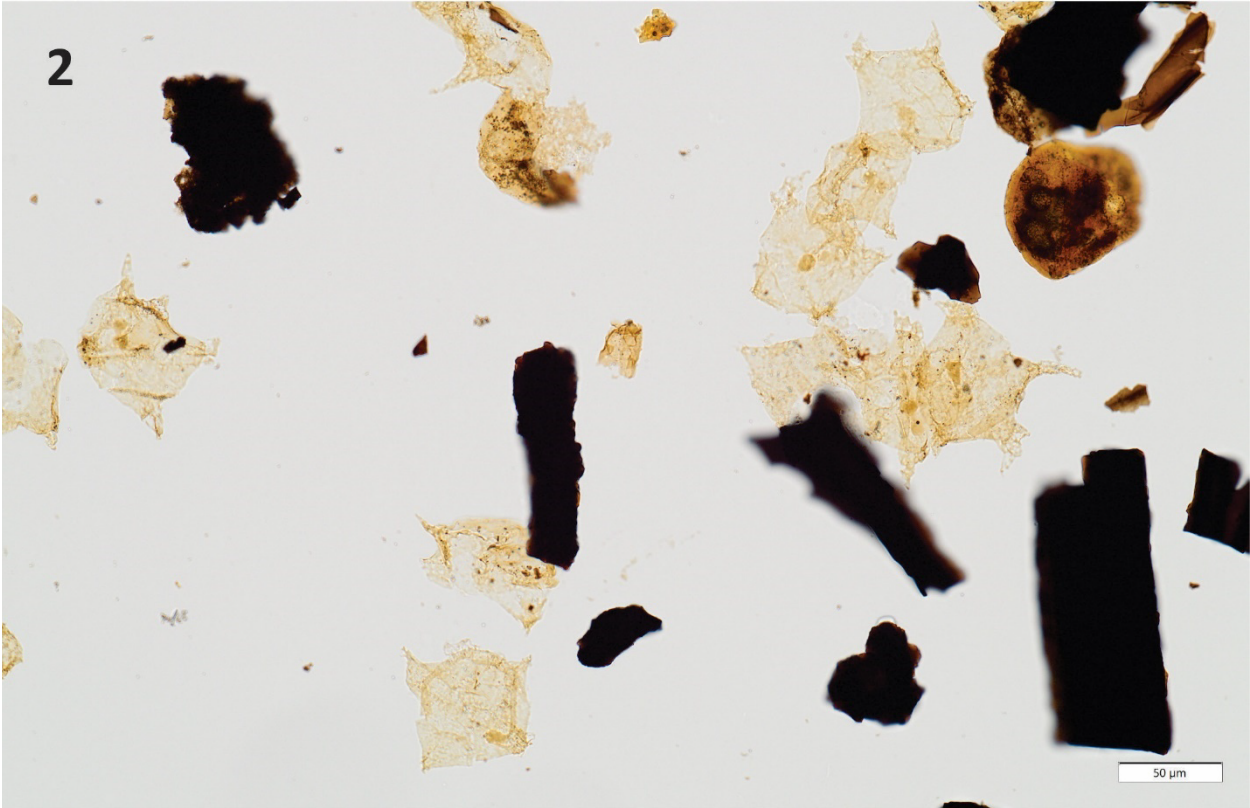
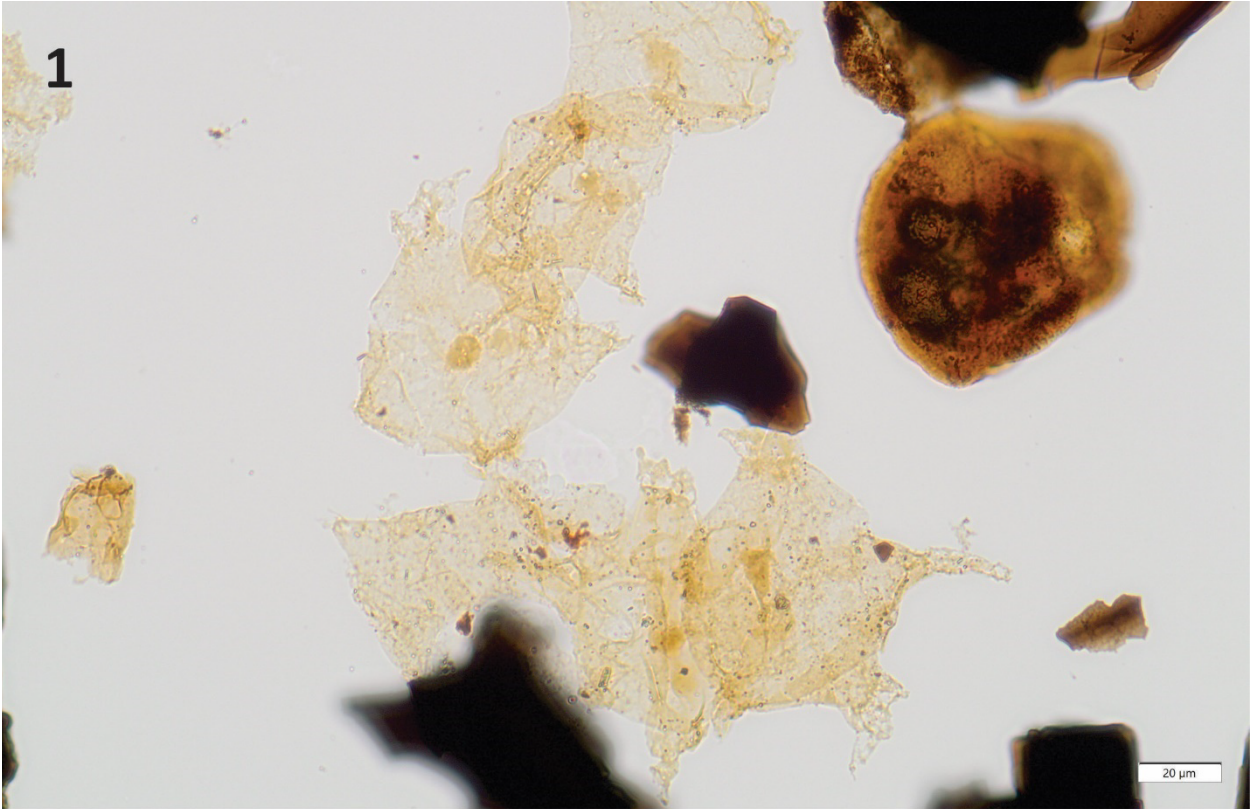


