

PALYNOMORPHS AND SELECTED MESOFOSSILS FROM THE CRETACEOUS
DAKOTA FORMATION, MINNESOTA, USA

By

SHUSHENG HU

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By

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To Yuxian, David, Mark, and my parents.

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Abstract of Dissertation Presented to the Graduate School
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By

Shusheng Hu

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The middle Cenomanian palynomorphs and selected mesofossils from the Dakota Formation of south central Minnesota were investigated. A total of 218 palynomorphs were recovered. Terrestrial palynomorphs include 41 types of angiosperm pollen in which five types are described as new species, 42 types of gymnosperm pollen, and 78 types of spores of ferns and fern allies. Spores of ferns and fern allies are most diverse among the terrestrial palynomorphs. Other palynomorphs include two types of megaspores, ten types of algal spores and colonies, seven types of fungal spores and fruiting body, 18 types of dinoflagellate cysts, and 20 types of acritarchs. Based upon the occurrence of *Artiopollis indivisus*, *Balmeisporites glenelgensis*, *Cicatricosisporites crassiterminatus*, *Dictyophyllidites impensus*, and *Nyssapollenites* sp., the age of the Cretaceous sediments exposed in south central Minnesota is probably middle Cenomanian. Based upon the analysis of angiosperm pollen morphological characters, the pollen types that appear to be insect-pollinated accounted for 77% on average, and the

pollen types which appear to be wind-pollinated accounted for 23% on average during the middle Cenomanian. The characteristic vegetation elements of the coastal swamps during middle Cenomanian were diverse angiosperms, dominant ferns and fern allies, and a relative low abundance of gymnosperms. The Trochodendrales and Buxales of the eudicots, which were not recovered from leaf fossil records, probably were present during the middle Cenomanian based upon the angiosperm pollen records. Two new marattioid ferns, *Goolangia minnesotensis* Hu, Dilcher, H. Schneid. et Jarzen gen. et sp. nov. and *Mesozoisynangia trilobus* Hu, Dilcher, H. Schneid. et Jarzen gen. et sp. nov., are described based on charcoalfied isolated sporangia and synangia. These fossils provide evidence for the existence of marattioid ferns during the mid-Cretaceous in North America and give the first unequivocal documentation of the Marattiaceae in post Jurassic times. Spores of *Goolangia minnesotensis* are comparable with the dispersed spore *Dictyophyllidites impensus*, which was distributed from Arizona to Alberta in west central North America during the middle Cenomanian.

CHAPTER 1 INTRODUCTION

The mid-Cretaceous was a critical period in the evolution of angiosperms. During this time, angiosperms began their adaptive radiation, and major lineages first appear (Upchurch and Dilcher, 1990; Dilcher, 2000). It has been suggested that early angiosperms diversified and became dominant along river channels during the mid-Cretaceous (Retallack and Dilcher, 1981; Wing and Boucher, 1998). Retallack and Dilcher (1981) further hypothesized that disturbed coastal areas were very important sites for early angiosperm worldwide dispersal. But as far as we know the data about early angiosperms in coastal areas during the mid-Cretaceous are very limited (Retallack and Dilcher, 1981) because of poor environmental interpretations and limited megafossil collections.

During the past 30 years early angiosperm pollination biology has been understood substantially through the studies on numerous Cretaceous fossil flowers (Dilcher et al., 1976; Dilcher 1979; Crepet, 1979; Friis and Skarby, 1981; Dilcher and Crane, 1984; Crane and Dilcher, 1984; Crane, et al., 1986; Drinnan, et al., 1990; Friis, et al., 1999, 2000a, 2000b; Dilcher, 2001). It was a widely accepted hypothesis that the dominant angiosperm pollination modes were insect-pollination during the early Cretaceous (Crepet and Friis, 1987; Friis et al., 1999; Field and Arens, 2005; Wing and Boucher, 1998). Dilcher (1979), on the other hand, presents evidence to support the presence of limited wind pollination by mid-Cretaceous time. Dilcher (1979) also proposed the hypothesis that the independent lineages of some anemophilous flowers may have

developed very early and separately from entomophilous flowers from a common ancestral bisexual stock. Moreover, Dilcher (2000) suggested that wind pollination was also important for Cretaceous angiosperms in addition to insect pollination. More studies are needed to better understand the role of pollination in the evolution of early angiosperms. The palynological data may provide new information about the diversity of pollination profiles of angiosperms during the Cenomanian.

Research on plant megafossils deposited along the Western Interior Seaway began with Lesquereux (1895) who described 437 species of angiosperms. However, Upchurch and Dilcher (1990) and Wang H. (2002) found only 20-25 species of angiosperms at each of several localities and Wang H. (2002) estimated 150-200 total species of angiosperms when six localities are tallied together. It is important also to undertake a palynological investigation of these sediments in order to provide evidence for angiosperm diversity as recorded by pollen during the mid-Cretaceous.

Mesofossils often consist of charcoaled plant remains, which are mid-sized fossils between the larger megafossils and smaller microfossils. When plant tissues are charcoaled, delicate structures, such as anthers containing pollen (Crane and Herendeen, 1996) and sporangia containing spores, are often well preserved. Therefore mesofossils provide additional characters that allow comparisons to morphological features unique to reproductive structures of extant plants. This information complements the megafossil and microfossil record by providing information not otherwise available. Dispersed pollen or spores may be related to a taxon with known affinities. The geographic distribution of a parent plant may be determined based upon the distribution range of the dispersed pollen or spores. However, mesofossil

investigation is limited in Western Interior Seaway (X. Wang, 2004) and there is no previous mesofossil research for the Cretaceous sediments in south western Minnesota.

“Dakota Formation” is used as a lithostratigraphic unit across a vast area of central and west-central North America (Ravn and Witzke, 1995). This name has also often been used without consideration of the relationship to the type Dakota Formation, either lithostratigraphically or chronostratigraphically (Witzke et al., 1983). Thus the age and lithology of the Dakota Formation are probably not the same from the west margin to the east margin of the Western Interior Seaway. Currently, the age of the Dakota Formation in southwest Minnesota is thought to be Cenomanian (Setterholm, 1994). However, because of the absence of marine fossils, this suggestion for a Cenomanian age is mainly based upon the interpretation from the paleobotanical work of Lesquereux (1895) and the palynological studies of Pierce (1961). The paleofloras of Lesquereux (1895) and palynofloras of Pierce (1961) need reexamination and reinterpretation (Upchurch and Dilcher, 1990; Wang H., 2002; Hu et al., 2004b). Austin (1972) proposed that the nonmarine Cretaceous sediments in the Minnesota River Valley are about middle Cenomanian based upon clay mineralogy. Setterholm (1994) also proposed that the upper mudstone unit in east-central Minnesota of the Dakota Formation may be time equivalent to the Graneros Shale in western Minnesota, and both units are placed in the late Cenomanian. The age of the Dakota Formation in southwest Minnesota remains uncertain at this time.

Therefore investigations of ancient coastal deposits should provide new data about early angiosperms. Considering that pollen and spores are more broadly distributed than leaves and therefore provide a broader regional record than plant megafossils (Jaramillo,

1999), the palynological record may provide a view with a different bias for early angiosperm diversity. Mid-Cretaceous sediments, rich in pollen and spores exposed recently at Courtland Clay Pit, Highway 4 Clay Pit, and Ochs Clay Pit in southwestern Minnesota, provided an opportunity for a palynological investigation. The present study will focus on the following topics:

1. Establish a record of the palynomorphs recovered from a series of samples collected from freshly exposed sections.
2. Use the described palynofloras, correlate the sections from three isolated clay pits (Courtland Clay Pit, Highway 4 Clay Pit, and Ochs Clay Pit) where the sedimentary relationships are difficult to determine in the absence of marine megafossils.
3. Determine the age of the sediments that is currently controversial and in question based upon the palynomorphs recovered from samples of the clay pits.
4. Consider the role of insect pollination and wind pollination in the evolution of early angiosperms as inferred from palynological data. Possible pollination profiles of some early angiosperms during early Late Cretaceous will be presented.
5. Present early angiosperm diversity during early Late Cretaceous in coastal areas, especially coastal swamps, based upon palynological investigation.
6. Compare the megafossil (leaf) and microfossil (pollen) record of angiosperms to assess the role of microfossils in an analysis of early angiosperm diversity.
7. Use of mesofossils in order to understand fern taxa not previously known from the Cretaceous.

