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Recommended citation
Galloway, J.M. and Gilbert, M. M., 2026. Palynology of the Mannville Group from north-central Saskatchewan (National Topographic System map sheets 73-I/10–15); Geological Survey of Canada, Open File 9288e, 32 p. https://doi.org/10.4095/p0vyvsd8uy

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

ISSN 2816-7155
ISBN 978-0-660-78049-8
Catalogue No. M183-2/9288E-PDF
https://doi.org/10.4095/p0vyvsd8uy

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FOREWORD

This project was undertaken as part of an initiative to improve the stratigraphy of the Early Cretaceous Mannville Group in north-central Saskatchewan to support evaluation of its economic potential as a placer gold resource. Samples were collected for palynological analysis investigation to provide biostratigraphic age interpretations.

PROJECT SUMMARY

The age of examined material from the Mannville Group of southeastern Saskatchewan is interpreted as early Barremian to early middle Albian in age based on the occurrence of dispersed spores and pollen identified as *Impardecispora trioreticulosa* (early Barremian or Aptian) and *Tricolpites* spp. (Albian) coupled with an absence of *Appendicisporites* spores and more complex

angiospermous pollen. Specifically, we interpret that the Cantuar Formation ranges in age from older than middle to late Albian to early to early middle Albian and that the Success Formation is older than middle to late Albian. The samples prepared from the Deadwood Formation did not yield palynomorphs.

INTRODUCTION

The Mannville Group is one of the oldest Mesozoic successions (Albian to Aptian stages; Fig. 1) spanning the entirety of the Western Interior Sedimentary Basin (WISB) as a southeastward-thinning, siliciclastic sedimentary wedge. Mannville Group sediments were deposited during a major episode of subsidence and sedimentation, whereby sediment was sourced from complex episodes of regional uplift and erosion, largely initiated by the onset of the Laramide Orogeny (Dawson et al., 1994; Hayes et al., 1994; Christopher, 2003).

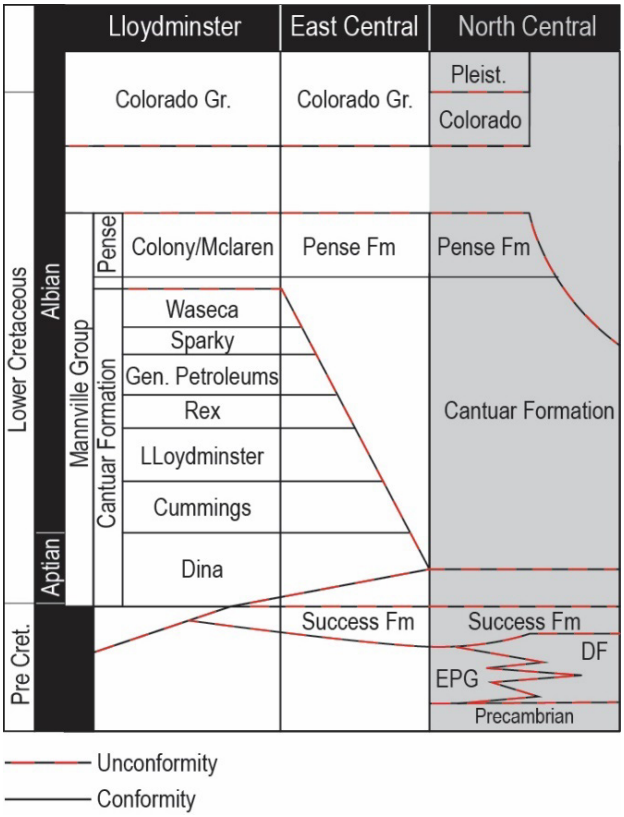

Figure 1. Stratigraphic nomenclature with the Lloydminster and east-central Saskatchewan areas included for regional reference. Modified from Christopher (2003). Abbreviations: Cret. – Cretaceous; DF – Deadwood Formation; EPG – Elk Point Group; Fm – formation; Gr. – Group; Gen. – General; Pleist. – Pleistocene. Solid black lines indicate conformable surfaces; red and black lines indicate unconformable surfaces. It is unclear whether the Pense Formation is present due to lack of core and outcrop resolution. After Gilbert (2025).

In Saskatchewan, the Mannville Group is unconformity-bound, consisting of heterogeneous fluvial to marginal marine deposits subdivided into the lower Cantuar and upper Pense formations (Price,

1963; Maycock, 1967; Caldwell, 1984a, 1984b; Christopher, 2003). The Cantuar Formation may be regionally subdivided into members (Fig. 1; Hein, 2015; Christopher, 2003). Regardless of regional subdivisions, the Cantuar Formation consists of a fluvial to marginal marine transgressive-regressive cycle that infills structurally controlled paleovalleys incised into underlying Paleozoic carbonate (Christopher, 2003; Kohlruss, 2012; Morshedian, 2012; Hein, 2015). The marine to marginal marine Pense Formation disconformably overlies the Cantuar Formation (Christopher, 2003). The Mannville Group is overlain by transgressive deposits of the Cretaceous-aged Colorado Group.

The study area includes National Topographic System (NTS) map sheet 73I10-15 in north-central Saskatchewan, where the Mannville Group forms the dominant bedrock and crops out along several lakes and rivers in the region (Fig. 2). It is overlain by the Colorado Group in the Wapawekka Hills to the east and is underlain in descending stratigraphic order by the Jura-Cretaceous Success Formation, Paleozoic limestones of the Elk Point Group, siliciclastics of the Deadwood and Winnipeg formations, and the Canadian Shield (Gilbert, 2025).

Facies and facies association of the Mannville Group in the study area are summarized by Gilbert (2025). The lowermost strata consist of interfingering coastal plain and sparsely bioturbated fluvio-estuarine distributary channels. These deposits are erosionally overlain by coarse-grained braided stream sediments consisting of kaolinite (believed to be altered feldspar grains and clasts) and quartz sourced from the Canadian Shield to the north. Paleocurrent measurements indicate a south and southwesterly paleoflow, demonstrating drainage to the south with water sourced from topographic highlands to the north (Gilbert, 2025).

The purpose of this study is to improve biostratigraphic age control of Mannville Group in the study area.

METHODS

Detailed sedimentologic and stratigraphic data were collected from outcrop and core during the summer and fall of 2022. Outcrop surfaces were cleaned and lithologs were created utilizing a Jacob's staff and level. Core was logged at the Precambrian Subsurface Laboratory in La Ronge, Saskatchewan. Standard sedimentological information (grain size, clast shape, sedimentary structures, paleocurrent indicators, bed geometry, bed contacts, body fossils, trace fossils) were recorded where possible. Sediment colour was assigned using the Munsell colour chart (Munsell, 2000).

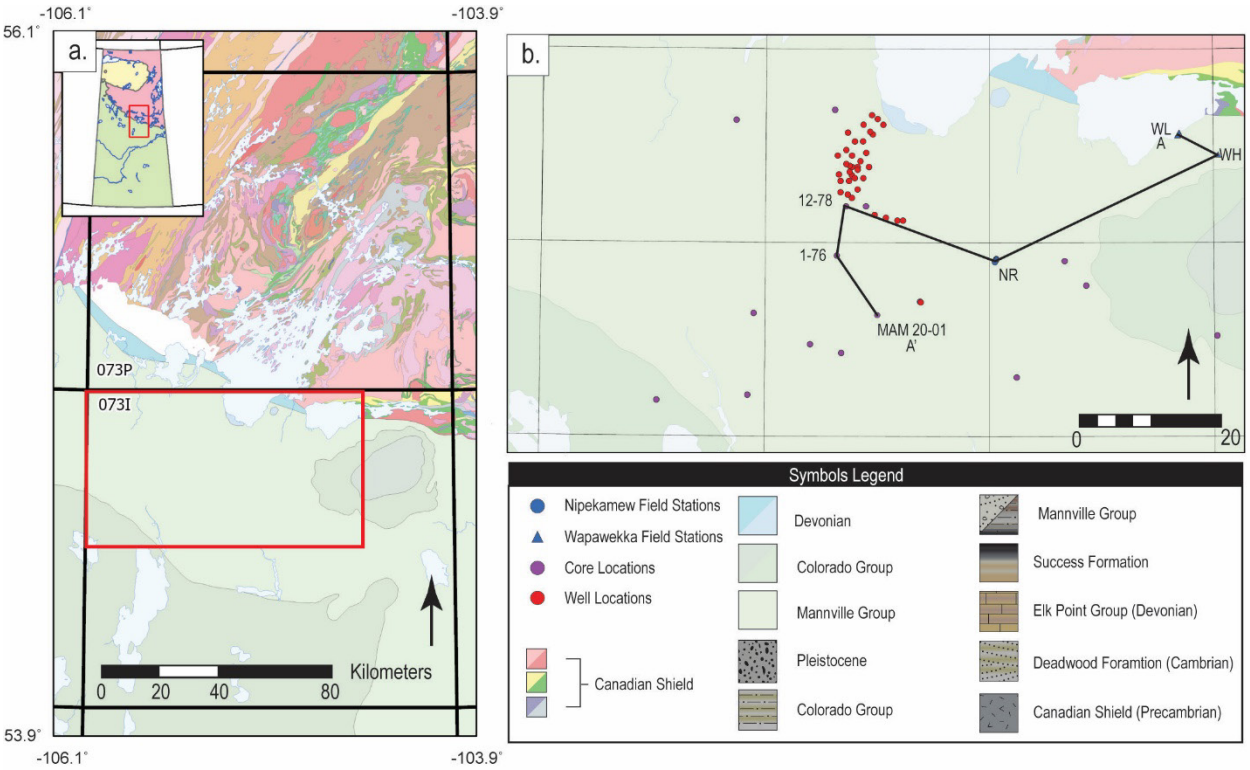

Figure 2. Maps of the study area with reference to regional landmarks and NTS map sheets. a) National Topographic System (NTS) 1:250, 000 map sheets 73I and 73P for the province of Saskatchewan (inset). The red square indicates the boundaries of inset b. b) Location of core, wells and outcrop (field stations) plotted in relation to NTS 73P/10, /11, /12, /13, /14 and /15 1:50 000 map sheets. The cross-section shown in Figure 3 is indicated on the map (A-A'). Abbreviations: 1-76 – DMR La Ronge 1-76 (core); 12-78 – WAPA 12-78 (core); NR – Nipikimew River (outcrop); WH – Wapawekka Hills (outcrop); WL – Wapawekka Lake (outcrop); MAM 20-02 (core). After Gilbert (2025).