Plate III. General views

General views of slides from the Upper Member of the Missisauga Formation in the Panuke B-90 conventional cores, Scotian Basin.

1. View showing a spore and a fungal hypha and terrestrial material, sample P41417 (plain transmitted light).
2. View showing a bisaccate pollen and plant cuticles, sample P41422 (plain transmitted light).

Plate III

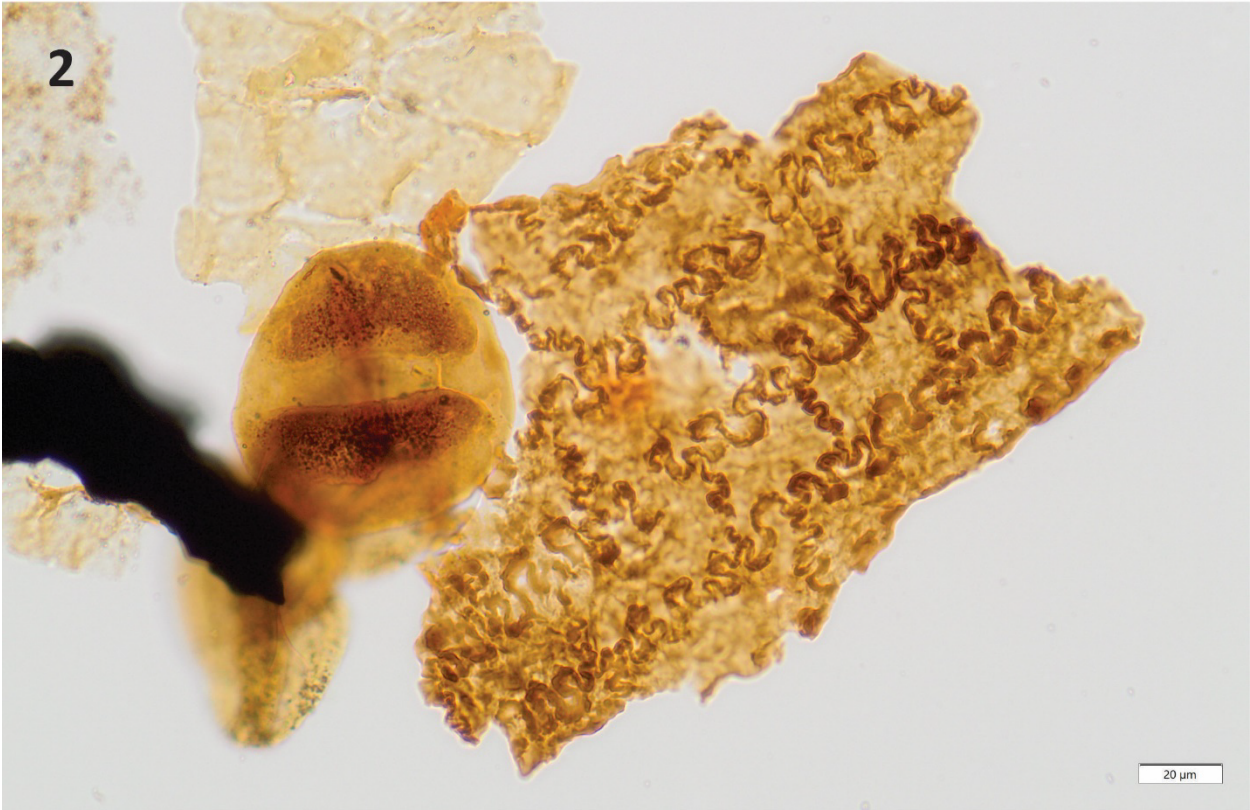


Plate IV. General views

General views of slides from the Upper Member of the Missisauga Formation in the Panuke B-90 conventional cores, Scotian Basin.

1. View showing a group of small spores (including *Gleicheniidites senonicus*) and terrestrial material, sample P41429 (DIC).
2. View showing a chain of small subspherical grains, sample P41436 (DIC).