CHAPTER 2 MATERIAL AND METHODS

Three localities which are located in southwest Minnesota (Figure 2-1) — Courtland Clay Pit (lat. 44°16'29" N, long. 94°23'13"W) (Plate 1, Figs. 1-2; Plate 2, Figs. 1-2), Highway 4 Clay Pit (lat. 44°26'05" N, long. 94°43'37"W) (Plate 5, Figs. 1-2) and Ochs Clay pit (lat. 44°13'26" N, long. 95°00'42"W) (Plate 3, Figs. 1-2; Plate 4, Figs. 1-2) are investigated in this research. I undertook my field work in the summer of 2003 (May 23-May 29) and the summer of 2004 (June 3-June 12). Five stratigraphic sections were measured. Pollen samples were collected vertically at about 30 centimeter intervals from each of the sections sampled. At the Courtland Clay Pit 23 samples were collected, nine samples were processed and eight samples had abundant palynomorphs. At Highway 4 Clay Pit, 12 samples were collected, eight samples were processed, and three samples had abundant palynomorphs. At Ochs Clay Pit 27 samples were collected, eight samples were processed, and seven samples have abundant palynomorphs.

The Canada Global Geolab processed 4 samples (sample 18297, 036690, 036708, and 036710) from Courtland Clay Pit in 2003 (see Appendix A for the processing methods used by Canada Global Geolab). I processed all of the other samples that I studied in this research myself in the chemical lab of the Paleobotany and Palynology Laboratory of the Florida Museum of Natural History during the summers of 2004 and 2005. In order to avoid any bias caused by the different processing methods, I have also reprocessed all those samples originally processed by Canada Global Geolab (except for sample Courtland 18297).



Figure 2-1. Map of Minnesota, showing three localities in study area.(Scale 1:7,500,000)

Processing methods for siliciclastic and lignite samples are described below.

Siliciclastic samples:

1. Crush a 10 g sample using a mortar and pestle.
2. Sieve a crushed sample using a tea strainer until the entire sample is sieved.
3. Put the crushed sample into a 1000 ml glass beaker and gradually add 25% HCL acid. If the reaction is too strong, add several drops of alcohol. Add enough of the 25% HCL acid to fill half of the beaker. At the same time, stir gently with a glass rod.
4. Cover the beaker with a Petri dish.
5. Wait about 2 hours until the sample has settled and all effervescence has ceased.
6. Pour the waste acid out and wash with distilled water until the slurry is neutral.
7. Transfer the sample into a 600 ml plastic beaker and slowly pour 100 ml of 49% HF acid into the slurry while stirring. Exercise caution when using HF.
8. After 6 hours, dump the waste acid and add 100 ml of 49% HF acid.
9. Wait for at least 3 days while stirring occasionally.

10. Dump the waste acid and wash the sample using distilled water until the slurry is neutral.
11. Transfer the slurry into a 50 ml glass tube.
12. Add enough 25% HCL acid into the tube to fill half of the tube.
13. Put the tube into a water bath (about 90°C) for about 5 minutes. At the same time stir the sample occasionally.
14. Repeat this procedure at least 3 times until the supernatant is clear.
15. Oxidize the sample using the following procedure: First, pour enough 10% nitric acid into the tube to fill half of the tube. Second, put the tube into a water bath for about 5 minutes while stirring occasionally. Third, check one drop under the microscope. If strong oxidation is needed, repeat the procedure using 50% nitric acid.
16. After the oxidation procedure, wash the sample 3 times using distilled water.
17. Pour enough 5% ammonium hydroxide to fill half of the tube.
18. Wait about 5 minutes while stirring occasionally.
19. Check one drop under the microscope.
20. Wash with distilled water at least 3 times or until the supernatant is clear.
21. If the slurry is gritty, pour enough zinc chloride heavy liquid (specific gravity about 2.0) to fill half of the tube.
22. Centrifuge the sample for 30 to 40 minutes at 2000 rpm.
23. Pour out the top part of the mixture (heavy liquid and organic residue) into a 250 ml beaker and dilute with distilled water.
24. Centrifuge for the mixture for 10 minutes at 2000 rpm.
25. Wash and centrifuge the residue for 10 minutes at 2000 rpm at least 3 times.
26. If the residue is full of fine organic particles, add 10 ml of Darvan #1 solution and 20 ml of distilled water, stirring thoroughly.
27. Centrifuge for 1 minute under about at 1500 rpm.

28. Dump the supernatant and repeat the previous step and this step until the supernatant is clear. If the palynomorphs are present in the supernatant, stop processing and keep the supernatant.
29. If using acetolysis, first wash with glacial acetic acid. Second, pour enough acetolysis mixture to fill half of the tube and put it into a hot bath (90 °C) for 3 minutes. Third, wash with glacial acetic acid. Fourth, wash with distilled water 3 times. If staining with Safranin-O, first pour distilled water and one or two drops of HCL and Safranin-O into the tube and stir. Second, wash with distilled water 3 times.
30. After acetolysis or staining, wash the sample using 50% glycerin.
31. Centrifuge for 10 minutes.
32. Place the tube upside down for at least half hour. The residual material is ready for making slides.

Lignite samples:

1. Crush 2 g of lignite using a mortar and pestle.
2. Sieve the crushed sample using a tea strainer to sieve until the entire sample is sieved.
3. Mix the crushed and sieved sample with 2 g of potassium chlorate in a 50 ml glass tube.
4. Add 5 cc of concentrated nitric acid drop by drop into the tube.
5. Wait for several hours and check if the palynomorphs are visible.
6. Centrifuge and decant the supernatant.
7. Add 5% KOH and place into a water bath (90°C) for 3-5 minutes. At the same time checking frequently the condition of the palynomorphs.
8. Centrifuge and wash 3 times.
9. If the palynomorphs are not well concentrated, use heavy liquid to process the sample using the same procedure used to concentrate the siliciclastic rock sample.
10. If the palynomorphs are not transparent enough, add 10% nitric acid to the sample and place it into a water bath (90°C) for 3 minutes.

11. Use the same procedures (ammonium hydroxide, Darvan #1, 1% Safranin-O staining and acetolysis) used to process the silicified rock samples.

The procedures for slide preparation follows:

1. Thoroughly mix a small amount of glycerol gelatin with the residue.
2. Put one drop onto a microscope slide (size: 3 x 1 x 1mm).
3. Cover the sample with a number 1 cover glass (size: 22 x 30 x 1).
4. Place the slide on a warming table to make sure the residue spreads evenly.
5. Prepare at least 3 slides for each sample.
6. Label slides as soon as possible to avoid loss of data.

At least two slides were scanned in order to build a catalogue of pollen and spore types for each sample. When making pollen count, at least 300 palynomorphs were counted. A ZEISS Axiophot™ microscope and an AxioCam digital camera and imaging capturing software were used for the palynomorph identification and photography. Slides are stored in the Paleobotany and Palynology Collection of the Florida Museum of Natural History, Gainesville, Florida, USA.

Pollen and spore identification were made through comparisons with images and descriptions in published papers and the holotype materials of Hedlund, Richard .W. which are deposited in the Sam Noble Oklahoma Museum of Natural History. Published papers on the Western Interior Seaway, Atlantic Coastal Plain and Gulf Coast were used as primary reference sources for palynomorph identification (Bergad, 1973; Brenner, 1963, 1967; Burden and Hills, 1989; Hedlund, 1966; Norris, 1967; Phillips and Felix, 1972a, 1972b; Pierce, 1961; Ravn and Witzki, 1995; Singh, 1964, 1971, 1983; Srivastava, 1992; Tschudy, 1973; Ward, 1986). Other papers also included in this work from similar age sediments from other parts of the world include Below, 1984; Couper,

1953; Davey, 1969, 1970; Dettmann, 1963, 1973; Jarzen, 1979; Srivastava, 1975; Zippi, 1998.

Methods used for the mesofossils that were isolated from organic rich clay samples are given in Chapter 9.

CHAPTER 3 PREVIOUS WORK

Along the eastern margin of the Western Interior Seaway (WIS), Pierce described 103 species of spores and pollen which he recovered from the lowermost upper Cretaceous of Minnesota (Pierce, 1961). He did not consider the sedimentary facies. Farley and Dilcher (1986) undertook research concerning the relationships between miospores and depositional environments of the Dakota Formation from north-central Kansas and adjacent Nebraska. They chose four different sedimentary facies from three localities. They presented the pollen and spore flora found, but did not consider the vegetation succession through time. Ravn (1981) made preliminary observations of the palynology of the Upper Dakota Formation lignites in northwestern Iowa and northeastern Nebraska and described 125 palynomorph species. Later Ravn and Witzke (1995) published their palynostratigraphic research of the Dakota Formation from the same area, focusing on biostratigraphy.

On the western margin of the WIS, May and Traverse (1973) undertook the palynological investigation of the Dakota Formation in Willis Creek Canyon, Paunsaugunt Plateau, near Bryce Canyon, Utah. About 40 genera and 125 species of palynomorphs were identified. Although these authors mentioned the sedimentary environments in their abstract, detailed discussion and identification of the sedimentary environments were not presented in their paper. Therefore it is not possible to correlate any relationship between palynomorphs and the sedimentary environments.