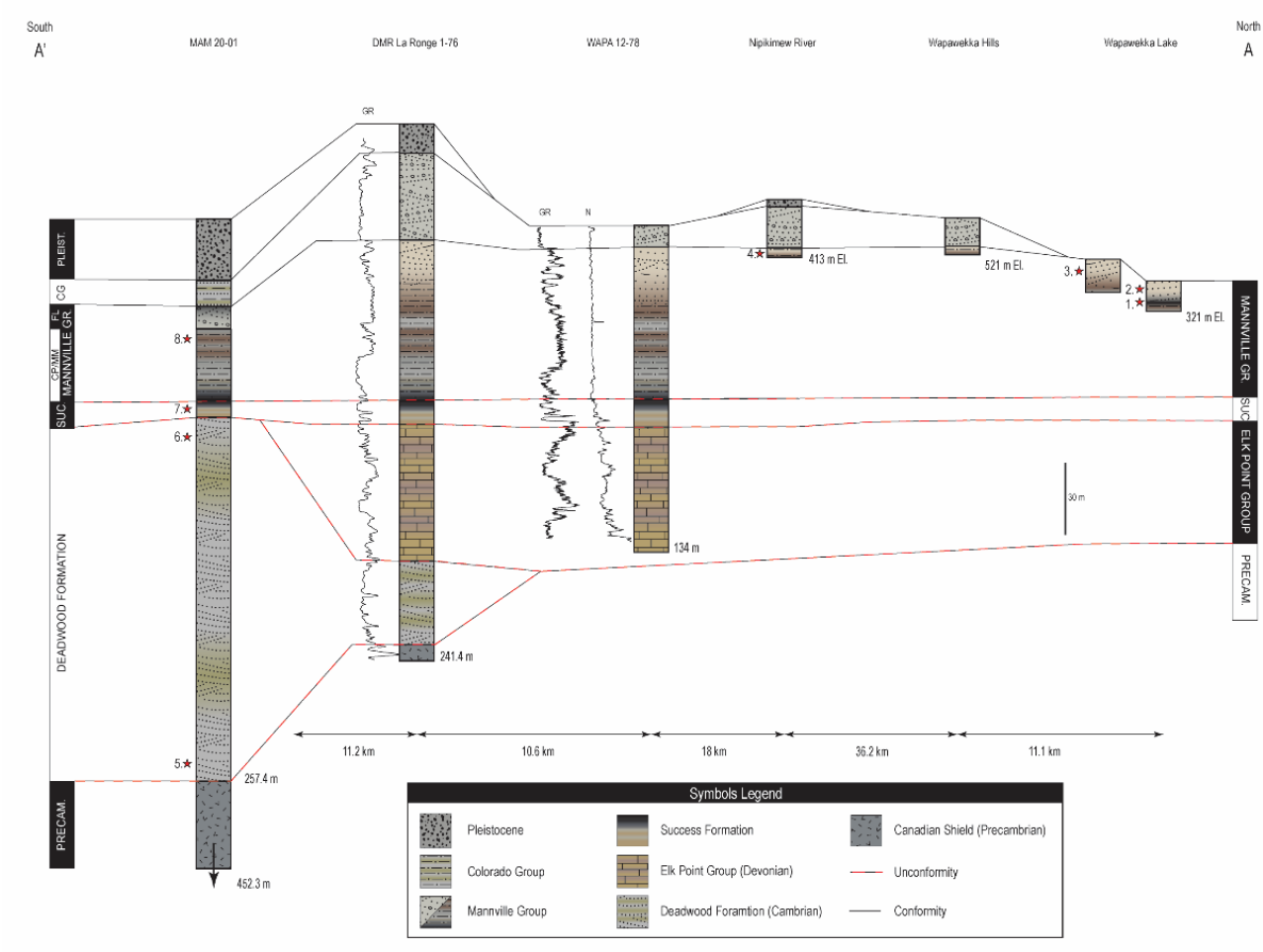

Figure 3. Cross-section A-A' represents a dip-oriented transect through the study area interpreted from core and well log data to provide regional stratigraphic context. The datum used for the cross-section is the top of the Success Formation. Geographic location of wells, outcrop, and cross section A-A' shown in Figure 2. Abbreviations: El. – elevation; CG – Colorado Group; GR – gamma ray log; N – neutron density; PLEIST. – Pleistocene; PRECAM. – Precambrian; SUC – Success Formation; Stars indicate horizons sampled for palynology (Table 1): 1. Wapawekka Lake (MG-22-04-01); 2. Wapawekka Lake 1 (MG-22-04-02); 3. Wapawekka Lake 2 (MG-22-05-04); Nipikimew River (MG-22-01-02); MAM-20-01 (MAM-20-01-01, MAM-20-01-02, MAM-20-01-03, MAM-20-01-04). After Gilbert (2025).

Sample collection

Palynology samples were collected from outcrop and core (Figs. 2, 3), targeting organic-rich lithologies (Table 1). Outcrop samples were obtained from cleaned surfaces. Both core and outcrop samples were collected with a metal spatula that was washed with deionized water between collection, and material was placed into a plastic sample bag. Two samples were collected from fluvial claystone of the Deadwood Formation (MAM-20-01-03 and 04) and one from the Success Formation (MAM-20-01).

Table 1. Samples analyzed for palynology. See also Figures 2, 3.

Well Name/Field station	Latitude, Longitude	Sample Name	Lithology	Lithostrati-graphy	Meter-age (m)[a,b]	Facies	Paleoenviron-ment
Nipekamew River (outcrop)	54.729, -104.985	MG-22-01-02	Claystone	Mannville Group (Cantuar Formation)	2.2[a]	Wavy to lenticular bedded IHS[c]	Middle estuary and tidal point bar channels
Wapawekka Lake 1 (outcrop)	54.888, -104.580	MG-22-04-01	Claystone	Mannville Group (Cantuar Formation)	0.42[a]	Wavy to lenticular bedded IHS[c]	Middle estuary and tidal point bar channels
Wapawekka Lake 1 (outcrop)	54.888, -104.580	MG-22-04-02	Claystone and siltstone	Mannville Group (Cantuar Formation)	1.13[a]	Wavy to lenticular bedded IHS[c]	Middle estuary and tidal point bar channels
Wapawekka Lake 2 (outcrop)	54.892, -104.577	MG-22-05-04	Claystone	Mannville Group (Cantuar Formation)	5.3[a]	Wavy to lenticular bedded IHS[c]	Middle estuary and tidal point bar channels
MAM-20-01 (core)	54.674, -105.156	MAM-20-01-01	Claystone	Deadwood Formation	248[b]	Fluvial (undifferen tiated)	Fluvial
MAM-20-01 (core)	54.674, -105.156	MAM-20-01-02	Claystone	Deadwood Formation	114[b]	Fluvial (undifferen tiated)	Fluvial
MAM-20-01 (core)	54.674, -105.156	MAM-20-01-03	Coal	Success Formation	93[b]	Carbonac eous siltstone, shale, and coal	Floodplain, peat-forming mires, swamps, marshes
MAM-20-01 (core)	54.674, -105.156	MAM-20-01-04	Coal and carbonaceo us mud	Mannville Group (Cantuar Formation)	60[b]	Carbonac eous siltstone, shale, and coal	Floodplain, peat-forming mires, swamps, marshes

[a]meterage reported from base of measured section.
[b]meterage reported as meters below drilling platform.
[c]IHS – inclined heterolithic stratification.

Palynological processing

Samples were processed at Global GeoLabs Ltd. in Medicine Hat, Alberta. Samples were prepared for palynology following extraction techniques outlined by Traverse (2007). Briefly, the process included washing, acid digestion, oxidation with Schulze's solution, and staining with Safranin O. Residues were mounted with polyvinyl and liquid bioplastic. All samples analyzed for pollen and spores are the >10 µm size fraction. Each preparation is labelled with an R-number.

Microscopy

Observations of terrestrial palynomorphs were completed using an Olympus BX53® and an Olympus BX61® transmitted light microscope with oil immersion at 400× and 1000× magnification. Digital images were captured using an Olympus DP72 camera and Stream Motion® software under differential interference contrast (Nomarski interference contrast) and oil immersion. Microscope slides and residues are stored at the Geological Survey of Canada, Calgary, Alberta.

A quantitative approach was used in the analysis, and a minimum of 200 spores and pollen from obligately terrestrial parent plants were enumerated for each sample. Relative abundances are calculated based on this pollen and spore sum. The abundance of non-pollen palynomorphs, while not included in the pollen and spore sum, are calculated relative to it. Slides were also scanned for biostratigraphically important taxa. Age diagnostic specimens are plated and England Finder coordinates are reported for them.

Thermal Alteration Index (TAI) after Pearson (1984) should be assessed on unoxidized (kerogen) slides but these were not prepared. Stain acceptance and colouration of pollen and spores of stained and oxidized material were therefore used to determine the TAI.

RESULTS

A diverse and exceptionally well-preserved flora was recovered (Table 2, Fig. 4), although two preparations (MAW-20-01, R-3977-5 and MAW-20-01-02, R-3977-6) were effectively barren for palynomorphs. Taxonomic authorities and affinities for pollen and spore taxa encountered in this study are listed in Table 3.

The pollen and spore sum ranged from 209 to 467. Assemblages contain angiosperm pollen (MG samples only) and representatives of Pinaceae, Cupressaceae/Taxaceae, Auracariaceae, Podocarpaceae, Cheirolepidaceae, Cycadaceae, Ephedraceae, and Caytoniaceae. Ferns are represented by Gleicheniaceae, Dipteridaceae, Cycatheaceae/Dicksoniaceae, Polpodiaceae/Blechinaceae, Schizaceae, Osmundaceae, Marrittiaceae, and Filicopsid spores of uncertain affinity (Table 3; Fig. 4). Lycophytes include members of Lycopodiaceae and Selaginellaceae and Bryophytes include members of Sphagnaceae. Dinoflagellate cysts, acritarchs, and other non-pollen palynomorphs are rare (Table 3; Fig. 4).

Angiosperm pollen are absent in samples MAW-20-03 and MAW-20-04, but *Tricolpites* and *Clavatipollenites* are present in the MG sample suite (MG-22-01-02, MG-22-04-01, MG-22-04-02, MG-22-05-04; Table 2). Members within the *Trilobosporites-Impardecispora-Concavissimisporites* complex may also provide biostratigraphic age information. Non-pollen palynomorphs are absent to rare.

Table 2. Summary of palynological results. Lithostratigraphic unit from Table 1. See also Figure 4.