Plate IV

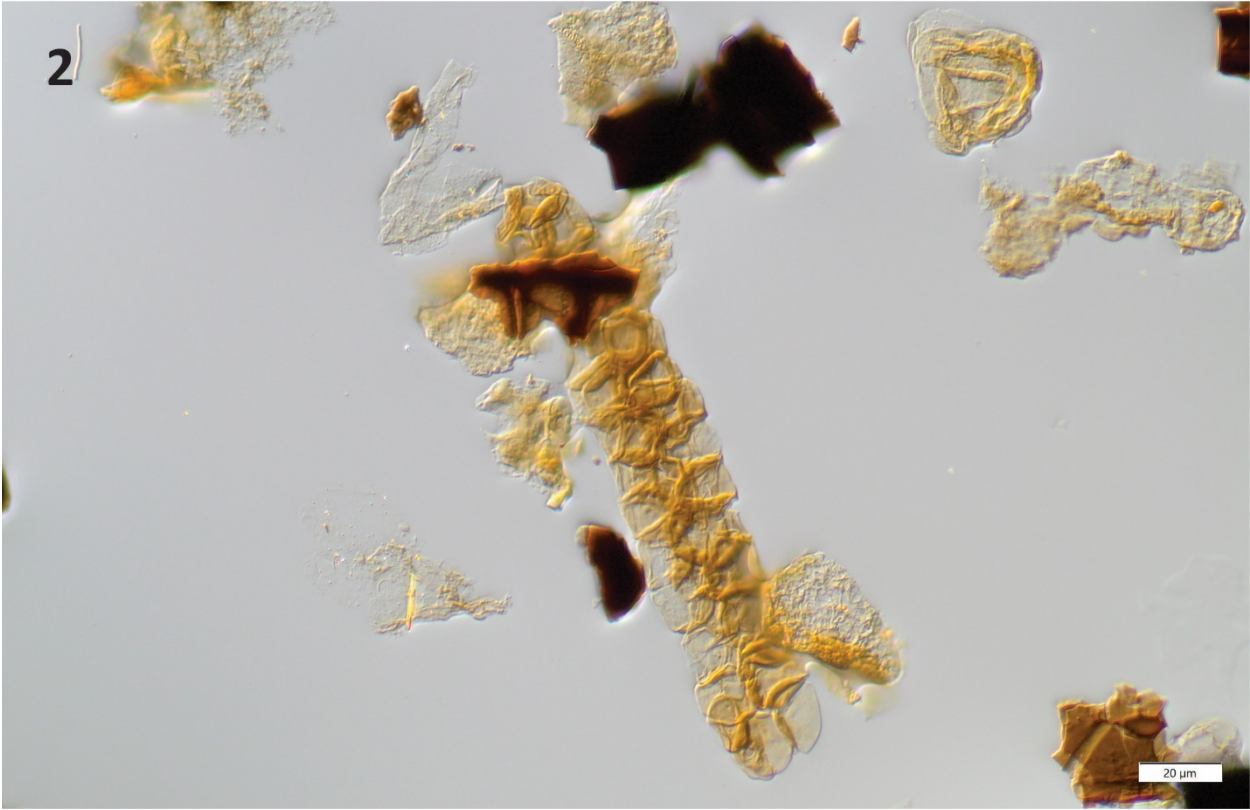
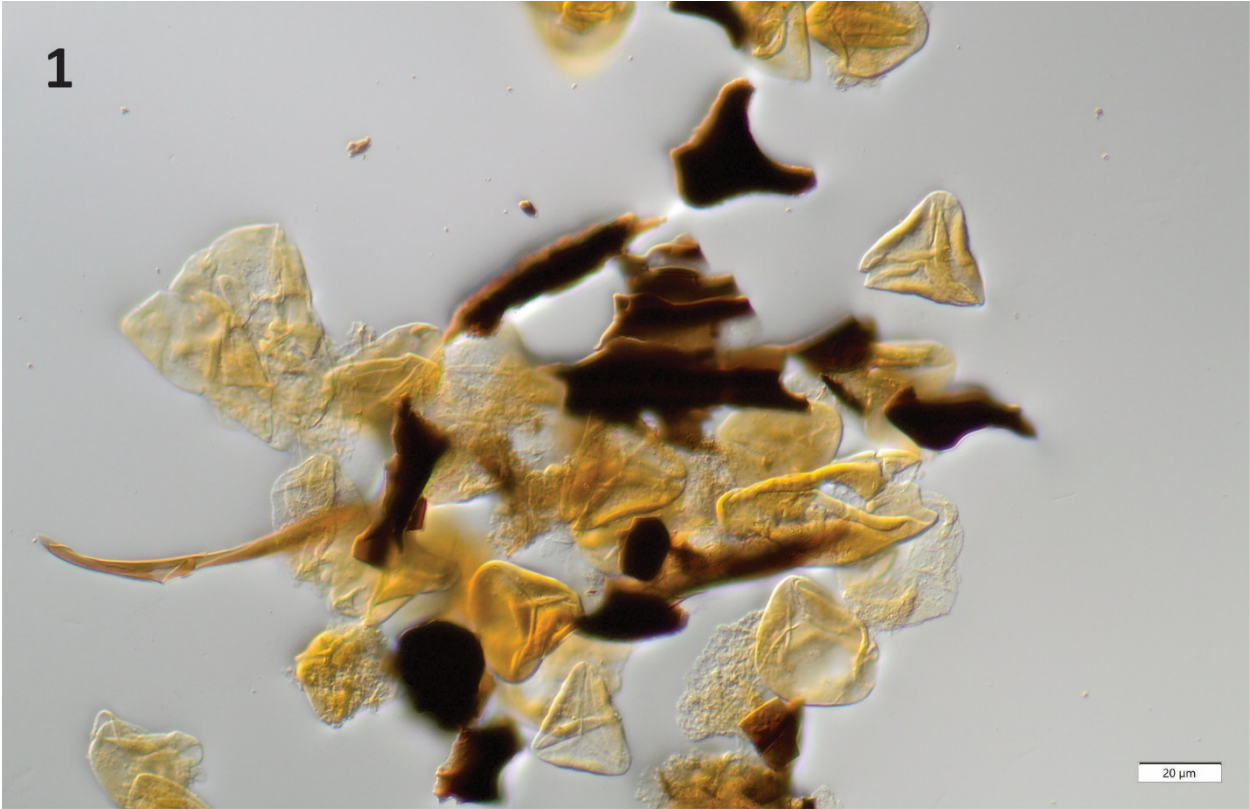