Agasie (1969) studied palynomorphs from the middle carbonaceous member of the Dakota Sandstone in northeastern Arizona. About 39 species of palynomorphs were recovered. Fern spores dominated the assemblage, while gymnosperm pollen was rare. Agasie indicated that ferns and angiosperms probably dominated the coal swamps with minor gymnosperm presence. In the same way, Romans (1975) studied the palynomorphs recovered from coal seams of the Dakota Sandstone in Black Mesa, Arizona. There were 62 pollen and spore species in the Dakota Sandstone. Fern spores dominated the assemblage with angiosperm pollen being the least abundant in the assemblage. Moreover, Romans (1975) did not give any specific placement of the coal-forming swamp on the Dakota landscape and its sedimentary environments. Hedlund (1966) studied the palynology of the Red Branch Member of the Woodbine Formation (Dakota equivalent), in Oklahoma. He reported 74 forms of spores and pollen grains in the Red Branch palynological assemblage. Fern spores and angiosperm pollen dominate the assemblage. Hedlund noted that the sedimentary environment was probably non-marine because of the absence of marine palynomorphs.

Cretaceous palynomorphs from Atlantic Coastal Plain were very important for this research. Brenner (1963) investigated the palynomorphs of the Potomac Group identifying about 125 palynomorph taxa. Two major zones were divided based upon palynological characteristics. Later, Doyle and Robbins (1977) undertook further palynological research in the Atlantic Coastal Plain and suggested five major zones based upon the changes observed in the assemblages of angiosperm pollen through the reconstructed section.

CHAPTER 4
SYSTEMATIC PALEONTOLOGY

Angiosperm Pollen

Anteturma **POLLENITES** Potonie 1931

Turma **PLICATES** Naumova emend. Potonie, 1960

Subturma **MONOCOLPATES** Iversen & Troels-Smith, 1950

Genus *Clavatipollenites* Couper, 1958

Type species: *Clavatipollenites hughesii* Couper, 1958.

Clavatipollenites tenellis Phillips & Felix 1972

Plate 6, Figs. 1-3

Pollen grains free, monosulcate; circular to subcircular; exine 2.5 μm , two layered, nexine about 1 μm , sexine coarse columellae, pila with a big head (about 0.5 μm in diameter), pila head link together; reticulate, lumina ca. 1 μm in diameter, irregular.

Dimensions: 28 μm (1 grain).

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Distribution: Albian, Louisiana (Phillips and Felix 1972b); Albian and Cenomanian, Atlantic Coastal Plain, USA (Doyle and Robbins 1977); and Cenomanian, northwestern Alberta (Singh 1983).

Clavatipollenites sp.2

Plate 6, Figs. 4-6

Pollen grains free, monosulcate; circular to subcircular; exine 1 μm , two layered, sexine columellate, pila dense, pila head link together; microreticulate, lumina less than 0.5 μm in diameter.

Dimensions: 20(24)28 μm (2 grains).

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

? *Clavatipollenites* sp.3

Plate 6, Figs. 7-9

Pollen grains free, monosulcate; circular to subcircular; sulcus narrow, often split into two halves; exine 2 μm , two layered, sexine columellate, pila dense, pila head not developed; granulate to microfoveolate.

Dimensions: 24(27)29 μm (4 grains).

Occurrence: Ochs Clay Pit.

Genus *Liliacidites* Couper, 1953

Type species: *Liliacidites kaitangataensis* Couper, 1953.

Liliacidites sinuatus Hu, sp. nov.

Plate 6, Figs. 10-13

Pollen grains free, monosulcate; elliptical, sulcus wide; exine 2 μm , two layered, sexine columellate, pila rare and thick, ca. 1 wide; reticulate, lumina ca. 4-7 μm in diameter, elongate to irregular, muri sinuous, ca. 0.6 μm wide.

Dimensions: 18(22)25 x 33(34)34 μm (2 grains)**Holotype:** 046535-PY02A, Y39/1

Remarks: This species is distinct from other species of *Liliacidites* by its sinuous muri and relatively large lumina. *Liliacidites crassatus* differs in having smaller lumina (1 to 2.5 μm).

Occurrence: Ochs Clay Pit

Name derivation: The species name *sinuatus* from the Latin sinuous, meaning full of bendings.

Liliacidites giganteus Singh 1983

Plate 6, Fig. 14

Pollen grains free, monosulcate; elliptical, sulcus not clear; exine 2.5 μm , two layered, sexine columellate, pila head fused together by membrane; reticulate, lumina ca. 1-6 μm in diameter, polygonal, muri ca. 1.2 μm wide, with a single row of granules on the muri surface.

Dimensions: 48 x 76 μm (1 grain)

Remarks: There are two rows of granules on the muri for the holotype (Singh 1983).

Occurrence: Courtland Clay Pit.**Distribution:** Cenomanian, northwestern Alberta (Singh 1983).*Liliacidites cf. reticulatus* (Brenner) Singh 1971

Plate 6, Figs. 15-19; Plate 7, Figs. 1, 2

Pollen grains free, monosulcate; elliptical, sulcus narrow and long, reaching to margin; exine 2 μm , two layered, sexine columellate, pila ca. 1.5 μm high, pila fused together by membrane; reticulate, lumina ca. 1-2 μm in diameter, polygonal, muri ca. 0.5 μm .

Dimensions: 19(20)23 x 22(24)28 μm (5 grains)

Remarks: Compared with the holotype described by Brenner (1963), the lumina are smaller, muri are narrower, and grain size is slightly bigger for this species.

Occurrence: Ochs Clay Pit, Courtland Clay Pit and Highway 4 Clay Pit.

Distribution: Barremian to Albian, Maryland (Brenner 1963); Albian, Oklahoma (Hedlund and Norris 1968); and middle to late Albian, northwestern Alberta (Singh 1971).

Liliacidites cf. inaequalis Singh 1971

Plate 7, Figs. 3, 4

Pollen grains free, monosulcate; sulcus wide open; exine 1-2 μm , two layered, sexine columellate, nexine less than 0.5 μm ; reticulate, lumina ca. 2-3 μm in diameter, polygonal, lumina size decreasing toward poles, there are granules on the muri.

Dimensions: 15 (16) 18 x 22 (24) 26 μm (3 grains)

Remarks: The lumina are 3 to 6 μm in the middle region for the holotype of *L. inaequalis* (Singh 1971). Also the size of *L. inaequalis* is larger than this species.

Occurrence: Highway 4 Clay Pit.

***Liliacidites* sp.2**

Plate 7, Figs. 5-7

Pollen grains free, monosulcate; sulcus wide open; exine 1 μm , two layered, sexine columellate, pila rare, not clear; reticulate, lumina ca. 1-4 μm in diameter, size uneven, polygonal, muri width even, ca. 0.5 μm wide.

Dimensions: 21 μm (1 grain)

Remarks: It differs from *Liliacidites* sp.3 in its thinner exine and absence of the small fovea on the muri. It differs from *Liliacidites* sp.5 in its smaller lumina and thinner exine.

Occurrence: Ochs Clay Pit.

***Liliacidites* sp.3**

Plate 7, Figs. 8-10

Pollen grains free, monosulcate; elliptical, sulcus wide open; exine 2 μm , two layered, sexine columellate, pila rare and thick, ca. 0.5 μm wide; reticulate, lumina ca. 0.5-4 μm in diameter, elliptical to round to polygonal, muri with occasional small fovea.

Dimensions: 15(21)31 x 19(30)43 μm (11 grains)

Remarks: It is distinct from other species of *Liliacidites* in its small fovea on the muri. *Liliacidites* sp.3 is similar to *in situ* pollen of early or middle Albian well-preserved flower *Virginianthus calycanthoides* from the Puddledock locality, Virginia (Friis et al., 1994) in shape, aperture, and ornamentation. Friis et al. (1994) suggested that these *in situ* pollen grains are similar to *Clavatipollenites*. However the typical features of *Clavatipollenites* such as lumina size 1 μm or less and closely spaced pilate columellae (Burden and Hills, 1989) were absent on these *in situ* pollen grains which possess sparse and short columellae (Friis et al., 1994). The only difference is that *Liliacidites* sp.3 (which is 21 x 30 μm) is larger than *in situ* pollen of *Virginianthus calycanthoides* (which is 18 μm in diameter).