Sample Name	R-number	Paleoenvironment interpreted from facies analyses after Gilbert (2025)	Palynological summary	Age Interpretation
MG-22-01-02 (Cantuar Fm)	R-3877-1	Middle estuary and tidal point bar channels	Angiosperm pollen *Clavatipollenites* and *Tricolpites* present. Dominated by bisaccate pollen (40%). Cupressaceae-Taxaceae pollen absent. *Classopollis classoides* present (1%). *Vitreisporites pallidus* abundant (19%). *Concavissimisporites* spores present. *Impardecispora* spores common (6%).	Early to early middle Albian
MG-22-04-01 (Cantuar Fm)	R-3877-2	Middle estuary and tidal point bar channels	Angiosperm pollen *Clavatipollenites* and *Tricolpites* present. Dominated by bisaccate (73%) pollen. Cupressaceae-Taxaceae pollen common (8%). *Impardecispora* spores present (2%).	Early to early middle Albian
MG-22-04-02 (Cantuar Fm)	R-3877-3	Middle estuary and tidal point bar channels	Angiosperm pollen *Tricolpites* present. Dominated by bisaccate (55%) and Cupressaceae-Taxaceae (28%) pollen.	Early to early middle Albian
MG-22-05-04 (Cantuar Fm)	R-3877-4	Middle estuary and tidal point bar channels	Angiosperm pollen *Clavatipollenites* and *Tricolpites* present. Dominated by bisaccate (32%) and Cupressaceae-Taxaceae (36%) pollen. *Cycadopites* pollen common (12%). *Impadecispora apiverrucata* spores present.	Early to early middle Albian
MAM-20-01-01 (Deadwood Fm)	R-3977-5	Fluvial	Barren for palynomorphs	N/A
MAM-20-01-02 (Deadwood Fm)	R-3977-6	Fluvial	Barren for palynomorphs	N/A
MAM-20-01-03 (Success Fm)	R-3977-7	Floodplain, peat-forming mires, swamps, marshes	Dominated by bisaccate (22%) and Cupressaceae-Taxaceae (43%) pollen. *Deltoidospora hallei* spores common (11%). Angiosperm pollen absent.	Older than middle to late Albian
MAM-20-01-04 (Cantuar Fm)	R-3977-8	Floodplain, peat-forming mires, swamps, marshes	Dominated by bisaccate (17%) and Cupressaceae-Taxaceae (53%) pollen. Angiosperm pollen absent.	Older than middle to late Albian

Sample MAW-20-01-04, R-3977-8 (Cantuar Formation)

The preparation of this sample contained abundant (total count 467 pollen and spores) and well-preserved palynomorphs with a TAI of 1+ to 2-. Undifferentiated bisaccate pollen represents 17% of the assemblage, *Cerebropollenites mesozoicus* pollen make up 2%, Cupressaceae-Taxaceae pollen 53%, *Perinopollenites elatoides* pollen 3%, *Cycadopites follicularis* pollen 5%, and *Monosulcites* pollen 2%. Of the Filicopsids, taxa present >1% abundance are *Glecheniidites senonicus* (4%), *Baculatisporites comaumensis* (2%), *Osmundacidites wellmannii* (2%), and *Deltoidospora hallei* (4%). Spores from Bryophytes are rare (e.g., *Stereisporites antiquasporites* makes up <1% of the assemblage). A single dinocyst specimen is present.

Age: Absence of angiosperm pollen suggests an age older than middle to late Albian (Singh, 1971, 1983; Galloway et al., 2012 and references therein).

Sample MAW-20-01-03, R-3977-7 (Success Formation)

The preparation of this sample contained abundant (277) and well-preserved palynomorphs with a TAI of 1. Undifferentiated bisaccate pollen represents 22% of the assemblage. Other pollen taxa with affinities to gymnosperm parent plants include *Cerebropollenites mesozoicus* (1%),

Cupressaceae-Taxaceae (43%), and *Perinopollenites elatoides* (4%) (Fig. 4, ay). *Cyadopites follicularis* pollen make up 5%. *Vitreisporites pallidus* pollen, dispersed from a Pteridosperm parent plant, comprise 1% of the assemblage. Of the Filicopsids, *Gleicheniidites senonicus* spores make up 5% of the assemblage, and *Baculatisporites comaumensis* (1%), *Osmundacidites wellmannii* (1%), *Deltoidospora hallei* (11%), *Foveosporites subtriangularis* (1%) spores are also important. Of taxa dispersed from parent plants with Lycophyte and Bryophyte affinities (e.g., *Stereisporites antiquasporites,* Fig. 4, ao, ap), only *Cingultriletes clavus* spores reach 1%. Non-pollen palynomorphs are absent.

Age: Collector notes that this sample may be from the top of the coal that represents the Success Formation (Fig. 3). This would mean that the sample is uppermost Jurassic-lowermost Cretaceous in age. The absence of angiosperm pollen accords with this interpretation.

Sample MAW-20-01-02, R-3977-6 (Deadwood Formation)

The preparation of this sample was effectively barren.

Sample MAW-20-01-01, R-3977-5 (Deadwood Formation)

The preparation of this sample was effectively barren.

Sample MG-22-05-04, R-3877-4 (Cantuar Formation)

The preparation of this sample contained abundant (211) and well-preserved palynomorphs with a TAI of 1+ to 2-. The preparation is flooded with intertinite and cutinite (coal macerals representing charcoal and plant cuticle, respectively). The angiosperm pollen genera *Tricolpites* (0.5%) and *Clavatipollenites* (1%) are present. Undifferentiated bisaccate pollen represent 32% of the total assemblage. *Cerebropollenites mesozoicus* pollen make up 1%, and *Callialasporites* (1%), Cupressaceae-Taxaceae (36%), *Monosulcutes* (2%), and *Cycadopites follicularis* (12%) (Fig. 4, az) pollen are also present. The presence of *Equiseteosporites* pollen (0.5%) is notable. Of the Filicopsids, *Laevigatosporites ovatus* (4%) and *Deltoidospora hallei* (6%) spores are present in important abundances. A number of *Impardecispora apiverrucata* specimens (5) were encountered when scanning the slide in addition to the 2 specimens encountered during slide enumeration (<1%). An unidentified tuberculate spore was found (Fig. 4, ai) and one dinocyst specimen was encountered.

Age: early to early middle Albian based on the occurrence, but not abundance or diversity of, angiosperm pollen (Singh, 1971, 1983; Galloway et al., 2012 and references therein).

Sample MG-22-04-02, R-3877-3 (Cantuar Formation)

The preparation of this sample contained abundant (240) and well-preserved palynomorphs with a TAI of 2-. *Tricolpites* pollen are present at 0.4% but *Clavatipollenites* pollen are absent. Undifferentiated bisaccate pollen make up 55% of the assemblage and Cupressaceae-Taxaceae pollen make up 28%. *Cyadopites follicularis* pollen are present at 2%. Of the taxa with Filicopsid

affinities, spores assigned to *Gleicheniidites senonicus* make up 1%, *Osmundacidites wellmannii* 4%, and *Deltoidospora hallei* 3%. Non-pollen palynomorphs are absent.

Age: early to early middle Albian based on the occurrence, but not abundance or diversity of, angiosperm pollen (Singh, 1971, 1983; Galloway et al., 2012 and references therein).

Sample MG-22-04-01, R-3977-2 (Cantuar Formation)

The preparation of this sample contained abundant (286) and well-preserved palynomorphs with a TAI of 2-. *Tricolpites* (Fig. 4, au) and *Clavatipollenites* (Fig. 4, ar) pollen are present in this preparation (both at 0.3% of the total assemblage). Undifferentiated bisaccate pollen (Fig. 4, aw, aab) make up 73% of the assemblage. *Cerebropollenites mesozoicus*, *Callialasporites*, and Podocarpaceae (*Podocarpidites*) pollen make up 1% each. Cupressaceae-Taxaceae pollen make up only 8% of the assemblage (Fig. 4, ax). *Perinopollenites elatoides* pollen are present at 1%, and *Cycadopites follicularis* pollen at 2%. Of the Filicopsids, *Gleicheniidites senonicus* and *Laevigatisporties ovatus* spores make up 1% of the assemblage each, and *Deltoidospora hallei* spores make up 3%. *Impardecispora apiverrucata* (Fig. 4, d) spores are relatively abundant, representing 2% of the assemblage. *Osmundacidites wellmannii* (Fig. 4, ah) and *Baculatisporites comaumensis* (Fig. 4, aj) spores are also present but at an abundance of <1%. Non-pollen palynomorphs are absent. During the scan of this preparation, one specimen of *Entylissa* was encountered. An unidentified spore is recorded in this preparation and shown on Figure. 4 (z) that may be *Dictyophyllidites*.

Age: early to early middle Albian based on the occurrence, but not abundance or diversity of, angiosperm pollen (Singh, 1971, 1983; Galloway et al., 2012 and references therein).

Sample MG-22-01-02, R-3977-1 (Cantuar Formation)

The preparation of this sample contained abundant (260) and well-preserved palynomorphs with a TAI of 2-. The angiosperm taxa *Tricolpites* (Fig. 4, as, at) was encountered during a scan of the preparation but not during the enumeration. *Clavatipollenites* pollen was also rare (<0.5% of the assemblage). Undifferentiated bisaccate pollen make up 40% of the assemblage. Cupressaceae-Taxaceae pollen are absent, and *Perinopollenites elatoides* pollen make up 1.5% of the assemblage. *Classopollis classoides* pollen are present at 1% (Fig. 4, av). *Cycadopites follicularis* pollen represent 4% of the assemblage (Fig. 4, aaa) and *Virtreisporites pallidus* pollen make up 19%. Of the Filicopsid taxa, *Gleicheniidites senonicus* spores (Fig. 4, aa, al) represent 4% of the assemblage, and spores of *Cyathidites australis* (1%) (Fig. 4, t, v), *Cyathidites minor* (2%) (Fig. 4, ab), *Concavissimisporties* (Fig. 4, q, r, u), *Osmundacidites wellmannii,* and *Laevigatosporites ovatus* (Fig. 4, ag) occur near 1%. Similar to MG-22-04-01, *Impardicispora apiverrucata* (Fig. 4, a, b, e, f, g, h, I, j) spores are common (6%), including a malformed specimen (Fig. 4, s). *Impardecispora triobotrys* (Fig. 4, p) and *Impardecispora trioreticuluosus* (Fig. 4, m, n, o) also occur. *Deltoidospora hallei* (Fig. 4, aa) spores represent at 7% and *Dicytophyllidites harissii* (Fig. 4, am, an) at 2% of the assemblage. Five specimens of *Pilosisporites trichopapillosus* (Fig. 4, w, x, y) and 1 specimen of *Neoraistrickia truncata* were encountered during a scan of the preparation. Bryophyte spores are rare but present (e.g., *Triporoletes*; Fig. 4, ak). One dinocyst specimen and 2 acritarch specimens were enumerated and 1 specimen of *Schizophacus* was encountered during

the scan of the preparation (Fig. 4, aq). This assemblage also includes *Baculatisporites comaumensis* (Fig. 4, ac), *Biretisporites potoniaei* (Fig. 4, ad), and *Undulatisporites undulapolus* (Fig. 4, ae, af) spores, albeit in low abundances (<1%).