Plate V. Dinoflagellate cysts

Selected dinocysts from the Upper Member of the Missisauga Formation in the Panuke B-90 conventional cores, Scotian Basin. All photographs in plain transmitted light; scale bars represent 20 μm .

1. *Circulodinium distinctum*, sample P41403.
2. *Circulodinium distinctum*, sample P41403.
3. *Circulodinium distinctum*, sample P41403.
4. *Circulodinium distinctum*–*Pseudoceratium retusum* intermediate morphotype, sample P41403.
5. *Pseudoceratium retusum*, sample P41403.
6. *Pseudoceratium brevicornutum*, sample sample P41403.
7. *Pseudoceratium pelliferum*, sample P41403.
8. *Pseudoceratium* cf. *gochtii*, sample P41398.
9. *Tenua anaphrissa*, sample P41398.
10. *Tenua hystrix*, sample P41411.
11. *Subtilisphaera perlucida*, sample P41398.
12. *Palaeoperidinium cretaceum*, sample P41427.
13. *Druggidium rhabdoreticulatum*, sample P41398.
14. *Gardodinium trabeculosum*, sample P41398.
15. *Odontochitina operculata*, sample P41404.
16. *Odontochitina costata*, sample P41411.
17. *Exochosphaeridium phragmites*, sample P41411.
18. *Hystriochodinium pulchrum*, sample P41403.

Plate V

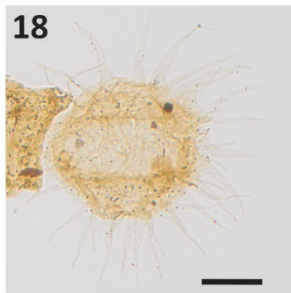
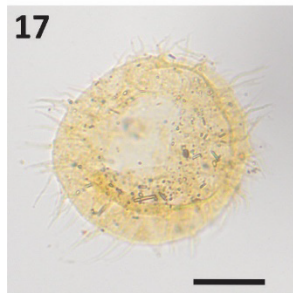
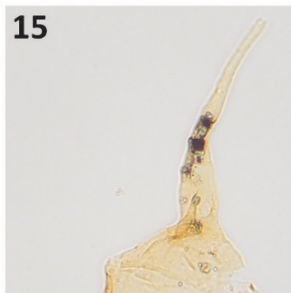
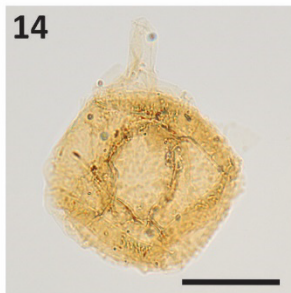
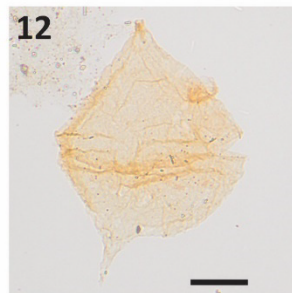
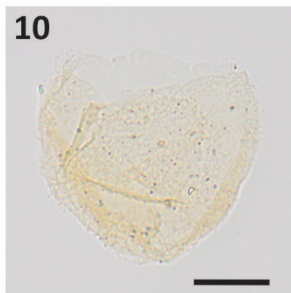
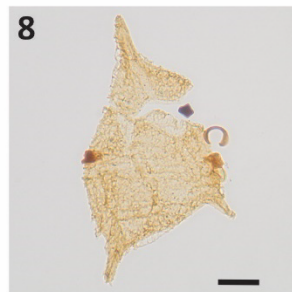
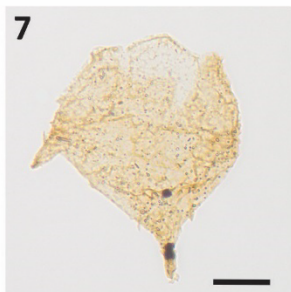
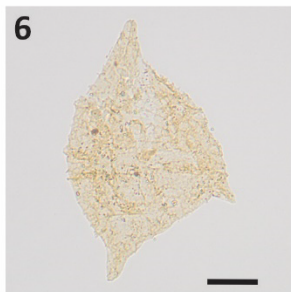
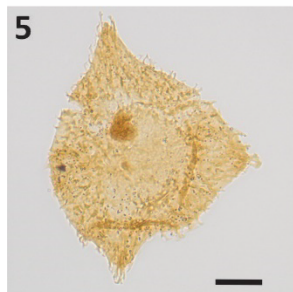
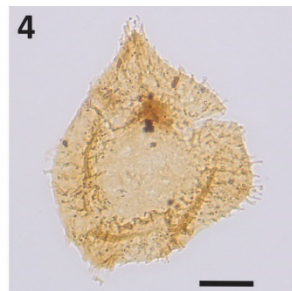
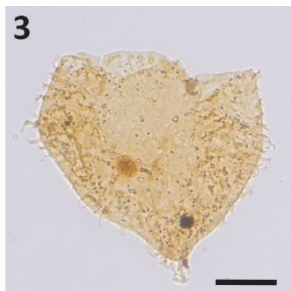
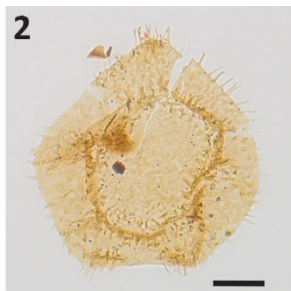
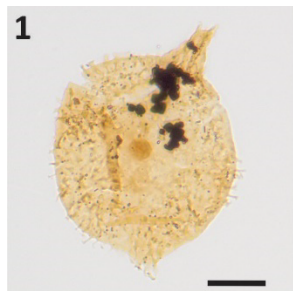