Occurrence: Ochs Clay Pit

***Liliacidites* sp.4**

Plate 7, Figs. 11-13

Pollen grains free, monosulcate; circular to subcircular, sulcus not clear; exine 1.5-2.5 μm , two layered, nexine thicker than sexine, sexine columellate, short pila with big pila head (ca. 0.5 μm in diameter); reticulate, lumina ca. 0.5-2 μm in diameter, polygonal, muri ca. 0.5 μm wide, with granules on it.

Dimensions: 29(37)48 μm (9 grains)

Remarks: It is very similar to *Retimonocolpites reticulatus* Brenner, 1963. But its size (17-22 μm) is much smaller than *Liliacidites* sp.4. It also differs from other species in its circular shape and granules on the muri. Although there are granules on the muri of *Liliacidites* cf. *inaequalis*, except for its oval shape, its size and lumina are smaller than *Liliacidites* sp.4.

Occurrence: Ochs Clay Pit

***Liliacidites* sp.5**

Plate 8, Figs. 1-3

Pollen grains free, monosulcate; circular to subcircular, sulcus narrow; exine 2 μm , two layered, sexine columellate, pila rare; reticulate, lumina ca. 1-7 μm in diameter, polygonal to ovate, there are small granules on muri.

Dimensions: 20 (23) 25 x 23 (24) 25 μm (2 grains)

Remarks: Although there are granules on the muri of *Liliacidites* cf. *inaequalis* and *Liliacidites* sp.4, the large lumina of *Liliacidites* sp.5 can differentiate from them. It differs from others in this study in its larger lumina and granules on the muri.

Occurrence: Highway 4 Clay Pit.

Genus *Retimonocolpites* Pierce, 1961

Type species: *Retimonocolpites dividuus* Pierce, 1961.

***Retimonocolpites dividuus* Pierce 1961**

Plate 8, Fig. 4

Pollen grains free, monosulcate; amb circular to subcircular, colpi long and straight, somewhat raised; exine 1.5 μm , two layered, nexine about 1 μm , sexine columellate, pila short about 0.5 μm high; reticulate, lumina 0.5-1.5 μm in diameter, polygonal.

Dimensions: 32(35)38 μm (2 grains).

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Distribution: Albian to Cenomanian, North America and Europe (Ravn and Witzke, 1995).

Genus *Spinizonocolpites* Muller, 1968

Type species: *Spinizonocolpites echinatus* Muller, 1968.

? *Spinizonocolpites* sp.

Plate 8, Figs. 5, 6

Pollen grains free, with encircling colpus (?); subcircular to elliptical, sulcus not clear; exine 1 μm , two layered not clear; scabrate, with short spines (ca. 3 μm).

Dimensions: 25 μm (1 grain).

Remarks: This pollen type has often been compared with extant *Nypa fruticans* of the Palmae (Germeraad et al., 1968).

Occurrence: Courtland Clay Pit.

Genus *Stellatopollis* Doyle, 1975

Type species: *Stellatopollis barghoornii* Doyle, 1975.

***Stellatopollis largissimus* Singh 1983**

Plate 8, Fig.7

Pollen grains free, monosulcate; elliptical, sulcus long and extending nearly the full length of the grain; exine 4 μm , two layered, sexine columellate; reticulate, each lumen surrounded by 4-8 clavate projections, the projection ca. 3 μm high, the head of

projection ca. 1.5 μm in diameter, subtriangular, the head of projections form a crotonoid sculptural pattern in surface view.

Dimensions: 64 x 123 μm (1 grain).

Occurrence: Courtland Clay Pit.

Distribution: Cenomanian, northwestern Alberta (Singh 1983).

***Stellatopollis* sp.**

Plate 8, Fig. 8

Pollen grains free, monosulcate; elliptical, sulcus not clear in this single occurrence; exine 1 μm , two layered, sexine columellate, pila very short; reticulate, lumina ca. 1-1.5 μm , forming an indistinct crotonoid sculptural pattern.

Dimensions: 38 x 53 μm (1 grain).

Remarks: This grain differs from *Stellatopollis largissimus* Singh 1983 in its smaller size and indistinct crotonoid sculptural pattern.

Occurrence: Courtland Clay Pit.

Genus *Doyleipollenites* Ravn & Witzke, 1995

Type species: *Doyleipollenites robbinsiae* Ravn & Witzke, 1995

***Doyleipollenites robbinsiae* Ravn & Witzke, 1995**

Plate 8, Figs. 9-11

Pollen grains free, trichotomosulate; subtriangular, rays of sulcus extending to $\frac{3}{4}$ or entire of the radius and thickened; exine 1.5 μm , two layered, sexine ca. 1 μm ; foveolate to reticulate, lumina uneven, ca. 0.5-1 μm , lumina are larger in interradian areas (ca. 1 μm) and decrease near the sulcus (ca. 0.5 μm).

Dimensions: 22(27)34 μm (7 grains)

Remarks: The lumina are smaller than the holotype (which is 1-3 μm).

Doyleipollenites robbinsiae is similar to *in situ* pollen associated with Early or Middle Albian fruiting units *Anacostia virginensis* from the Puddledock locality, Virginia (Friis et al., 1997) in shape, aperture, and ornamentation. Only difference between them is that *Doyleipollenites robbinsiae*, with a diameter of 22(27)34 μm , is larger than *in situ* pollen on a fruiting units *Anacostia virginensis*, which is 12(13)15 μm in diameter.

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Distribution: ?upper Albian, Atlantic Coastal Plain, United States (Doyle 1973); ?middle Albian to ?lower Cenomanian, Atlantic Coastal Plain, United States (Doyle and Robbins 1977); ?lower to upper Cenomanian, northwestern Iowa and northeastern Nebraska (Ravn and Witzke 1995).

Turma **JUGATES** Erdtman, 1943

Subturma **TETRADITES** Cookson, 1947

Genus *Artiopollis* Agasie, 1969, emend.

Type species: *Artiopollis indivisus* Agasie, 1969.

***Artiopollis indivisus* Agasie, 1969**

Plate 8, Fig. 12; Plate 9, Figs. 1-7

Pollen in tetrads, following Fisher's law; pollen grain tricolpate, isopolar; amb circular to subcircular; exine ca. 2 μm , two layered, sexine columellate, with dense pila; microreticulate, lumina about 0.5 μm in diameter.

Dimensions: For entire tetrad 17(23)31 μm (10 tetrads); for individual pollen grain 9(15)19 μm (9 grains).

Occurrence: Ochs Clay pit.

Remarks: The exine of specimens recovered from Ochs Clay Pit is somewhat thinner (2 μm) than that of the holotype (2.5 to 3 μm).

Subturma **TRIPTYCHA** Naumova, 1939

Genus *Cupuliferoidaepollenites* Potonie, Thomson, & Thiergart, 1950

Type species: *Cupuliferoidaepollenites liblarensis* Thomson in Potonie, Thomson, & Thiergart, 1950.

***Cupuliferoidaepollenites* sp.**

Plate 10, Figs. 4-7

Pollen grains free, isopolar; subprolate, prolate to perprolate (P/E=1.25-2.38), amb circular to subcircular; tricolpate, colpi nearly extending to the poles, somewhat raised, apocolpia small; exine thin, ca. 0.6-1 μm , two layered, nexine very thin, sexine scabrate.

Dimensions: equatorial view 7(11)17 μm x 10(16)25 μm (10 grains); polar view 12(16)22 μm (5 grains).

Remarks: This species may be similar to *Psilatricolpites psilatus*, Pierce, 1961. It differs from *P. psilatus* (21 x 29 μm) in being smaller.

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Genus *Foveotricolpites* Pierce, 1961

Type species: *Foveotricolpites sphaeroides* Pierce, 1961.

***Foveotricolpites* sp.**

Plate 10, Figs. 8-10

Pollen grains free, isopolar; subprolate (P/E=1.14-1.2), amb circular to subcircular; tricolpate, colpi nearly extending to the poles, not straight, apocolpia small; exine ca. 1.5 μm , two layered, sexine foveolate, fovea irregular to elongate, 0.5-1.5 μm , fovea becoming smaller and fewer toward colpi and poles.

Dimensions: equatorial view 30(33)35 x 36(38)40 μm (2 grains); polar view 30 μm (1 grain).

Remarks: This species may be similar to *Foveotricolpites concinnus*, Singh, 1971. But fovea are angular and equidimensional to occasionally elongated (1-2 μm) in *F. concinnus*. Also, fovea size is relatively constant toward colpi and poles in *F. concinnus*. This species is distinct from *Foveotricolpites sphaeroides* in its larger size and the unthickened aperture margin.