Age: early to early middle Albian based on the occurrence, but not abundance or diversity of, angiosperm pollen (Singh, 1971, 1983; Galloway et al., 2012 and references therein).

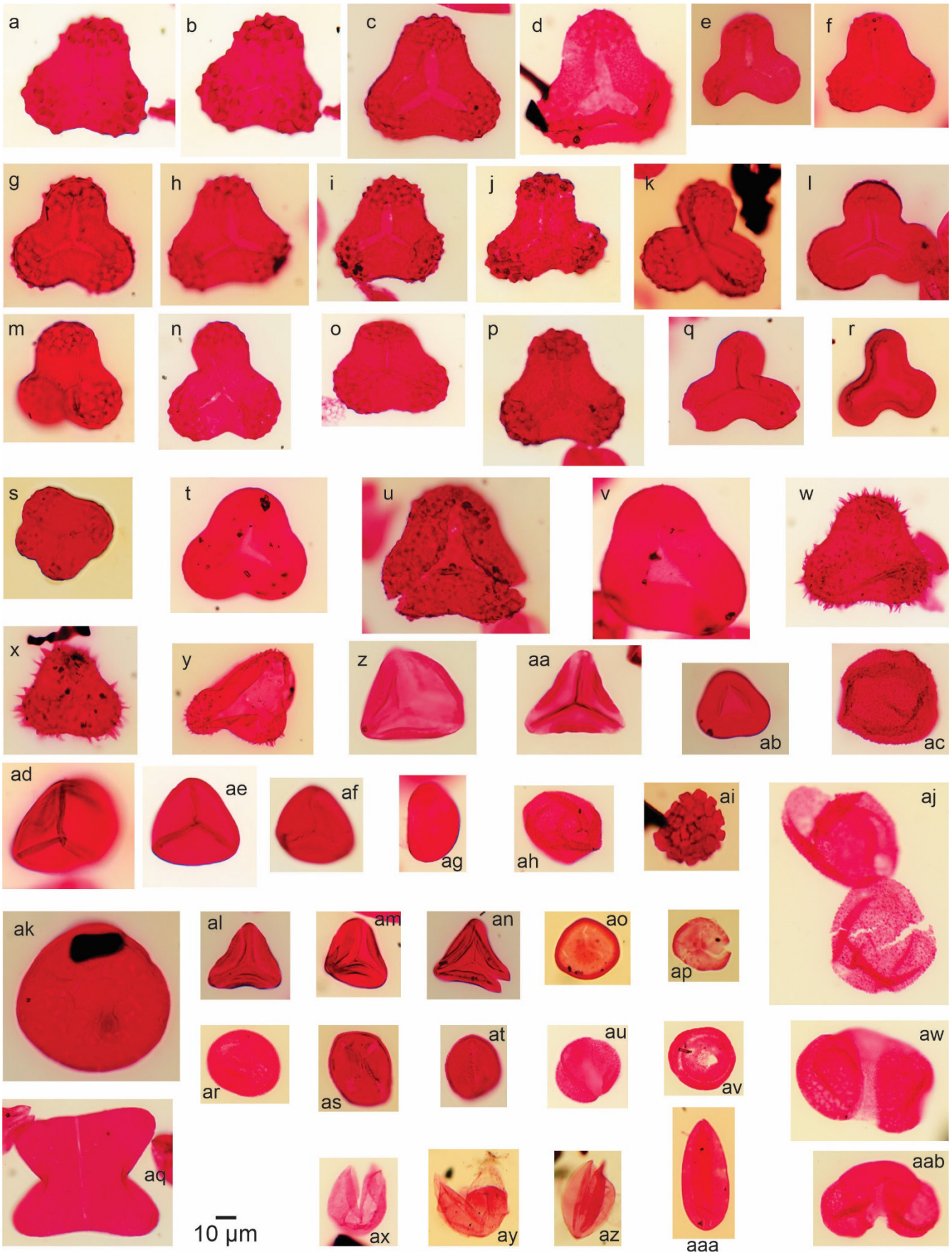
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Figure 4. Photomicrographs of pollen, spore, and non-pollen palynomorphs preserved in preparations of samples of Mannville Group. Taxa name, sample name, preparation name (R-number), England Finder coordindates. See also Tables 1, 2, 3. A. *Impardecispora apiverrucata*, MG-22-01-02, R-3977-1, X41/3**;** b. *Impardecispora apiverrucata*, MG-22-01-02, R-3977-1, X41/3**;** c. *Impardecispora apiverrucata*, MG-22-01-02, R-3977-1, S40/4**;** d. *Impardecispora apiverrucata*, MG-22-04-01, R-3977-2, JW19/2**;** e. *Impardecispora apiverrucata*, MG-22-01-02, R-3977-1, J29/4**;** f. *Impardecispora apiverrucata*, MG-22-01-02, R-3977-1, U35/4**;** g. *Impardecispora apiverrucata*, MG-22-01-02, R-3977-1, P40/4**;** h. *Impardecispora apiverrucata*, MG-22-01-02, R-3977-1, J29/4**;** i. *Impardecispora apiverrucata*, MG-22-01-02, R-3977-1, Y37/2**;** j. *Impardecispora apiverrucata*, MG-22-01-02, R-3977-1, Y38/2**;** k. *Concavissimisporites* sp. , MG-22-01-02, R-3977-1, J29/4**;** l. *Concavissimisporites* sp. , MG-22-01-02, R-3977-1, U33/2**;** m. *Impardecispora trioreticululosa*, MG-22-01-02, R-3977-1, P40/4**;** n. *Impardecispora trioreticululosa*, MG-22-01-02, R-3977-1, R33/1**;** o. *Impardecispora trioreticululosa*, MG-22-01-02, R-3977-1, R40/4**;** p. *Impardecispora triobotrys*, MG-22-01-02, R-3977-1, X35-4**;** q. *Concavissimisporites* sp. , MG-22-01-02, R-3977-1, U41/4**;** r. *Concavissimisporites* sp. , MG-22-01-02, R-3977-1, G25/1**;** s. *Impardecispora lobata*, MG-22-01-02, R-3977-1, E19/4**;** t. *Cyathidites australis*, MG-22-01-02, R-3977-1, U35/4**;** u. *Concavissimisporites* sp. , MG-22-01-02, R-3977-1, S41/3**;** v. *Cyathidites australis*, MG-22-01-02, R-3877-1, V40/4**;** w. *Pilosisporites trichopapillosus*, MG-22-01-02, R-3977-1, S33/2**;** x. *Pilosisporites trichopapillosus*, MG-22-01-02, R-3977-1, X34/2**;** y. *Pilosisporites trichopapillosus*, MG-22-01-02, R-3977-1, S41/1**;** z. Unknown, MG-22-04-01, R-3977-2, Q19/4**;** aa. *Gleicheniidites senonicus*, MG-22-01-02, R-3977-1, T41/3**;** ab. *Cyathidites minor*, MG-22-01-02, R-3877-1, N40/3**;** ac. *Baculatisporites comaumensis*, MG-22-01-02, R-3977-1, U41/3**;** ad. *Biretisporites potoniaei*, MG-22-01-02, R-3977-1, V40/4**;** ae. *Undulatisporites undulapolus*, MG-22-01-02, R-3977-1, P40/3**;** af. *Undulatisporites undulapolus*, MG-22-01-02, R-3977-1, X41/3**;** ag. *Laevigatisporites ovatus*, MG-22-01-02, R-3977-1, U33/2**;** ah. *Osmundacidites wellmannii*, MG-22-04-01, R-3977-2, N25/2**;** ai. Unknown tuberculate spore, MG-22-05-04, R-3977-4, L36/2**;** aj. *Baculatisporites comaumensis*, MG-22-04-01, R-3877-2, M25/1**;** ak. *Triporoletes* sp., MG-22-01-02, R-3977-1, P40/4**;** al. *Gleicheniidites senonicus*, MG-22-01-02, R-3977-1, P40/4**;** am. *Dictyophyllidites harrisii*, MG-22-01-02, R-3977-1, N32/3**;** an. *Dictyophyllidites harrisii*, MG-22-01-02, R-3977-1, M32/2**;** ao. *Stereisporites antiquasporites*, MAW-20-01-03, R-3977-7, M30/4**;** ap. *Stereisporites antiquasporites*, MAW-20-01-03, R-3977-7, J35/1**;** aq. *Schizophacus* sp., MG-22-01-02, R-3977-1, X41/3**;** ar. *Clavatipollenites* sp., MG-22-04-01, R-3977-2, L22/3**;** as. *Tricolpites* sp., MG-22-01-02, R-3977-1, F21/4**;** at. *Tricolpites* sp., MG-22-01-02, R-3977-1, R33/1**;** au. *Tricolpites* sp., MG-22-04-01, R-3977-2, R38/3**;** av. *Classopollis classoides*, MG-22-01-02, R-3977-1, Y38/2**;** aw. Undifferentiated bisaccate pollen, MG-22-04-01, R-3977-2, R38/3**;** ax. Cupressaceae-Taxaceae, MG-22-04-01, R-3977-2, O20/2**;** ay. *Perinopollenites elatoides*, MAW-20-01-03, R-3977-7, O23/2**;** az. *Cycadopites follicularis*, MAW-20-01-03, R-3977-7, M38/4**;** aaa. *Cycadopites follicularis*, MG-22-01-02, R-3977-1 G25/1**;** aab. Undifferentiated bisaccate pollen, MG-22-04-01, R-3977-2, L24/1.

Table 3. List of taxa identified in preparations of samples listed in Tables 1 and 2 with their taxonomic authorities and known affinities.