Plate VI. Dinoflagellate cysts

Selected dinocysts from the Upper Member of the Missisauga Formation in the Panuke B-90 conventional cores, Scotian Basin. The scale bar in all photographs represents 20 μm .

1. *Hystrichosphaerina schindewolfii*, sample P41404 (plain transmitted light).
2. *Oligosphaeridium "complexpulcherrimum"*, sample P41403 (plain transmitted light).
3. *Oligosphaeridium pulcherrimum*, sample P41467 (DIC).
4. *Oligosphaeridium dictyophorum*, sample P41436 (DIC).
5. *Kiokansium unituberculatum*, sample P41398 (plain transmitted light).
6. *Kiokansium williamsii*, P41436 (DIC).
7. *Kleithriasphaeridium eoinodes*, sample P41403 (plain transmitted light).
8. *Kleithriasphaeridium fasciatum*, sample P41403 (plain transmitted light).
9. *Spiniferites ramosus*, sample P41440 (DIC).
10. *Callaiosphaeridium asymmetricum*, sample P41467 (DIC).
11. *Apteodinium* sp., sample P41467 (DIC).
12. *Cribroperidinium* sp., sample P41467 (DIC).
13. *Muderongia microperforata*, sample P41403 (plain transmitted light).
14. *Muderongia microperforata*, sample P41440 (DIC).
15. *Canningia* sp., sample P41440 (DIC).
16. *Cerbia tabulata*, sample P41440 (DIC).
17. *Cerbia tabulata*, sample P41441 (DIC), high focus.
18. *Cerbia tabulata*, sample P41441 (DIC), medium focus (same specimen as in 17).
19. *Cerbia tabulata*, sample P41441 (DIC).
20. *Cerbia tabulata*, sample P41467 (DIC).