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Genus *Fraxinoipollenites* Potonie 1951 ex Potonie 1960

Type species: *Fraxinoipollenites pudicus* (Potonie) Potonie 1951

Fraxinoipollenites constrictus (Pierce) Chlonova, 1976

Plate 10, Figs. 11-15

Pollen grains free, isopolar; prolate (P/E=1.37-1.94), amb circular to subtriangular, tricolpate, colpi nearly extending to the poles, ragged, apocolpia small; exine 1.5µm, two layered, nexine thinner than sexine, sexine columellate; sexine microfoveolate, fovea less than 0.5 µm and faint.

Dimensions: equatorial view 18(24)34 x 28(38)48 µm (11 grains); polar view 30(35)38 µm (5 grains).

Remarks: *Fraxinoipollenites constrictus* was described as “sculpture of small, close-spaced baculae” (Pierce 1961). Singh (1983) indicated that it is microfoveolate.

Occurrence: Highway 4 Clay Pit and Courtland Clay Pit and Ochs Clay Pit.

Distribution: ? Cenomanian, Minnesota (Pierce 1961); Cenomanian, Alberta (Singh 1983); and lower to middle Cenomanian, northwestern Iowa and northeastern Nebraska (Ravn and Witzke, 1995).

Genus ***Rousea*** Srivastava, 1969Type species: ***Rousea subtilis*** Srivastava, 1969.***Rousea cf. delicipollis*** Srivastava, 1975

Plate 10, Figs. 16-18

Pollen grains free, isopolar; prolate (P/E=1.64), tricolpate, apocolpia small; exine 0.8 µm, exine thickness decreasing toward colpi, two layered, sexine columellate, pila rare and short, but with thick pila head, ca. 0.5 µm wide; reticulate to foveolate, lumina 0.3-1.5 µm, irregular to elongate, lumina size decreasing toward colpi and poles.

Dimensions: equatorial view 14 x 23 µm (1 grain), polar view 16(23)35 µm (7 grains).

Remarks: The lumina are circular in *Rousea delicipollis*. But lumina are irregular to elongate in the specimens described here.

Occurrence: Highway 4 Clay Pit and Courtland Clay Pit.

Genus ***Satishia*** Ward, 1986Type species: ***Satishia glyceia*** Ward, 1986.***Satishia* sp.**

Plate 10, Figs. 19-20

Pollen grains free, isopolar; tricolpate, colpi ragged, apocolpia small; exine 1 µm, two layered not clear; sexine microreticulate, lumina 0.5-1 µm, lumina decreasing toward colpi not poles.

Dimensions: 28 µm (1 grain).

Remarks: It differs from *Rousea* in that the lumina of *Rousea* become finer toward the poles and toward the colpi margins. The type species *Satishia glyceia* Ward 1986 has larger (1.3-2.8 µm) lumina compared with specimen (lumina 0.5-1 µm) described here.

Occurrence: Courtland Clay Pit.

Genus ***Striatopollis*** Krutzsch, 1959Type species: ***Striatopollis sarstedtensis*** Krutzsch, 1959.

Striatopollis paraneus (Norris) Singh, 1971

Plate 11, Figs. 1-6

Pollen grains free, isopolar; subprolate (P/E=1.2), amb circular to subcircular; tricolpate, colpi nearly extending to the poles, apocolpia small; exine ca. 0.8 μm , two layered, nexine very thin; striato-reticulate, striate ridge ca. 0.3 μm wide, lumina equidimensional, ca. 0.3 μm in diameter, lumina arranged into rows between striae, striae closely spaced, ca. 0.3 μm apart.

Dimensions: equatorial view 15 x 18 μm (1 grain); polar view 21 μm (1 grain).

Remarks: *Striatopollis paraneus* is similar to *in situ* pollen of early Cenomanian inflorescence *Spanomera mauldinensis*, which was discovered at Mauldin Mountain locality of Maryland (Friis et al., 1991), in size, aperture, and the unique ornamentation. Drinnan et al. (1991) indicated that the *in situ* pollen grains of *Spanomera mauldinensis* were comparable to the dispersed pollen species *Striatopollis paraneus*.

Occurrence: Courtland Clay Pit.

Distribution: Middle and late Albian, central Alberta (Norris 1967); Albian, Oklahoma (Hedlund and Norris, 1968); and middle and late Albian, northwestern Alberta (Singh 1971), Cenomanian, Bathurst Islands, Northern Territory and Mornington Islands, Queensland, Australia (Dettmann 1973).

Genus ***Tricolpites*** Cookson ex Couper, 1953Type species: ***Tricolpites reticulatus*** Cookson, 1947.***Tricolpites labeonis*** Hu, sp. nov.

Plate 11, Figs. 7-15

Pollen grains free, isopolar; subprolate, prolate (P/E=1.21-2), amb circular to subcircular; tricolpate, colpi nearly extending to the poles, apocolpia small; exine thin, ca. 0.5 μm , two layered, sexine columellate, pila very short; microreticulate, lumina less than 0.5 μm . SEM studies have shown that there is an about 0.7 μm wide margin along the colpi on which the lumina are small (less than 0.1 μm in diameter) and rare or absent.

Dimensions: equatorial view 6(10)14 x 9(14)19 μm (14 grains); polar view 18 μm (1 grain).

Holotype: 046526-PY03A, Y37

Remarks: *Tricolpites labeonis* Hu is similar to *Tricolpites minutus* in size and ornamentation, but it is differentiated from *Tricolpites minutus* by its narrow margin along the colpi on which lumina are rare, tiny or absent. *Tricolpites labeonis* is also similar to *in situ* pollen of early to middle Albian flower *Aquia brookensis* from "Bank near Brooke" locality, Virginia, in shape, size, and ornamentation, especially the feature of lumina diminishing in size and becoming more scattered along the margin of colpi (Crane et al., 1993). The only difference is that the verrucate surface of colpi membrane for *in situ* pollen of *Aquia brookensis* is absent in *Tricolpites labeonis*.

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Name derivation: Species name *labeonis* is from Latin, meaning large lips.

Tricolpites nemejci Pacltova 1971

Plate 12, Figs. 1-3

Pollen grains free, isopolar; subprolate to perprolate (P/E=1.16-2.06), amb circular to subcircular, tricolpate, colpi nearly extending to the poles, apocolpia small; exine 1.5 μm , two layered, sexine columellate, with dense pila; microreticulate, lumina 0.2-0.6 μm in diameter, irregular, circular to elongate.

Dimensions: equatorial view 17(19)21 μm x 22(27)35 μm (10 grains); polar view 21(26)31 μm (4 grains).

Remarks: Compared with *Tricolpites* cf. *vulgaris*, this species has a thicker exine, dense pila, and small lumina.

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Distribution: Cenomanian, Czech Republic (Pacltova 1971); Lower Cenomanian, Atlantic Coastal Plain (Doyle and Robbins 1977); upper Albian, Kansas (Ward 1986); middle Cenomanian, northwestern Iowa and northeastern Nebraska (Ravn and Witzke 1995).

Tricolpites* cf. *vulgaris (Pierce) Srivastava, 1969

Plate 12, Figs. 4-7

Pollen grains free, isopolar; prolate (P/E=1.64), amb circular to subcircular; tricolpate, colpi nearly extending to the poles, apocolpia small; exine thin, ca. 1 μm , two layered, sexine columellate; sexine reticulate, lumina polygonal to elongate, 0.5-1 μm in diameter.

Dimensions: equatorial view 11(14)19 x 16(20)24 μm (5 grains).

Distribution: Courtland Clay Pit, Highway 4 Clay Pit and Ochs Clay Pit.

Tricolpate sp.4

Plate 12, Figs. 8-10

Pollen grains free, isopolar; subprolate to prolate (P/E=1.16-1.55), amb circular to subcircular, tricolpate, colpi nearly extending to the poles, apocolpia small; exine 1-2 μm , thickness uneven, two layered, sexine columellate, with few pila, pila head small, less than 0.5 μm in diameter; reticulate, lumina 0.5-5 μm in diameter, muri thin less than 0.5 μm in width.

Dimensions: equatorial view 11(15)18 x 17(21)24 μm (3 grains); polar view 15 μm (1 grain).

Remarks: This species can be differentiated from *Tricolpites cooksonae* in following features: 1. *T. cooksonae* has smaller lumina (0.4-1.8 μm). 2. *T. cooksonae* shows granules on muri.

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Tricolpate sp.7

Plate 12, Figs. 11-13

Pollen grains free, isopolar; amb circular to subcircular, tricolpate, colpi nearly extending to the poles, colpi edge slightly ragged, apocolpia small; exine ca. 1 μm , two layered, nexine very thin, less than 0.5 μm ; sexine microfoveolate, fovea less than 0.5 μm .

Dimensions: polar view 17(18)18 μm (2 grains).

Remarks: It differs from other tricolpate type species encountered in this research in its smaller size (18 μm), ragged colpi, and microfoveolate sexine.