Division	Class	Order	Family	Genus and species	Authority
Tracheophyta	Magnoliopsida	*incertae sedis*		*Tricolpites*	Cookson 1947 ex Couper 1953
				Clavatipollenites	Couper 1958
	Pinopsida	Pinales	Pinaceae	Pinaceae-type bisaccate	n/a
				Cerebropollenites mesozoicus	(Couper1958) Nilsson 1958
			Araucariaceae	*Araucariacites australis*	Cookson 1947
				Callialasporites	Sukh Dev 1961
			Podocarpaceae	*Podocarpidites*	Cookson 1947 ex Couper 1953
		Cupressales	Cupressaceae/ Taxaceae	*Perinopollenites elatoides*	Couper 1958
				Cupressaceae-Taxaceae	n/a
		incertae sedis	Cheirolepidaceae	*Classopollis classoides*	Pflug 1953
	Cycadopsida/ Gingkopsida	Cycadales/ Ginkgoales	Cycadaceae	*Cycadopites follicularis*	Wilson and Webster 1946
			incertae sedis	*Monosulcites*	Cookson 1947 ex Couper 1953
				Entylissa	Naumova 1939 ex Ishchenko 1952
	Gnetopsia	Ephedrales	Ephedraceae	*Equiseteosporites*	Daugherty 1941
	Pteridospermopsida	Caytoniales	Caytoniaceae	*Vitreisporites pallidus*	(Reissinger 1938) Nilsson 1958
	Filicopsida	Polypodiales	Cycatheaceae/ Dicksoniaceae	*Concavissimisporites*	Delcourt and Sprumont1955
				Cyathidites australis	Couper 1953
				Cyathidites minor	Couper 1953
			Polpodiaceae/ Blechinaceae	*Laevigatosporites ovatus*	Wilson and Webster 1946
		Gleicheniales	Gleicheniaceae	*Gleicheniidites senonicus*	Ross 1949
			Dipteridaceae	*Concavissimisporites variverrucatus*	Brenner 1963
		Polypodiopsida	Schizales	*Trilobosporites*	Pant 1954 ex Potonié 1956
				Trilobosporites trioreticulosa	Cookson & Dettmann 1958
		Osmundales	Osmundaceae	*Baculatisporites comaumensis*	(Cookson 1953) Potonié 1956
				Osmundacidites wellmannii	Couper 1953
				Biretisporites potoniaei	Delcourt and Sprumont 1955
		incertae sedis		*Deltoidospora hallei*	Miner 1935
				Dictyophyllidites	Couper 1958
				Dictyophyllidites harrisii	Couper 1958
				Pilosisporites trichopapillosus	(Thiergart 1949) Delcourt and Sprumont 1955
				Impardecispora	Venkatachala et al. 1968
				Impardecispora apiverrucata	(Couper 1958) Venkatachala et al. 1968
				Impardecispora lobata	Venkatachala, 1969
				Undulatisporites undulapolus	Brenner 1963
				Foveosporites subtriangularis	Brenner 1963
	Lycopsida	Lycopodiales	Lycopodiaceae	*Retitriletes austroclavatidites*	(Cookson 1953) Döring, Krutzsch, Mai and Schulz in Krutzsch 1963
	Isoetopsida	Selaginellales	Selaginellaceae	*Neoraistrickia truncata*	(Cookson 1953) Potonié 1956
Bryophyta	Sphagnopsida	Sphagnales	Sphagnaceae	*Stereisporites antiquasporites*	(Wilson and Webster 1946) Dettmann 1963
				Cingutriletes clavus	(Balme 1957) Dettmann 1963
	incertae sedis			*Zlivisporis reticulatus*	(Pocock) Pacltová and Simoncsics 1970
incertae sedis				Indetermined pollen or spores	n/a
Dinophyta	Dinophyceae	*incertae sedis*		Dinoflagellate cyst	n/a
incertae sedis				*Schizophacus* sp.	n/a

DISCUSSION

Taxonomy & Biostratigraphy

Trilobospotires – Impardecispora- Concavissimisporites – complex

Dörhöfer and Norris (1977) analyzed Tithonian, Berriasian, and Valanginian sediments in southern England and northern Germany deposited in marginal marine and non-marine facies. They noted morphologic gradations between *Trilobosporites, Concavissimisporites*, and *Impardecispora* that they considered evolutionary trends with potential stratigraphic significance during the Berriasian-Valanginian interval. Thus, these form genera are considered as a complex. Also of note is the first occurrence of *Pilosisporites* and *Plicatella* Maljavkina 1949 in the Cretaceous of their studied strata.

Dörhöfer and Norris (1977) described different palynological suites for each region they studied. In Britain, Suite A was interpreted as Tithonian in age and contained high abundances of *Corollina* (cf. *Classopollis*) and taxodiaceaous inaperturate pollen (Cupressaceae-Taxaceae). Other taxa of

note are *Klukisporites pseudoreticulatus* and *Cicatricosisporites australiensis* (*Rufforidaspora australiensis*). Their Suite B (of Britain) was considered lower Berriasian (upper Volgian) in age and first appearances include *Acanthotriletes varispinosus* and *Converrucosisporites* (*Concavissimisporites*) *variverrucatus*. Their Suite C (upper Berriasian-lower Valanginian) is where *Plicatella* (*P. pseudomarcrohyza*) and *Impardecispora apiverrucata* first appeared. In the same interval are the first appearances of two species of *Trilobosporites* (*T. aornatus* and *T. bernissartensis*). Some of the taxa from Suite A persisted throughout Suite C, including *Cicatricosisporites australiensis* and *Klukisporites pseudoreticulatus*. In the upper part of Suite C, a diversification of pteridophyte spores occurred, with new species of *Pilosisporites* (*P. ericius* and *P. delicatulus*) and *Trilobosporites* (*T. obsitus*).

In Germany, four palynoassemblages (hils 1 through 4) were described from the Berriasian to Valanginian Bückeberg Formation of the Lower Saxony Basin by Dörhöfer (1977). Hils 1 (named after the Hils Clays near Hannover, Germany) contained a high abundance of *Trilobosporites* spores. In hils 2 the same elements from hils 1 persisted, but with the addition to 22 new species. These included *Plicatella pseudomacrorhyza*. In hils 3, the lower boundary is marked by an increase *Cicatricosisporties* species. In hils 4, *Trilobosporites* spores were abundant, and the first appearance of *Concavissimisporites verrucosus* occurred.

Dörhöfer and Norris (1977) described a gradation in morphology among the form genera *Trilobosporites* and *Concavissimisporites* as follows: the *Trilobosporites* species that occur in the lower Berriasian are large and possess pronounced valvae (e.g., *Trilobosporites bernissartensis* group). From this basal morphology, subsequent forms exhibit either splitting of the valvae in the apical area or reduction of the valvae (fig. 4, Dörhöfer and Norris, 1977). The splitting of the valvae do not appear to have any stratigraphic significance, but the second variation first appears as soon as spores of pronounced *Concavissimisporites* type occur – i.e., forms that are more "concavissime" in amb shape *sensu* Delcourt and Sprumont (1955) (cf. only slightly concave). In Dörhöfer's (1977) hils 2 assemblage, *Concavissimisporites* species then exhibit a morphological trend from low to high concavity. *Impardecispora*, a genus that has concentration of elements at the apices but no valvae, is then the result of both reduction of valvae from a form-lineage of *Trilobosporites*, or the result of the evolution of concentration of elements at apices from the *Concavissimisporites* form-lineage (fig., 4, Dörhöfer and Norris, 1977), and commonly occurs in the "higher Lower Cretaceous" (e.g., Valanginian).

In contrast to the stratigraphic importance placed on the gradation amongst verrucate, concave spores by Dörhöfer and Norris (1977) and several other authors, others assert that "except for *Trilobosporites* and *Concavissimisporites*, the use of several other genera commonly applied to Mesozoic verrucate spores, such as *Converrucosisporites* and *Impardecispora*, is considered unnecessary." (Polette et al., 2018). Polette et al.'s (2018) make this claim because principal components analysis, based on 120 verrucate spores (categorized with about 10 different morphological variables) preserved in Lower Cretaceous (Berriasian-Valanginian) material from Angeac, Charente, southwest France, separated only *Trilobosporites* and *Concavissimisporites*.

Despite contrasting views on the validity of differentiation of *Trilobosporites*, *Concavissimisporites*, and *Impardecispora*, all three genera all commonly referred to in literature. Venkatachala et al. (1969) designated *Impardecispora apiverrucatus* Couper 1958 as the type of

Impardecispora. The species had previously been accommodated in *Trilobosporites*, distinguishable from *Concavissimisporites* by one or several valvae at each apex. Herein, we distinguish *Impardecispora* from other concave verrucate spore by its concentration of sculptural elements at apices, and by lack of valvae. In contrast, *Concavissimisporites* is used to accommodate concave spores with evenly distributed verrucae.

Trilobosporites Potonié 1955

The type species of the genus *Trilobosporites* is *T. hannonicus* (Delcourt & Sprumont 1955) Potonié 1956, *ibid*. The genus has valvae. *Trilobosporites* was a nomen nudem in Pant (1954). The type species was redescribed and illustrated by Delcourt, Dettmann & Hughes (1963).

The herein observed specimens are assigned to the genus *Impardecispora* because they lack valvae. However, due to what appears to be a degree of subjectivity, perhaps stemming from the gradation of forms, many authors have identified what were subsequently assessed as non-valvate forms to *Trilobosporites*. See discussion in Venkatachala (1969). For this reason, the morphology of select *Trilobosporites* species are discussed below.

Trilobosporites apiverrucatus Couper 1958

The holotype of *Trilobosporites apiverrucatus* (Couper, 1958, p. 142 and pl. 21, fig. 11) was recombined to *Impardecispora apiverrucata* by Venkatachala et al. (1968).

It is these author's opinion that specimens plated in Singh (pl. 8, figs. 16-18, 1964) as *Trilobosporites apiverrucatus* should also be assigned to *Impardecispora apiverrucata* because they lack valvae. The specimens of *Trilobosporites hannonicus* shown (pl. 8, figs. 14, 15, Singh, 1964) have valvae and should therefore assignment to the genus *Trilobosporites* is appropriate. See also Venkatachala et al. (1968).

Trilobosporites tribotrys Dettmann 1963

Trilobosporites tribotrys was erected as a species nova by Dettmann (1963, p.61) to accommodate:

> Miospores trilete; amb triangular with straight or concave sides and rounded angle; polar outline elliptical. Laesurae straight, length ¾ spore radius, and with conspicuous, verrucate lips 5-7 µm wide. Exine 2-3 µm thick, thicker in equatorial, radial regions (valvate). Valvae with low, narrow (2-3 µm wide), anastomosing muri which enclose polygonal lumina (4-5 µm in diameter) and from which arise conspicuous, hemispherical to spherical (4-5 µm high, 4-5 µm in basal diameter) verrucae. Remainder of exine with low, closely-spaced, irregular granules and verrucae (1-3 µm in basal diameter, 1-2 µm high).

However, the holotype for *Trilobosporites tribotrys* (pl. 12, fig. 10, Dettmann, 1963) lacks valvae and should therefore be assigned to *Impardecispora tribotrys* (Ventkatachala et al., 1968).