Plate VI

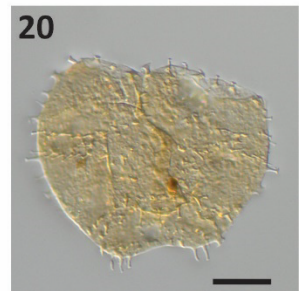
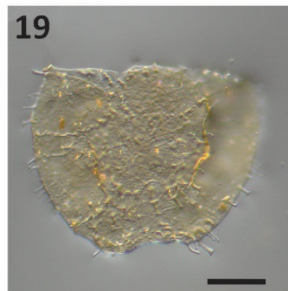
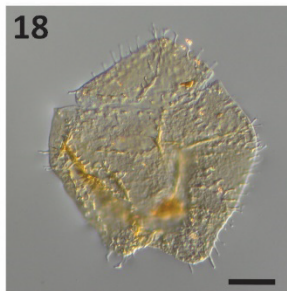
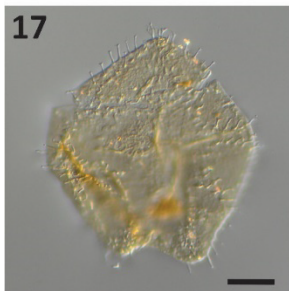
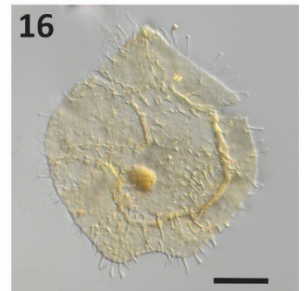
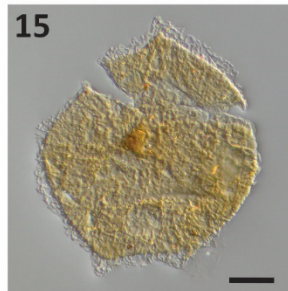
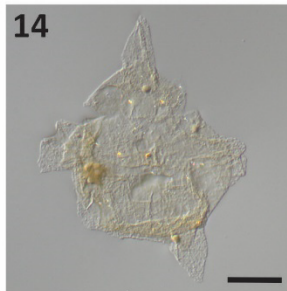
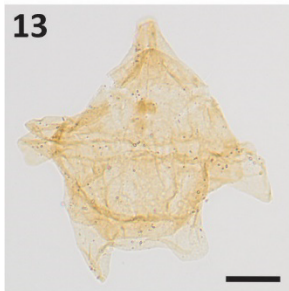
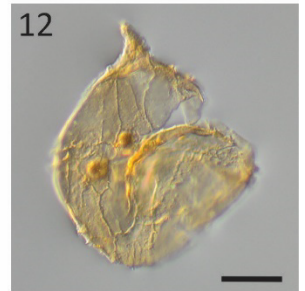
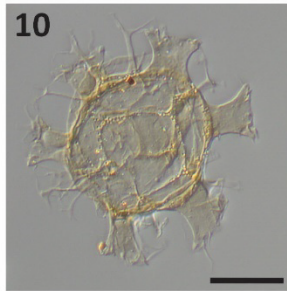
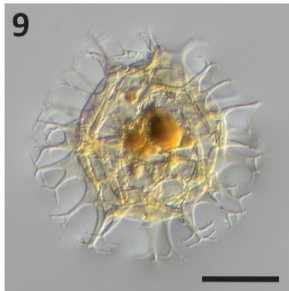
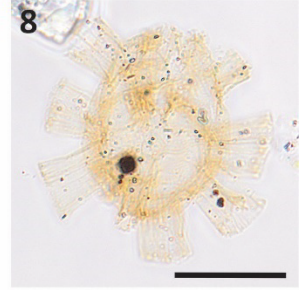
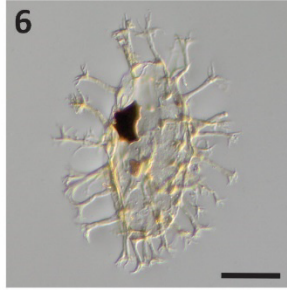
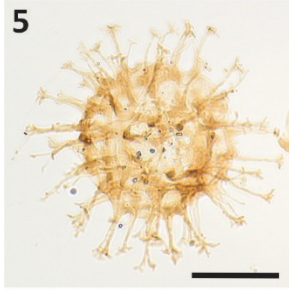
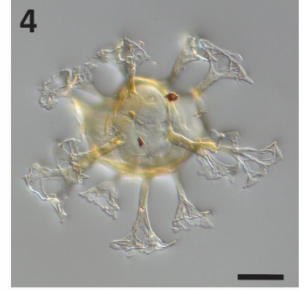
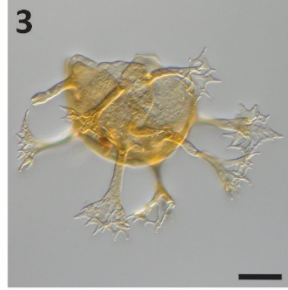
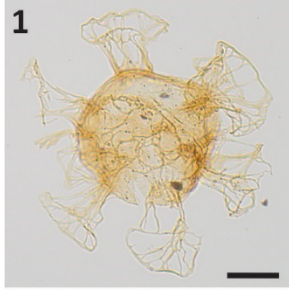
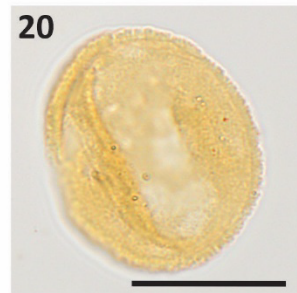
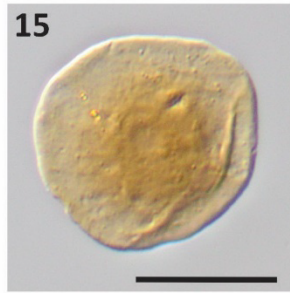
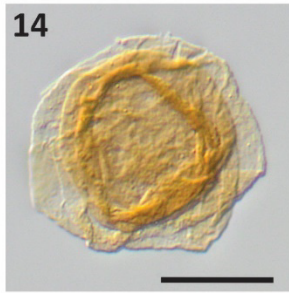
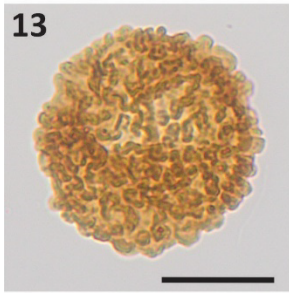
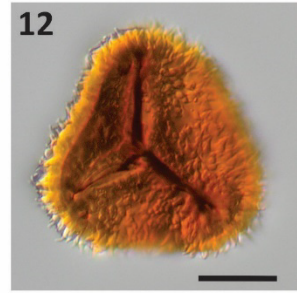
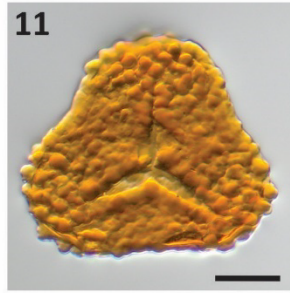
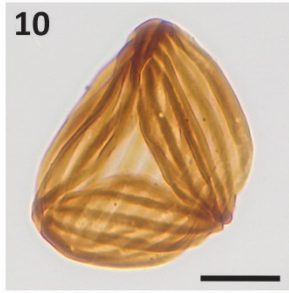
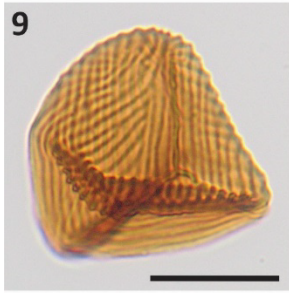
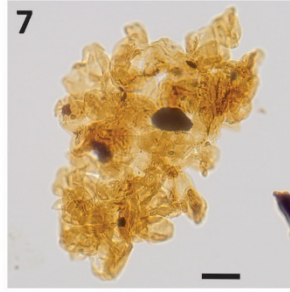
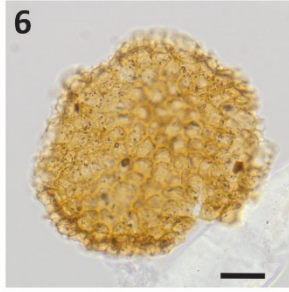
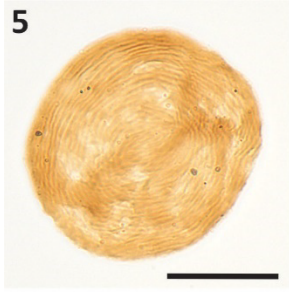
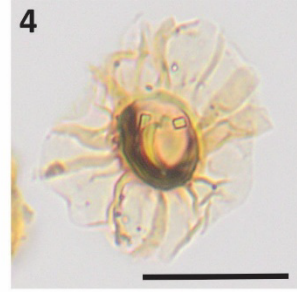
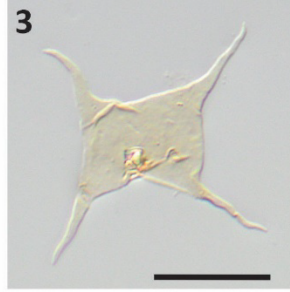
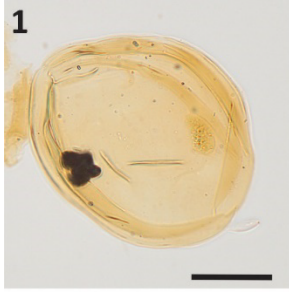