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Tricolpate sp.8

Plate 12, Figs. 14-16

Pollen grains free, isopolar; amb triangular, tricolpate, colpi nearly extending to the poles, apocolpia small; exine thin, ca. 0.8 μm , two layered, nexine and sexine 0.4 μm each; sexine scabrate to faint granulate.

Dimensions: polar view 23(26)28 μm (2 grains).

Remarks: It differs from other tricolpate type species encountered in this research in its scabrate to faint granulate sexine.

Occurrence: Ochs Clay Pit.

Tricolpate sp.10

Plate 12, Figs. 17-19

Pollen grains free, isopolar; subprolate to prolate (P/E=1.2-1.89), amb circular to subcircular, tricolpate, colpi nearly extending to the poles, apocolpia small; exine 2.5 μm , two layered, sexine columellate, with dense pila; reticulate to foveolate, lumina 0.5-1 μm in diameter between colpi and less than 0.5 μm toward colpi, irregular, polygonal to elongate, muri relatively thick ca. 0.5 μm and with granules (ca. 0.3 μm) on it.

Dimensions: equatorial view 14(21)32 x 19(29)40 μm (9 grains); polar view 46 μm (1 grain).

Remarks: It differs from other tricolpate type species in this research in its larger size (21 x 29 μm) and thick muri with granules on it.

Occurrence: Ochs Clay Pit.

Tricolpate sp.11

Plate 12, Figs. 20-22

Pollen grains free, isopolar; subprolate (P/E=1.27-1.33), amb circular to subcircular, tricolpate, colpi nearly extending to the poles, apocolpia small; exine 0.8-1 μm , two layered, sexine columellate, with short pila; microreticulate to microfoveolate, lumina uneven, 0.2-0.8 μm in diameter, lumina size decreasing toward colpi and poles.

Dimensions: equatorial view 11(12)12 x 14(15)16 μm (2 grains); polar view 11(13)14 μm (2 grains).

Remarks: It differs from other tricolpate type species in this research in its smaller size (13 μm), microreticulate to microfoveolate, and lumina decreasing toward colpi and poles.

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Tricolpate sp.12

Plate 13, Figs. 1-3

Pollen grains free, isopolar; subprolate (P/E=1.15-1.22), amb circular to subcircular, tricolpate, colpi nearly extending to the poles, apocolpia small; exine 1 μm , two layered, sexine columellate, rare pila, with thick pila head (ca. 0.5 μm), reticulate, lumina uneven, 0.5-1.5 μm in diameter, irregular, muri narrow, ca. 0.2 μm wide.

Dimensions: equatorial view 13(16)18 μm x 15(19)22 μm (2 grains); polar view 14 μm (1 grain).

Remarks: It differs from other tricolpate type species in this research in its reticulate with uneven lumina (0.5-1.5 μm), and thick pila head (ca. 0.5 μm).

Occurrence: Ochs Clay Pit.

Tricolpate sp.14

Plate 13, Figs. 4-6

Pollen grains free, isopolar, prolate (P/E=1.46-1.67), tricolpate, colpi straight and nearly extending to the poles, apocolpia small; exine 1 μm , two layered, sexine columellate, pila not perpendicular to nexine; microfoveolate, fovea less than 0.5 μm in diameter.

Dimensions: equatorial view 9(11)13 μm x 15(18)20 μm (3 grains).

Remarks: It differs from other tricolpate type species in this research in its smaller size (11 x 18 μm), straight colpi, and tilted pila.

Occurrence: Ochs Clay Pit.

Subturma **PTYCHOTRIPORINES** Naumova, 1939

Genus *Dryadopollis* Srivastava, 1975

Type species: *Dryadopollis argus* Srivastava, 1975.

Dryadopollis minnesotensis Hu, sp. nov.

Plate 13, Figs. 7-14; Plate 14, Fig. 1

Pollen grains free, isopolar; prolate spheroidal, subprolate to prolate (P/E=1.11-1.88), tricolporate, apocolpia small; exine 1 μm , two layered, sexine columellate, pila short size; microreticulate, lumina 0.1-1 μm , muri ca. 0.5 μm wide, lumina decreasing toward colpi and poles, ora small, about 0.8 μm in diameter.

Dimensions: equatorial view 8(15)19 μm x 15(19)23 μm (5 grains), polar view 16(17)19 μm (13 grains).

Holotype: 036694-PY01A, S31/1

Remarks: This species is distinct from *Dryadopollis argus* Srivastava, 1975, and *Dryadopollis vestalis* Ward, 1986, in its smaller lumina and ora, and thinner exine.

Occurrence: Courtland Clay Pit.

Name derivation: *minnesotensis* is from the state name "Minnesota" where the fossil pollen was recovered.

Dryadopollis minutus Hu, sp. nov.

Plate 14, Figs. 2-4

Pollen grains free, isopolar; subprolate (P/E=1.11-1.88), tricolporate, apocolpia small; exine thin, ca. 0.5 μm , two layered, sexine columellate, pila very short size; microreticulate, lumina 0.1-0.5 μm , muri ca. 0.2 μm wide, lumina decreasing toward colpi and poles.

Dimensions: equatorial view 8 x 10 μm (1 grain), polar view 9(10)10 μm (2 grains).

Holotype: 036704-PY01A, L41

Occurrence: Courtland Clay Pit.

Remarks: It is similar to *Dryadopollis argus*, but its size and lumina are smaller.

Name derivation: Species name *minutus* indicating the grain is very small.

Genus *Foveotricolporites* Pierce, 1961

Type species: *Foveotricolporites rhombohedralis* Pierce, 1961.

Foveotricolporites rhombohedralis Pierce, 1961

Plate 14, Figs. 5-10

Pollen grains free, isopolar; prolate spheroidal, spheroidal, subprolate to prolate (P/E=1.03-1.55), amb circular to subcircular; tricolporate, colpi nearly extending to the poles, pore ca. 6 μm , apocolpia small; exine ca. 2.5 μm , two layered, nexine ca. 1 μm , sexine coarse columellae, head of pila fused together; foveolate, fovea irregular to elongate, 0.5-1 μm .

Dimensions: equatorial view 20(27)31 μm x 31(34)39 μm (4 grains); polar view 42(47)51 μm (4 grains).

Remarks: *Caprifoliipites acopus* Ward, 1986, has similar features, but its size is smaller (15-18 x 19-24 μm) and its fovea size is larger (1.3-2 μm). Also, the fovea become smaller toward the colpi and poles in some specimens recovered in Minnesota.

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

cf. *Foveotricolporites* sp.

Plate 14, Figs. 11-13

Pollen grains free, isopolar; prolate (P/E=1.58), amb circular to subcircular, tricolporate, colpi nearly extending to the poles, slightly raised, apocolpia small; exine ca. 2.5 μm , two layered, sexine decreasing toward colpi and nexine increasing toward colpi in thickness; foveolate, fovea ca. 0.5 μm .

Dimensions: equatorial view 19 x 30 μm (1 grain); polar view 27 μm (1 grain).

Remarks: It is similar to *Foveotricolporites* sp., but the wall structure is different.

Occurrence: Courtland Clay Pit.

Genus *Phimopollenites* Dettmann 1973

Type species *Phimopollenites pannosus* (Dettmann and Playford) Dettmann 1973

Phimopollenites striolata Hu, sp. nov.

Plate 14, Figs. 14-21; Plate 15, Figs. 1-3

Pollen grains free, isopolar; prolate spheroidal, subprolate to prolate (P/E=1.06-1.62), amb circular to subcircular; tricolporoidate, colpi slightly ragged and raised, apocolpia small; exine 1-2 μm , two layered, nexine thinner than sexine, sexine columellate, pila dense with expended pila head; sexine microreticulate, lumina less than 0.5 μm . SEM studies have indicated that there are striates on the inner wall of lumina.

Dimensions: equatorial view 12(14)19 x 16(19)21 μm (10 grains); polar view 15(18)24 μm (7 grains).

Holotype: 046517-A1, + 10 μ , N29/3

Remarks: This species has striate structure (muri with weak, transverse striations) on the inner wall of lumina that is different from other species of *Phimopollenites*, as seen in SEM images.

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit and Ochs Clay Pit.

Name derivation: Species name *striolata* is from Latin, diminutive for furrow.

Genus *Nyssapollenites* Thiergart 1937

Type species *Nyssapollenites pseudocruciatus* (Potonie) Thiergart 1937

***Nyssapollenites* sp.**

Plate 15, Figs. 4-12

Pollen grains free, isopolar; prolate spheroidal, subprolate to prolate (P/E=1-1.56), amb circular to subcircular; tricolporate, colpi nearly extending to the poles, pore ca. 1µm, apocolpia small; exine ca. 0.8-1 µm, two layered; sexine scabrate to microfoveolate, fovea very small.