It is the large spherical verrucae that are developed in the apical regions that distinguish the species from *T. trioreticulosus* Cookson & Dettmann 1963 and *T. purvelulentus* (Verbitskaya 1958) Dettmann 1963 (or its synonym *Lygodium purvelulenyus* Verbitskaya 1958, and thus from *I. trioreticulosa* and *I. purvelulentus*) (see new combinations of Venkatachala et al. (1968)). While

T. apiverrucata (and thus *I. apiverrucata*) resembles *T. tribotrys* (and thus *I. tribotrys*), the former is distinct in having larger verrucae in the polar regions and the absence of anastomosing muri in apical regions.

Trilobosporites trioreticulosus Cookson & Dettmann 1958

This species of *Trilobosporites* appears variously in the literature as *T. trioreticulosa* (e.g., Venkatachala et al., 1968) and *T. trioreticulosus*. The original description in Cookson and Dettmann (1958) uses *Trilobosporites trioreticulosus.*

Cookson and Dettman (1958) used *Trilobosporites trioreticulosus* to accommodate valvate spores belonging to the genera *Trilobosporites* that have developed a reticulum on their valvae. This reticulum has weakly sinuous, anastomosing muri (3-5 µm wide, 2-3 µm high) and fourteen to twenty, polygonal to subcircular lumina 7-9 µm in diameter. However, the holotype of Cookson and Dettmann (1958) is not valvate (pl. 17, fig. 3, Cookson and Dettmann, 1958) but could be interpreted as a reticulate or foveolate valva. *Trilobosporites trioreticulosus* was thus recombined to *Impardecispora trioreticulosa* by Venkatachala et al. (1968). Specimens shown as *T. trioreticulatus* (pl. 9, figs. 1, 2, Singh, 1964) should also be assigned to *I. trioreticulosa* because they lack valvae.

Impardecispora Venkatachala, Kar, & Razi 1968

Venkatachala et al. (1968) noted that several authors, amongst them Dettmann (1963) and Cookson and Dettmann (1958), illustrated specimens assigned to *Trilobosporites*, and erected new species, that were not distinctly valvate. Venkatachala et al. (1968) suggested that the contention is the tendency to equate the crowded ornamentation on the apical regions with valvae. However, true valvae are well-defined areas separate from gradation in the density of size of ornamental elements. Venkatachala et al. (1968) proposed a new genus, *Impardecispora*, to accommodate non-valvate triangular spores with concave inter-apical (interradial) regions and with granulose to verrucose sculptural elements that are crowded (concentrated) at angular apices (see Venkatachala et al., 1968, p. 124).

The specimens illustrated in Singh (pl. 9, figs. 1, 2, 1964) and Singh (pl. 19 figs. 7, 8, pl. 20 figs. 1, 2, 1971) as *Trilobosporites* should be considered as *Impardecispora* because valvae are not conspicuously apparent in the figured specimens.

Impardecispora apiverrucata (Couper 1958) Venkatachala, Kar, & Raza 1968

The holotype for *Impardecispora* is *I. apiverrucata* (Couper 1958) Venkatachala, Kar, & Razi, 1968, *ibid. Trilobosporites apiverrucatus* Couper 1958. Its diagnosis in Venkatachala et al. (1968, p. 124) is:

> Spore triangular, trilobed with concave inter-apical margins. Trilete. Exine thick, granulose-verrucose or covered with muri at angular apices, sculptural elements also crowded at angular apices.

Venkatachala et al. (1968) use Couper's (pl. 21, fig. 11, 1958) holotype for *Trilobosporites apiverrucatus* (pl. 1, figs. 1, 2, Venkatachala et al., 1968) for *Impardecispora apiverrucata* (note the species name change from *apiverrucatus* to *apiverrucata* in this recombination, although this is not consistently followed in literature – see Williams, 2006, p. 3). Venkatachala et al. (1968) also transfer a number of specimens that were considered as *Trilobosporites* to *Impardecispora*, including *T. trioreticulosus* Cookson & Dettmann 1958 (pl. 167, fig. 3, Cookson and Dettmann, 1958) and *T. tribotrys* Dettmann 1963 (pl. 12, fig. 10, Dettmann, 1963).

Age: *Impardecispora apiverrucata* ranges from the Late Jurassic to the early Cenomanian or is entirely Cretaceous in age. The first and last occurrence of *I. apiverrucata* is in the Albian Eider Formation preserved in the Grand Falls H-09 oil and gas well from the Whale Basin, Grand Banks of Newfoundland, although the first occurrence of the genus is in the Oxfordian (upper Voyager Formation) as *I.* sp. A Dörhöfer 1977 (Williams, 2006). Occurrences of *I. apiverrucata* in pre-Tithonian deposits is rare, and questionable (Sajjadi et al., 2007). It occurs in Tithonian-Berriasian deposits of Porto Pinheiro and Vale Painho in Portugal (Mohr, 1989; Mendes et al., 2011) and in the Berriasian of the Cameros Basin in Spain (Rodríguez-Barreiro et al., 2022). It also occurs in the Lastres Formation in northwestern Spain interpreted to be Kimmeridgian to Tithonian in age (Santos et al., 2022).

Impardecispora tribotrys (Dettmann 1963) Venkatachala, Kar, & Razi 1968

Impardecispora tribotyrs is a new combination proposed by Venkatachala et al. (1968) whereby they re-combined Dettmann's (1963) holotype of *Trilobosporites tribotrys* to *I. tribotrys* because the type specimen lacked valvae.

Age: *Impardecispora tribotrys* is an element in a Hauterivian to Aptian assemblage from China, where it co-occurs with *Clavatipollenites* (Li & Liu, 1994).

Impardecispora trioreticulosa (Cookson & Dettmann 1958) Venkatachala 1969

Venkatachala et al. (1969) recombined *Trilobosporites trioreticulosus* to *Impardecispora trioreticulosa* (p. 124). The description of this species is as follows, after Venkatachala, 1969 (p. 212):

> Microspores trilete, amb triangular with slightly concave sides, 60 µ. Y-mark distinct, rays up to ¾ radius. Exine up to 3 µ thick, laevigate – infrapunctate, apical areas foveoreticulate with fine muri enclosing less than 2 µ wide foveola.

Impardecispora lobata Venkatachala 1969

Impardecispora lobata is a new species proposed by Venkatachala (1969, p. 211). This taxon is described from the Pat river section, near Bhuj, in Bhuj Series (Lower Cretaceous) as:

> Microspores, trilete, variously lobed, (4 lobed ones illustrated here) ornamentation verrucose, verrucae set uniformly except at the lobes where it is crowded. The species comes closes to *I. apiverrucatus* in distribution

> of ornamentation and the nature of the mark etc. This species is here considered as a variation of the type exemplified in *T. apiverrucata*.

It is probable that *Impardecispora lobata* represents aberration of *Impardecispora apiverrucata* spores.

Concavissimisporites (Delcourt & Sprumont 1955) Delcourt, Dettmann, & Hughes 1963

Concavissimisporites Delcourt and Sprumont 1955 was emended by Delcourt, Dettmann, & Hughes (1963) (p. 284) to:

> Microspores trilete; amb triangular with concave to almost straight sides. Exine of uniform thickness (inclusive of sculpture), verrucate; verrucae more or less uniformly developed and evenly distributed over entire spore surface.

Delcourt et al. (1963, p. 284) stated that the genus was originally erected to include trilete, azonate microspores characterized by a "concavissime" amb. "Concavissime" is a French description used by Delcourt and Sprumont (1955, p. 22) to describe spores with an amb that has rounded apices and is strongly concave in outline. They morphometrically define the level of concavity required to meet the criteria to be termed "concavissime" (which is 1.4/1 ratio of different metrics outlined their description) (table 2, Delcourt and Sprumont, 1955). *Concavissimiporites* (*Concavisporites* of Delcourt and Sprumont, 1955) does not include spores that are overly concave.

Delcourt et al. (1963) also stated that Potonié (1956) suggested, but did not formally propose, that the genus should be restricted to contain only specimens with verrucate sculpture. Delcourt et al. (1963) formally restrict the genus to verrucate spores which have concave, but not necessarily strongly concave ambs, in accordance with the original description in Delcourt and Sprumont (1955).

Angiosperm pollen

Angiosperm taxa are identified to genus level only. Angiosperm pollen grain morphology (e.g. tri(poly)-colpate vs. tri(poly)colporate types) has biostratigraphic significance (Galloway et al., 2012). In general, the diversity of morphologies (e.g., tri(poly)colpate, tricolporoidate, tricolporate, triporate forms) of angiosperm pollen types are higher in mid-latitudes in North America than in higher northern latitudes (fig. 10, Galloway et al., 2012 and references therein).

Focusing on generic level identification or morphology also reduces biases associated with taxonomy. Taxonomic issues are associated with some forms, particularly *Tricolpites* Cookson 1947 ex Couper 1953 emend. Potonié 1960 and *Retitricolpites* van der Hammen 1956 ex Pierce 1961 (see discussions by Srivastava 1966; Playford 1971; Singh 1971).

Tricolpites Cookson 1947 ex Couper 1953 *ibid.*

Tricolpites sp. is used to accommodate small (c. 20–25 µm polar axis), spheroidal to prolate, tricolpate pollen with micro-reticulate (lumina width ≤1 µm diameter) sculpture (see Galloway et

al., 2012). Colpi are long, extending almost to the poles, narrow to broad and psilate. In contrast, pollen grains that are also c. 20–25 µm long on polar axis, spheroidal to prolate, but have a reticulum with lumina >1 µm in diameter are assigned to *Retitricolpites* sp. (Singh 1971, p. 199). Similar to *Tricolpites* sp., colpi vary from narrow to broad, are psilate and extend almost to the poles (Burden and Hills, 1989). Note that some authors (e.g., Playford, 1971) question the validity of meaningful separation for the genera *Tricolpites* and *Retitricolpites*.

Clavatipollenites Couper 1958

Some problems remain for defining genus *Clavatipollenites* (Friis et al., 2011), and *Clavatipollenites hughesii* may also include several morphological types (Hughes et al., 1979).

Clavatipollenites (type species *C. hughesii*) Couper 1958 (p. 159, pl. 31, figs. 19-22.) is diagnosed as:

> Pollen monosulcate, sulcus broad and long; grains broadly elliptical to almost spherical in equatorial contour; exine clearly stratified, consisting of an inner unsculptured layer (nexine) arising from which is a sculptured layer (sexine) made up of clavate projections, tending to expand and fuse together at their tips to form a tectate exine.

The type species *C. hughesii* is 15-20 x 18-39 µm; nexine 0.75 µm thick, clavate projections about 1 µm long; in surface view exine pattern forms micro-reticulum. It was first described from the Wealden of Southern England.