Plate VII. Other aquatic palynomorphs and miospores

Selected aquatic palynomorphs (acritarchs, microalgae and foraminiferal test lining) and miospores (terrestrial) from the Upper Member of the Missisauga Formation in the Panuke B-90 conventional cores, Scotian Basin. The scale bar in all photographs represents 20 μm .

1. *Leiosphaeridia* sp. (acritarch), sample P41411 (plain transmitted light).
2. *Nummus* sp. (acritarch), sample P41411 (plain transmitted light).
3. *Veryhachium* sp. (acritarch), sample P41432 (DIC).
4. *Pterospermella australiensis* (prasinophyte alga), sample P41409 (plain transmitted light).
5. *Chomotriletes* sp. (freshwater zygnematacean alga), sample P41398 (plain transmitted light).
6. *Schizosporis reticulatus* (freshwater zygnematacean alga), sample P41418 (plain transmitted light).
7. *Botryococcus* sp. (freshwater colonial alga), sample P41408 (plain transmitted light).
8. Foraminiferal test lining, sample P41403 (plain transmitted light).
9. *Cicatricosisporites* sp. (spore), sample P41400 (plain transmitted light).
10. *Ruffordiaspora* sp. (spore), sample P41400 (plain transmitted light).
11. *Impardecispora* sp. (spore), sample P41433 (DIC).
12. *Pilosisorites trichopapillosus* (spore), sample P41467 (DIC).
13. *Cerebropollenites macroverrucosus* (pollen), sample P41400 (plain transmitted light).
14. *Perinopollenites elatoides* (pollen), sample P41432 (DIC).
15. *Exesipollenites tumulus* (pollen), sample P41439 (DIC).
16. *Vitreisporites pallidus* (bisaccate pollen), sample P41398 (plain transmitted light).
17. *Clavatipollenites* sp. (early-angiosperm pollen), sample P41398 (plain transmitted light).
18. *Clavatipollenites* sp. (early-angiosperm pollen), sample P41398 (plain transmitted light).
19. *Clavatipollenites* sp. (early-angiosperm pollen), sample P41398 (plain transmitted light).
20. *Clavatipollenites* sp. (early-angiosperm pollen), sample P41411 (plain transmitted light).

Plate VII



Appendix 1. Taxa cited with authorships

Below we list all palynomorph taxa cited in text and plates, with authorship. The full reference from the acritarch and dinoflagellate-cyst authorships can be found in Fensome et al. (2019) and DINOFLAJ3: http://dinoflaj.smu.ca/dinoflaj3/index.php/Main_Page. The informal names are identified between “ ”. The taxa are listed alphabetically in four groups.

Dinoflagellate cysts

Achomospaera neptuni (Eisenack 1958a) Davey and Williams 1966a
Aptea Eisenack 1958a
Apteodinium Eisenack 1958a
Bourkidinium granulatum Morgan 1975
Druggidium rhabdoreticulatum Habib 1973
Callaiosphaeridium asymmetricum (Deflandre and Courteville 1939) Davey and Williams 1966b
Canningia Cookson and Eisenack 1960b
Cerbia tabulata (Davey and Verdier 1974) Below 1981a
Circulodinium distinctum (Deflandre and Cookson 1955) Jansonius 1986
Cometodinium? comatum Srivastava 1984
Coronifera oceanica Cookson and Eisenack 1958
Cribroperidinium Neale and Sarjeant 1962
Exochosphaeridium Davey et al. 1966
Exochosphaeridium phragmites Davey et al. 1966
Florentinia Davey and Verdier 1973
Gardodinium trabeculosum (Gocht 1959) Alberti 1961
Hystrichodinium pulchrum Deflandre 1935
Hystrichosphaerina schindewolfii Alberti 1961
Kiokansium Stover and Evitt 1978
Kiokansium unituberculatum (Tasch in Tasch et al. 1964) Stover and Evitt 1978
Kiokansium williamsii Singh 1983
Kleithriasphaeridium Davey 1974
Kleithriasphaeridium cooksoniae (Singh 1971) Fensome et al. 2009
Kleithriasphaeridium eoinodes (Eisenack 1958a) Davey 1974