Dimensions: equatorial view 9(11)14 x 11(14)17 µm (7 grains); polar view 11(14)15 µm (3 grains).

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Remark: This species is distinct from *Nyssapollenites albertensis* Singh, which has a larger pore (ca. 2.5 µm) and thickened pore and colpi margin.

***Tricolporate* sp.2**

Plate 16, Figs. 1-3

Pollen grains free, isopolar; spheroidal, subprolate, to prolate (P/E=1.12-1.58), amb circular to subcircular; tricolporate, colpi nearly extending to the poles, pore ca. 1.5 x 3 µm, apocolpia small; exine ca. 1 µm, two layered; sexine striate, striae ca. 0.5µm wide.

Dimensions: equatorial view 19(25)30 x 17(18)19 µm (2 grains); polar view 15(17)19 µm (2 grains).

Occurrence: Ochs Clay Pit.

Genus *Psilatricolporites* Van der Hammen, 1956 ex van der Hammen and Wijmstra, 1964

Type Species: *Psilatricolporites operculatus* van der Hammen and Wijmstra, 1964

Psilatricolporites subtilis (Groot, Penny and Groot) Singh 1983

Plate 16, Fig. 4

Pollen grains free, isopolar; subprolate (P/E=1.27), amb circular to subcircular; tricolporoidate, colpi nearly extending to the poles, raised, pore not clear, apocolpia small; exine thin, ca. 1 µm, two layered; sexine psilate to scabrate.

Dimensions: equatorial view 11 x 14 µm (1 grain); polar view 11(12)12 µm (2 grains).

Occurrence: Ochs Clay Pit.

Remarks: This species is distinct from *P. distinctus*, which has larger pores (ca. 2µm).

Distribution: Cenomanian to Coniacian, eastern United States (Groot, Penny and Groot 1961); Cenomanian, Atlantic Coastal Plain of United States (Brenner 1967); Cenomanian to Coniacian, Alberta (Singh 1983).

Gymnosperm Pollen

Anteturma **POLLENITES** Potonie

Turma **SACCITES** Erdtman

Subturma **DISACCITES** Cookson

Genus *Alisporites* Daugherty, 1941

Type species: *Alisporites opii* Daugherty, 1941.

Alisporites rotundus Rouse, 1959

Plate 16, Fig. 5

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus ellipsoidal to subspherical, microreticulate, proximal cap ca. 3.5 μm ; sacci coarser reticulate, lumina 1-4 μm , polygonal.

Dimensions: Overall breadth 45(77)112 μm (5 specimens).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: ? upper Jurassic, western Canada (Rouse 1959); middle Albian, east-central Alberta (Singh 1964).

Genus *Cedripites* Wodehouse, 1933

Type species: *Cedripites eocenicus* Wodehouse, 1933

Cedripites cretaceous Pocock 1962

Plate 16, Fig. 6

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus ellipsoidal, proximal cap ca. 4 μm thick, reticulate to granulate; sacci reticulate, lumina 1-3 μm , irregular and uneven.

Dimensions: Overall breadth 95 μm ; overall height 69 μm (1 specimen).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: McMurray Formation, Alberta (Pocock 1962); middle Albian, east-central Alberta (Singh 1964); Albian to ? Cenomanian, central Alberta (Norris 1967); and middle to late Albian, northwestern Alberta (Singh 1971).

Cedripites sp.

Plate 16, Fig. 7

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus ellipsoidal, proximal cap ca. 2 μm thick, reticulate; sacci distally pendant, sacci reticulate, lumina 1-3 μm , irregular and uneven.

Dimensions: Overall breadth 88 μm ; overall height 58 μm ; sacci height 33 μm ; sacci depth 55 μm (1 specimen).

Remarks: It can be distinguished from *Cedripites canadensis* by the reticulate proximal cap surface.

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Genus *Parvisacites* Couper, 1958

Type species: *Parvisacites radiatus* Couper, 1958.

Parvisacites radiatus Couper 1958

Plate 16, Fig. 8

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus ellipsoidal, granulate, proximal cap ca. 3 μm ; sacci semicircular, reticulate to rugulate, with thickening or ribs at the proximal root with corpus.

Dimensions: Overall breadth 45 μm ; overall height 36 μm ; sacci height 23 μm ; sacci depth 30 μm (2 specimens).

Occurrence: Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: Wealden and Aptian, England (Couper 1958); McMurray and Clearwater Formations, Alberta (Pocock 1962); Barremian to Albian, Maryland (Brenner 1963); middle Albian, east-central Alberta (Singh 1964); Albian to ? Cenomanian, central Alberta (Norris 1967); and middle to late Albian, northwestern Alberta (Singh 1971).

Genus *Pityosporites* Seward, 1914

Type species: *Pityosporites antarcticus* Seward, 1914

Pityosporites constrictus Singh 1964

Plate 16, Fig. 9

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus ellipsoidal, microreticulate, proximal cap thin, less than 1 μm ; sacci coarser reticulate to rugulate.

Dimensions: Overall breadth 66 μm ; overall height 52 μm ; sacci height 34 μm ; sacci depth 32 μm (1 specimen).

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Distribution: Throughout much of the Cretaceous of North America and Europe.

? *Pityosporites constrictus*

Plate 16, Fig. 10

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus ellipsoidal, fine reticulate to granulate; sacci coarser reticulate to rugulate, with thickening or ribs at distal root.

Dimensions: Overall breadth 75 μm ; overall height 43 μm ; body breadth 53 μm ; body height 43 μm ; sacci height 27 μm ; sacci depth 45 μm (1 specimen).

Occurrence: Highway 4 Clay Pit, Ochs Clay Pit.

Genus *Podocarpidites* Cookson, 1947 ex Couper, 1953

Type species: *Podocarpidites ellipticus* Cookson, 1947

Podocarpidites canadensis Pocock, 1962

Plate 16, Fig. 11

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus subspherical, fine granulate; sacci coarser reticulate, with radial thickening at distal sacci junction with corpus.

Dimensions: Overall breadth 126 μm ; body breadth 65 μm ; sacci depth 74 μm (1 specimen).

Occurrence: Ochs Clay Pit.

Distribution: Deville and Ellerslie Members, Alberta (Pocock 1962); middle Albian, east-central Alberta (Singh 1964); and middle to late Albian, northwestern Alberta (Singh 1971).

Podocarpidites minisculus Singh 1964

Plate 16, Fig. 12

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus subspherical, fine reticulate; sacci coarser reticulate, with radial thickening at distal sacci junction with corpus.

Dimensions: Overall breadth 70 μm ; overall height 52 μm ; sacci height 31 μm ; sacci depth 49 μm (1 specimen).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: middle Albian, east-central Alberta (Singh 1964); and middle to late Albian, northwestern Alberta (Singh 1971).

***Podocarpidites* sp.**

Plate 16, Fig. 13

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus ellipsoidal to subspherical, scabrate to granulate; sacci reticulate, lumina irregular, with radial thickening at distal sacci junction with corpus.

Dimensions: Overall breadth 71 μm ; overall height 33 μm ; sacci height 24 μm ; sacci depth 35 μm (1 specimen).

Remarks: It is different from *Podocarpidites minisculus* Singh in its scabrate to granulate corpus.

Occurrence: Highway 4 Clay Pit, Ochs Clay Pit.

Genus *Pristinuspollenites* Tschudy, 1973

Type species: *Pristinuspollenites microsaccus* Tschudy, 1973

***Pristinuspollenites crassus* (Pierce) Tschudy, 1973**

Plate 17, Fig. 1

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus subspherical, granulate; sacci small, not bordering the furrow, coarser granulate.

Dimensions: Overall breadth 52 μm ; overall height 47 μm (1 specimen).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit.

Distribution: ?Cenomanian, Minnesota (Pierce 1961).

***Pristinuspollenites inchoatus* (Pierce) Tschudy 1973**

Plate 17, Fig. 2

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus subspherical to spherical, granulate to rugulate; sacci small and elongate, bordering the distal furrow, coarser granulate.

Dimensions: Overall breadth 64 μm ; overall height 64 μm (1 specimen).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: ?Cenomanian, Minnesota (Pierce 1961); and lower Barremian to upper Albian, western Canada (Burden and Hills 1989).

***Pristinuspollenites microsaccus* (Couper) Tschudy 1973**

Plate 17, Fig. 3

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus subspherical, microreticulate; sacci small and arc-shaped, granulate to reticulate, sulcus not clearly defined, .

Dimensions: Overall breadth 31(37)42 μm ; overall height 30(43)55 μm (2 specimens).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: Middle Jurassic, southeastern England (Couper 1958); upper Campanian, north-central Montana (Tschudy 1973).