Kemp (1968, p. 424) after examining specimens from Couper's type sample, emended the description of *C. hughesii* as follows:

> Monosulcate pollen grain; sulcus extending full length of grain, gaping in its central region and tapering slightly towards extremities, margin often ragged; sulcus frequently indistinct, or represented as an indeterminate tear in the exine. Equatorial outline variable, ranging from (strongly) elliptical to (sub) circular. Exine consisting of inner unsculptured nexine 0.5-1 µm thick and a sexine formed of baculate projections ca. 1 µm long, which either remain discrete or fuse at their tips to form a microreticulum; lumina of reticulum irregularly polygonal, 1-2 µm in diameter. Grains often folded, with the long axes of the folds parallel to the sulcus.

Laing (1976) rephotographed the holotype of *C. hughesii* and noted that the columellae in the polar and sulcal regions appear to be coarser than those along the sides, in the central parts.

Juhász & Góczán (1985) considered the rephrasing (and expanded description) by Kemp (1968) to amount to an emendation, which does not include the holotype, but rather the specimens illustrated in by Kemp (which were from the material examined originally by Couper). They consider the projections to be baculae, and that the tips of the columellate baculae are interconnected by the muri or a reticulate tectum, and therefore that the specimens belong to *Retimonocolpites* Pierce 1961 emend. Juhász & Góczán 1985. Jansonius & Hills (1987) do not agree with this assessment. Therefore, in *Clavatipollenites,* it may be considered that the heads of the clavae are fused to form a reticulum and in *Retimonocolpites* the columellate baculae are distally interconnected by muri forming a tectum. Morphologically similar forms *Liliacidites* and *Brenneripollis* have columellae that are not regularly spaced and not of uniform height.

Biostratigraphic significance of angiosperm pollen

Evidence for pre-Cretaceous presence of angiosperms is difficult to assess (Hochuli & Feist-Burkhardt, 2013). Some finds from the Jurassic proved to be based on wrong ages (He et al., 2004, 2006; Sun et al., 1998) and other interpretations of angiosperms in the Jurassic are controversial based on poor independent age constraints and/or contamination (Wang et al., 2007; van Konijnenburg-van Cittert et al., 2010; Wang, 2010; Friis et al., 2011; Doyle, 2012) (according to Hochuli & Feist-Burkhardt, 2013). The angiosperm pollen reported from the Oxfordian of France (Cornet and Habib, 1992) are regarded by Hochuli & Feist-Burkhardt (2013) as contamination (see also Friis et al., 2011). *Clavatipollenites* has been reported in Jurassic strata numerous times (e.g., Pocock, 1960, 1962, 1970; Schulz, 1967; Vigran & Thusu, 1975; Abbink, 1998). For at least some of these grains Doyle et al. (1975) and Batten & Dutta (1997) proved a clear gymnospermous affinity. Hochuli & Feist-Burkhardt (2013) note that in routine palynological studies it might be difficult to distinguish small monosulcate grains with distinct angiospermous columellate structure from those with a clearly gymnospermous spongy alveolar structure. *Clavatipollenites* is documented by Pocock (1960) in the upper Vanguard formation (dated by him as Purbeckian; Late Jurassic). The possible angiospermous affinity of this taxon were first discussed by Couper (1958) and Pocock (1960, p. 145) who notes that "this is the only genus from the Upper Jurassic or Neocomian of Canada for which any convincing claims for angiospermous origin can be made."

Early angiosperm pollen, and including those that occur in the earlier part of the Early Cretaceous (Valanginian/Hauterivian), tend to be small, monosulcate, or sometimes trichotomosulcate, finely reticulate to perforate, and show a distinct columellate structure (Hochuli & Feist-Burkhardt, 2013). The genus *Clavatipollenites,* and the species *C. hughesii*, are among the most frequently recorded taxa from this interval (e.g., Doyle, 1969; Gübeli et al., 1984; Burger, 1990, 1996; Trincão, 1990). A stratigraphically well constrained record exists for *C. hughesii* for the Valanginian of Morocco, where this taxon co-occurs with the age-diagnostic dinoflagellate cysts (Gübeli et al., 1984). However, within this age range, angiosperm pollen are still rare and continuous records exist only from the Barremian onwards for both low and mid-latitudes (Hickey & Doyle, 1977; Crane & Lidgard, 1989; Hughes, 1994; Schrank & Mahmoud, 2002). In high northern latitudes of Canada, angiosperm pollen do not appear until the late Albian (Galloway et al., 2012 and references therein).

Clavatipollenites hughesii was first described by Couper (1958) from the Wealden (Barremian) of England. Hughes (1994) also documents *Clavatipollenties* in the palynological record of the Wealden in the oldest phase (Phase 0, Hauterivian) of his schema (Hughes, 1994; Hochuli & Feist-Burkhardt, 2013), while the other phases contain grains that could fall within the morphological range of *Retimonocolpites* complex or be assigned to *Clavatipollenites* or *Tucanopollis* morphotypes (Hochuli & Feist-Burkhardt, 2013). *Clavatipollenites hughesii* is also documented from the late Hauterivian of Morocco (Gübeli et al., 1984) and Israel (Brenner, 1996) but in the latter occurrence, the preservation of the preserved specimens (figs. 5.4 a-d) are too poor to support an angiosperm affinity according to Hochuli & Feist-Burkhardt (2013).

Based on morphological similarities, *Clavatipollenites* has been associated with the family Chrloranthaceae (Magnoliales) (specifically, *Ascarina lucida* distributed in New Zealand today)

(Couper, 1960; Doyle, 1969; Walker & Walker, 1984; Endress, 1987; Eklund et al., 2004). The detailed work of Hughes (1994), however, suggests that grains determined as *Clavatipollenties* could have heterogenous affinity. *Clavatipollenites* grains were reported *in situ* from a carbonized anther closely similar to those of extant *Ascarina* from the Early Cretaceous (early Aptian) Baqueró Formation of Argentina (Archangelsky & Taylor, 1993). *Clavatipollenites hughesii* has also been reported *in situ* attached to the stigmatic area of the fossil fruit *Couperites mauldinensis* from the early Cenomanian of the Potomac Group, Maryland (Pedersen et al., 1991). It may also be related to *Austrobaileyales* (Endress & Honegger, 1980).

Age and correlation of the Mannville Group

The Cantuar Formation is known to range in age from the Aptian to the Albian. It is the lowermost of two formations comprising the Mannville Group of southern Saskatchewan (Fig. 1). The Success Formation is known to broadly span from the Jurassic to Lower Cretaceous. The majority of the samples treated here are from the Cantuar Formation. One sample is from the Success Formation (MAM-20-01-03) (Table 1). The preparations from the Deadwood Formation did not yield palynomorphs (Table 2). This study finds that the Cantuar Formation ranges in age fromolder than middle to late Albian to early to early middle Albian and that the Success Formation is older than middle to late Albian (Table 2).

Previous palynology studies have identified abundant and diverse assemblages of terrestrial and marine palynomorphs in the Lower Cretaceous Mannville Group (Pocock, 1962; Singh, 1964; Norris, 1967; Vagvolgyi and Hills, 1969; Playford, 197 1; Burden, 1984; Banerjee & Davies, 1988; Burden & Hills, 1989; Papadimitriou & Burden, 2000) and offer a means to establish age and correlations in Lower Cretaceous strata of eastern Alberta and western Saskatchewan (e.g., Table 4, Singh, 1964, 1983). In summary, age determinations are:

> Deville Member, McMurray Formation: late Barremian (Singh, 1964)
> Ellerslie Member, McMurray Formation: Aptian (Singh, 1964)
> Calcareous Member, McMurray Formation: early to early middle Albian (Singh, 1964)
> McMurray Formation: early to early middle Albian (Vagvolgyi and Hills, 1969)

Pocock (1962) ascribed a Neocomian (Berriasian-Barremian) age to the lower Mannville strata he examined from 18 localities in Alberta and southern Saskatchewan and Singh (Singh, 1964) provided a comprehensive study of palynoflora preserved in the Mannville Group from east-central Alberta (near Edmonton). In this locality the base of the Mannville Group sits unconformably on Paleozoic strata, and is likely Hauterivian or younger (Singh, 1964). Singh (1964) considered the Mannville Group of central Alberta to be correlative to other strata in the Western Canada Sedimentary Basin (Table 4). He provided a number of index species and age interpretations for the Deville, Ellerslie, and "calcareous" members (now Calcareous Member) of the McMurray Formation, the Wabiskaw and shale members of the Clearwater Formation, and the Grand Rapids Formation (Tables 4, 5). His material was sourced from core sections of the Mannville Group sampled in the following wells: Imperial Namao No. 1, Anglo-Home-C. & E., Fort Augustus No. 1, and Imperial Willingdon No. 1.

Table 4 Correlatives of Mannville Group strata after Singh (1964, 1983).

Mannville Group	Age	North-central Saskatchewan	Foothills	Northern plains
McMurray Formation	Early Albian and older	Not known	lower Blairmore, lower Luscar, Gladstone, Gething formations	McMurray and "Bullhead" formations
Clearwater and Grand Rapids formations	Middle Albian	Not known	middle Blairmore, upper Luscar and Mountain Park, and Moosebar and lower Commotion formations	Loon River, Clearwater, Fort Augustus, Beaver Mines formations

Table 5. Select index pollen and spore taxa of the Mannville Group in east-central Alberta after Singh (1964). See Singh (1964) for further explanation of taxa groups.