Kleithriasphaeridium fasciatum (Davey and Williams 1966b) Davey 1974
Kleithriasphaeridium mantellii (Davey and Williams 1966b) Fensome et al. 2016
Meiourogonyaulax Sarjeant 1966b
Muderongia Cookson and Eisenack 1958
Muderongia microperforata (Davey 1982b) Monteil 1991b
Muderongia staurota Sarjeant 1966c
Odontochitina Deflandre 1937b
Odontochitina costata Alberti 1961
Odontochitina operculata (Wetzel 1933a) Deflandre and Cookson 1955
Oligosphaeridium Davey and Williams 1966b
Oligosphaeridium albertense (Pocock 1962) Davey and Williams 1969
Oligosphaeridium asterigerum (Gocht 1959) Davey and Williams 1969
Oligosphaeridium complex (White 1842) Davey and Williams 1966b
Oligosphaeridium “complexpulcherrimum”
Oligosphaeridium diluculum Davey 1982b
Oligosphaeridium dictyophorum (Cookson and Eisenack 1958) Davey and Williams 1969
Oligosphaeridium pulcherrimum (Deflandre and Cookson 1955) Davey and Williams 1966b
Palaeoperidinium cretaceum (Pocock 1962 ex Davey 1970) Lentin and Williams 1976
Pseudoceratium Gocht 1957
Pseudoceratium brevicornutum Herngreen et al. 2000
Pseudoceratium gochtii Neale and Sarjeant 1962
Pseudoceratium pelliiferum Gocht 1957
Pseudoceratium retusum Brideaux 1977
Spiniferites Mantell 1850
Spiniferites ramosus (Ehrenberg 1837b) Mantell 1854
Subtilisphaera Jain and Millepied 1973
Subtilisphaera perlucida (Alberti 1959b) Jain and Millepied 1973
Subtilisphaera scabrata Jain and Millepied 1973
Subtilisphaera senegalensis Jain and Millepied 1973
Tenua Eisenack 1958a
Tenua anaphrissa (Sarjeant 1966c) Benedek 1972
Tenua hystrix 1958a

Acritarchs and microalgae

Baltisphaeridium Eisenack 1958a (acritarch)

Botryococcus Kützing 1849 (colonial alga)

Chomotriletes Naumova 1937 ex Naumova 1953 (zygnematacean alga)

Leiosphaeridia Eisenack 1958c (acritarch)

Micrhystridium Deflandre 1937b (acritarch)

Nummus Morgan 1975 (acritarch)

Pterospermella australiensis (Deflandre and Cookson) Eisenack and Cramer 1973 (prasin. alga)

Schizosporis reticulatus Cookson and Dettmann 1959 (zygnematacean alga)

Veryhachium Deunff 1954b (acritarch)

Spores

Aequitriradites Delcourt and Sprumont 1955

Appendicisporites Weyland and Krieger 1953

Auritulinasporites Nilson 1958

Baculatisporites comaumensis (Cookson 1953) Potonié 1956

Biretisporites potoniaei Delcourt and Sprumont 1955

Cibotiumspora jurienensis (Balme 1957) Filatoff 1975

Cicatricosisporites Potonié and Gelletich 1933

Concavissimisporites Delcourt and Sprumont 1955

Costatoperforosporites Deák 1962

Deltoidospora Miner 1935

Densoisporites Weyland and Krieger 1953

Dictyophyllidites Couper 1958

Distaltriangulisporites perplexus (Singh 1964) Singh 1971

Foveotriletes van der Hammen 1955 ex Potonié 1956

Gleicheniidites senonicus Ross 1949

Impardecispora Venkatachala et al. 1968

Ischyosporites Balme 1957

Osmundacidites wellmanii Couper 1953

Pilosisporites Delcourt and Sprumont 1955

Pilosisporites trichopapillosus (Thiergart 1949) Delcourt and Sprumont 1955
Plicatella Maljavkina 1947
Retitriletes Pierce 1961
Rotverrusporites Döring 1964
Ruffordiaspora Dettmann and Clifford 1992
Staplinisporites caminus (Balme 1957) Pocock 1962
Stereisporites Pflug in Thomson and Pflug 1953
Stoverisporites Burger 1976
Todisporites Couper 1958
Zlivisporis Pacltová 1961

Pollen

Araucariacites Cookson 1947 ex Couper 1958
Araucariacites australis Cookson 1947 ex Couper 1958
Balmeiopsis limbatus (Balme 1957) Archangelsky 1977
Callialasporites Sukh-Dev 1961
Callialasporites turbatus (Balme 1957) Schulz 1967
Cerebropollenites macroverrucosus (Thiergart 1949) Schulz 1967
Classopollis torosus (Reissinger 1950) Balme 1957
Clavatipollenites Couper 1958
Cycadopites Wodehouse 1933
Ephedripites Bolkhovitina 1953 ex Potonié 1958
Eucommiidites Erdtman 1948
Exesipollenites tumulus Balme 1957
Perinopollenites elatoides Couper 1958
Vitreisporites pallidus (Reissinger 1950) Nilsson 1958

Reference:

Fensome, R.A., Williams, G.L. and MacRae, R.A. 2019. The Lentin and Williams index of fossil dinoflagellates 2019 edition. *American Association of Stratigraphic Palynologists Contributions Series*, 50.