Lithostratigraphic unit	Group A taxa (youngest entrance recorded from Lower Cretaceous strata outside of western Canada)	Group B taxa (make entrance elsewhere in older strata of Cretaceous or Jurassic age)	Group C taxa (make entrance elsewhere in older strata of Cretaceous or Jurassic age)	Group D taxa	Microplankton
McMurray Formation, Deville Member	*Trilobosporites hannonicus* **First occurrence:** Aptian?, Belgian "Wealden" (Barremian).	*Trilobosporites apiverrucatus* now *Impardecispora apiverrucata* **First occurrence:** Berriasian, Fairlight Clay of the English Wealden (Barremian).	*Pilosisporites trichopapillosus* **Known range:** upper Purbeck (Tithonian) to Lower Cretaceous.	*Trilobosporites canadensis*; now *Impardecispora canadensis*	None noted
	Pilosisporites verus **First occurrence:** Aptian?, Belgian "Wealden" (Barremian).	*Appendicisporites crimensis* **First occurrence:** Hauterivian, Crimea, Russia. Range Hautervian to Albian.	*Appendicisporites cooksonii* **Known range:** Callovian to upper Albian, western Australia.	*Concavissimisporites parkinii*	
		Appendicisporites tricornitatus **First occurrence:** top of Berriasian, Fairlight Clay of the English Wealden.			
		Concavissimisporites punctatus **First occurrence:** top of Berriasian, Fairlight Clay of the English Wealden.			
Age interpretation	Not older than late Barremian	Pre-Barremian strata are absent	Pre-Barremian strata are absent		
Ellerslie Member, McMurray Formation	*Impardecispora trioreticulosus*	Various *Appendicisporites* species	*Pilosisporites trichopapillosus*	*Impardecispora canadensis*	None noted
	Cicatricosisporites perforatus **First occurrence:** Aptian, Siberia, U.S.S.R.	*Trilobosporites hannonicus*			
		Impardecispora apiverrucatus			
		Pilosisporites verus			
		Concanvissimiporites punctatus			
Age interpretation	*C. perforatus* and *I. trioreticulosa* are present at the base of the member and are the first species of definite Aptian age to appear in the McMurray Formation.	Broad Early Cretaceous age	Broad Early Cretaceous age		
"calcareous" member, McMurray Formation	Various dinocyst taxa.				3 species of microplankton first appear near the top of the member
Wabiskaw Member, Clearwater Formation	*Appendicisporties trichacanthus* **Known range:** Albian to Cenomanian, western Siberia, U.S.S.R.	Various species of *Appendicisporites*	*Pilosisporites trichopapillosus*	*Appendicisporites perplexus*	Diverse microplankton

		Impardecispora apiverrucata			
		Impardecispora trioreticulosa			
Age interpretation	Midde Albian				
Shale member, Clearwater Formation		Various species of *Appendicisporites*	*Pilosisporites trichopapillosus*	Various	Diverse microplankton
		Impardecispora apiverrucata			
Age interpretation	Middle Albian				
Grand Rapids Formation	*Appendicisporites unicus* Known range: Cenomanian, Siberia, U.S.S.R.	Various species of *Appendicisporites*	*Pilosisporites trichopapillosus*	Various	Diverse microplankton
		Impardecispora apiverrucata			
		Impardecispora trioreticulosa			
Age interpretation	Albian to Cenomanian, based on occurrence of *A. unicus*, but otherwise entirely Albian.				

Taxonomical authority of taxa mentioned in Table 5 and otherwise listed below:
Appendicisporites crimensis (Bolkhovitina 1961) Pocock 1964
Appendicisporites perplexus Singh 1964
Appendicisporites cooksonii (Balme 1957) Pocock 1964
Appendicisporties trichacanthus (Maljavkina 1958) var. *dissectus* (Markova 1961) Singh 1964
Appendicisporites tricornitatus Weyland and Greifeld 1953
Appendicisporites unicus (Markova 1961) Singh 1964
Cicatricosisporites perforatus (Baranov, Nemkova, Kondratiev 1957) Singh 1964
Concavissimisporites parkinii (Pocock 1962) Singh 1964
Concavissimisporites punctatus (Delcourt & Sprumont 1955) Singh 1964.
Impardecispora trioreticulosus (Cookson & Dettmann 1958) Venkatachala, Kar, & Razi 1968
Pilosisporites trichopapillosus (Thiergart 1949) Delcourt & Sprumont 1955
Pilosisporites verus Delcourt & Sprumont 1955
Trilobosporites apiverrucatus Couper 1958; now *Impardecispora apiverrucata* (Couper 1958) Venkatachala et al 1968
Trilobosporites canadensis Pocock 1962; now *Impardecispora canadensis* (Pocock 1962), Venkatachala et al. 1968
Trilobosporites hannonicus (Delcourt & Sprumont 1955) Potonié 1956

Based on the occurrence of *Impardecispora trioreticulosa* (early Barremian or Aptian; Singh, 1964; Burden, 1984) and *Tricolpites* spp. (Albian), and absence of *Appendicisporites* and more complex angiospermous pollen, the age of examined material from the Mannville Group of northcentral Saskatchewan is interpreted as early Barremian-early middle Albian in age.

The basis for this age determination is the presence of a low diversity and abundance of angiosperm pollen. The absence of *Appendicisporites* taxa, used by Singh (1964) as index taxa, is notable. Singh (1964) also used *Trilobosporites apiverrucata* (*I. apiverrucatus*) as a Group B index species for the Deville Member, McMurray Formation and *Trilobosporites* (*Impardecispora) trioreticulosus* as a Group A index species for the Ellerslie Member, McMurray Formation, both Aptian in age. These species of *Impardecispora* also occur in the Albian. Singh (1971) reports *T. apiverrucata* (*I. apiverrucatus*) in the Loon River Formation (middle Albian), Harmon, Cadotte, and Paddy members (middle to upper Albian) of the Peace River Formation, and the lower Shaftesbury Formation (upper Albian) of the Peace River area. *Trilobosporites apiverrucatus* also occurs in the Albian of Oklahoma (Hedlund & Norris, 1968), middle and late Albian of Colorado and Nebraska (Panella, 1966), the Wealden of England (Couper, 1958). *Impardecispora trioreticulosa* occurs in the early Barremian in western Canada. Burden (1984) examined in spores and pollen from the McMurray Formation (Mannville Group) of northeastern Alberta and correlated with palynomorphs of the Ellerslie and Calcareous members of central Alberta, and the lower part of the Kootenai Formation (Sunburst Member, Calcareous Member, of the McMurray Formation (Aptian), and an unnamed lignitic unit) near Great Falls, Montana. He recognizes three palynomorphs assemblage zones, in ascending order: the *Trilobosporites canadensis* -

Triporoletes incertus Assemblage-zone, of late Valanginian or Hauterivian age; the *Impardecispora trioreticulosa - Foraminisporis asymmetricus* Assemblage-zone, of Early Barremian age; and the *Retimonocolpites crassatus - Retimonocolpites peroreticulatus* Assemblage-zone, of late Barremian through earliest Albian age. Burden (1984) cautions that there is some diachronism in the deposits, and that strata may be slightly older in the south.

Playford (1971) examined the palynology of Early Cretaceous strata encountered in a borehole near Yorkton, southeastern Saskatchewan, and exposed to the northeast in the Swan River area, southwestern Manitoba. His analysis of Swan River Group material (that passes laterally into the Mannville Group) of Alberta and Saskatchewan, and then into the thick Blairmore Group of the foothills. He notes that an absence of angiospermous elements (e.g., *Retitricolpites, Tricolpites*) equates the strata he examined as being a Mannville Group equivalent (at least older than the Harmon Member of the Peace River Formation). The subsurface lower part of the Bredenbury No. 11-36 well (below 1353-1395 ft) he examined includes *Clavatipollenites rotundus* (probably synonym *Liliacidites dividuus*), which is unknown from pre-Albian strata (Kemp, 1968; Brenner, 1963; Hedlund, 1966; Hedlund & Norris, 1968). He also describes the presence of *Trilobosporites purverulentus*. These lower strata are given an early middle Albian age (older than the middle Albian Harmon Formation; but not pre-Albian in age) (Playford, 1971). In the upper Swan River sequence preserved in the Bredenbury well (1273-1345 ft), undisputed angiospermous elements, including *Retitricolpites* spp., *Tricolpites sagax*, and *Fraxinopollenties venusus*. occur with other taxa not present in the lower well section. These strata are interpreted to be later middle Albian in age (Playford, 1971). *Pilosisporites trichopapillous* occurs with this assemblage, and Playford (1971) notes that its youngest documented occurrence is upper middle Albian (Cadotte Member, Peace River Formation) in Alberta (Singh, 1971). Thus, its occurrence in the herein examined Mannville Group is also indicative of an Albian or older age.

In central Canada, the first appearance of dicotyledonous angiosperm pollen, that includes the tricolpate *Tricolpites* preserved in the Mannville Group material herein examined, occurs in middle Albian strata (Norris 1967; Playford 1971; Singh 1971; Brideaux & McIntyre 1975; Leckie & Burden 2001). Dicotyledonous angiosperm pollen also first appears by the middle Albian in the USA (Brenner, 1963; Panella, 1966; Hedlund & Norris, 1968), central Russia (Bolkhovitina, 1953), England (Kemp, 1968), Portugal (Groot & Groot, 1962; Hochuli et al., 2006), and New Zealand (Couper, 1960). After their initial appearance, dicotyledonous angiosperm pollen rapidly diversified during the late Albian and Cenomanian in Alberta (Singh, 1971; Leckie & Burden, 2001) and the USA (Brenner, 1967; Spicer & Parrish, 1986; Ward, 1986). In terrestrial rocks of south-western Alberta, Leckie & Burden (2001) found the earliest tricolpate pollen to occur in the early middle Albian and by the late middle to early late Albian, up to 23 species of 8 genera of tricolpate pollen and 1 genus of tricolporoidate pollen were present. Similarly, Singh (1971) documented 22 species of 7 genera of tricolpate angiosperm pollen and 1 genus (and 1 species) of tricolporate pollen in Upper Albian marine rocks in north-western Alberta; by the Cenomanian, a high diversity of dicotyledonous angiosperm pollen including tricolpate (4 genera, 20 species), stephanocolpate (1 genera, 2 species) and tricolporoidate, tricolporate and triporate (5 genera, 14 species) types were present in both marine and non-marine rocks from Alberta. Further south, in the Albian Kiowa and Cheyenne formations of Kansas, Ward (1986) documented 8 genera of tri(poly)colpate pollen that incorporate c. 40 species and 5 genera of tricolporoidate and

tricolporate forms representing 16 species. By the late Albian and Cenomanian in North America, Tricolporoidate and tricolporate pollen are common (Pierce, 1961; Brenner, 1963; Ward, 1986; Singh, 1971; Ravn, 1995; Ravn & Witzke, 1995; Leckie & Burden, 2001), but are absent from Upper Albian–Cenomanian strata in the Canadian High Arctic (Burden & Langille, 1991; Galloway et al., 2012), possibly due to barriers to migration or climate (Galloway et al., 2012). Interestingly, porate pollen types are also absent from radiometrically dated middle Cenomanian rocks of north-eastern British Columbia where a restricted angiosperm assemblage consisting mainly of *Tricolpites* sp. is present (Sweet in Bassett & Kleinspehn, 1997). So, while atypical, depauperate angiosperm pollen assemblages can persist into the middle Cretaceous.

ACKNOWLEDGEMENTS

We thank Russ Harms of Global GeoLabs Ltd. for preparing the material and we thank Jennifer McQuarrie (GSC-Calgary) for input of sample data into the Sample Management Systems database. We thank Dr. Manuel Bringué for his translation from the original French of Delcourt and Sprumont (1955) to English. We thank Leah Robert and Kees Carrier for their assistance in the field. We are grateful to Dr. Rob Fensome of the Geological Survey of Canada, Atlantic, for his internal peer review of this Open File.

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