Pristinuspollenites pannosus (Pierce) Tschudy 1973

Plate 17, Fig. 4

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus subspherical to spherical, granulate; sacci small and serpentine, parallel and bordering the narrow distal furrow.

Dimensions: Overall breadth 49 μm ; overall height 49 μm (1 specimen).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: ?Cenomanian, Minnesota (Pierce 1961).

Pristinuspollenites sulcatus (Pierce) Tschudy 1973

Plate 17, Fig. 5

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus subspherical to spherical, granulate; sacci small and elongate, not bordering the distal furrow, but parallel with it, microreticulate.

Dimensions: Overall breadth 40(46)51 μm (1 specimen).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: ?Cenomanian, Minnesota (Pierce 1961).

? *Pristinuspollenites* sp.

Plate 17, Fig. 6

Pollen grain free, heteropolar, bilateral; vesiculate, multisaccate; corpus subspherical, granulate to rugulate; with 2 small flaccid sacci on each side of distal furrow, not bordering the furrow; exine ca. 1.5 μm .

Dimensions: Overall breadth 30 μm (1 specimen).

Occurrence: Courtland Clay Pit.

Pristinuspollenites sp. 2

Plate 17, Fig. 7

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus elliptical, granulate to reticulate; sacci flaccid, small and elongate, not bordering the furrow; exine ca. 1.5 μm .

Dimensions: Overall breadth 27 μm , overall height 38 μm (1 specimen).

Occurrence: Courtland Clay Pit.

Genus *Punctabivesiculites* Pierce, 1961

Type species: *Punctabivesiculites constrictus* Pierce, 1961

Punctabivesiculites parvus Pierce, 1961

Plate 17, Fig. 8

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus ellipsoidal, faint reticulate to granulate; sacci small and elongate, granulate to rugulate, with radial thickening on distally pendant sacci.

Dimensions: Overall height 49 μm (1 specimen).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit, Ochs Clay Pit.

Distribution: ? Cenomanian, Minnesota (Pierce 1961).

Genus *Rugubivesiculites* Pierce, 1961

Type species: *Rugubivesiculites convolutus* Pierce, 1961

Rugubivesiculites convolutus Pierce 1961

Plate 17, Fig. 9

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus rugulate, rugulae not dense; sacci granulate, rugulate to reticulate.

Dimensions: Overall breadth 67(73)78 μm ; overall height 46(48)50 μm ; sacci height 24(26)27 μm ; sacci depth 28(38)48 μm (2 specimens).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: ?Cenomanian, Minnesota (Pierce 1961).

Rugubivesiculites cf. multiplex Pierce 1961

Plate 17, Fig. 10

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus dense rugulate, rugulae tortuous, psilate to scabrate in inter-ridge areas; sacci granulate, microreticulate to rugulate, flaccid.

Dimensions: Overall breadth 63(69)74 μm (2 specimens).

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Rugubivesiculites multisaccus Singh, 1983

Plate 17, Fig. 11

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus contour not clear, psilate to scabrate; with ca. 5 small and irregular saccate pouches on the proximal surface of the central body, sacci microreticulate.

Dimensions: Overall breadth 79 μm ; overall height 37 μm ; body breadth 23 μm ; body height 20 μm ; big sacci height 11 μm ; big sacci depth 17 μm ; small sacci height 7 μm ; small sacci depth 11 μm (1 specimen).

Occurrence: Highway 4 Clay Pit.

Distribution: Early Cenomanian, Alberta (Singh 1983).

Rugubivesiculites cf. reductus Pierce 1961

Plate 17, Fig. 12

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus ellipsoidal to subspherical, rugulate only along the proximal roots of sacci; proximal surface microreticulate, sacci flaccid.

Dimensions: Overall breadth 50 μm (1 specimen).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Rugubivesiculites rugosus Pierce 1961

Plate 17, Fig. 13

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate; corpus dense rugulate, rugulae ridge like; sacci fine reticulate, flaccid.

Dimensions: Overall breadth 59 μm (1 specimen).**Occurrence:** Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.**Distribution:** Mainly Albian to Maastrichtian, Northern Hemisphere.**? *Rugubivesiculites* sp.**

Plate 17, Fig. 14.

Pollen grain free, heteropolar, bilateral; vesiculate, bisaccate (?); corpus rugulate, rugulae short and low; sacci foveolate, and seems around entire central body.

Dimensions: Overall breadth 44 μm (1 specimen).**Occurrence:** Courtland Clay Pit.Turma **ALETES** IbrahimSubturma **AZONALETES** Lubert emend. Potonie & KrempInfraturma **GRANULONAPITI** CooksonGenus *Araucariacites* Cookson ex CouperType species: *Araucariacites australis* Cookson, 1947.***Araucariacites australis*** Cookson 1947

Plate 17, Fig. 15

Pollen grain free; subspherical to spherical; inaperturate, with folds on surface, granulate; exine thin, ca. 1 μm .

Dimensions: 60(62)64 μm (2 specimens).**Occurrence:** Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.**Distribution:** Jurassic to Tertiary, worldwide.Infraturma **PSILONAPITI** ErdtmanGenus *Inaperturopollenites* Pflug ex Thomson & Pflug emend. Potonie

Type species: *Inaperturopollenites dubius* (Potonie & Venitz) Thomson & Pflug, 1953

***Inaperturopollenites* sp.**

Plate 17, Fig. 16

Pollen grain free; spherical, inaperturate, with folds on surface, psilate to scabrate; exine thin, ca. 1 μm .

Dimensions: 30 μm (1 specimen).**Occurrence:** Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.Genus *Taxodiaceapollenites* Kremp, 1949 ex Potonie, 1958Type species: *Taxodiaceapollenites hiatus* Kremp, 1949 ex Potonie, 1958.***Taxodiaceapollenites hiatus*** (Potonie) Kremp 1949

Plate 17, Fig. 17

Pollen grain free; inaperture, but splitting open, with folds on surface, psilate to scabrate; exine thin, ca. 1 μm .

Dimensions: 27 μm (1 specimen).

Remarks: It differs from *Inaperturopollenites* sp. in that it splits open.

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: Middle Albian to Miocene, worldwide.

Turma **PLICATES** Naumova emend. Potonie

Subturma **PRAECOLPATES** Potonie & Kremp

Genus *Eucommiidites* Erdtman emend. Hughes

Type species: *Eucommiidites troedssonii* Erdtman, 1948.

***Eucommiidites* sp.1**

Plate 17, Fig. 18

Pollen grain free; elliptical, zonisulcate, distal sulcus widen at ends, other two sulcus narrow, psilate; exine ca. 1 μm .

Dimensions: 11(18)24 x 20(30)39 μm (2 specimens).

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

***Eucommiidites* sp. 2**

Plate 17, Fig. 19

Pollen grain free; elliptical, zonisulcate, distal sulcus short and narrow at ends, other two sulcus longer than distal furrow, psilate; exine ca. 0.5 μm .

Dimensions: 16 x 18 μm (1 specimen).

Occurrence: Ochs Clay Pit.

Subturma **POLYPLICATES** Erdtman

Genus *Equisetosporites* Daugherty emend. Singh

Type species: *Equisetosporites chinleana* Daugherty, 1941.

***Equisetosporites* sp.1**

Plate 17, Fig. 20

Pollen grain free; elliptical, polypligate, ridge dense, ca. 0.2 μm apart from each other; ridges ca. 1.5 μm wide; exine ca. 1 μm .

Dimensions: 17 x 40 μm (2 specimens).

Remarks: It differs from *E. sp.2* in its dense ridges, and from *E. sp.3* in its thin ridges.

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

***Equisetosporites* sp.2**

Plate 18, Fig. 1

Pollen grain free; elliptical, polypligate, ridge sparse, ridge ca. 1.5 μm wide, ridge scabrate; exine ca. 1.2 μm .

Dimensions: 11(13)14 x 37(38)38 μm (2 specimens).

Remarks: It differs from *E. sp.3* in its thin and sparse ridges.

Occurrence: Courtland Clay Pit.

***Equisetosporites* sp.3**

Plate 18, Fig. 2-3

Pollen grain free; elliptical, polyplicate, ridge dense, less than 1 μm apart from each other; ridge wide, ca. 4 μm wide; ridge scabrate.

Dimensions: 20(21)21 x 34 μm (2 specimens).

Occurrence: Courtland Clay Pit.

Subturma **MONOCOLPATES** Iversen & Troels-Smith

Genus *Cycadopites* Wodehouse ex Wilson & Webster

Type species: *Cycadopites follicularius* Wilson & Webster, 1946

***Cycadopites* sp.**

Plate 18, Figs. 4, 5

Pollen grain free; elliptical, monosulcate, sulcus long and extending full of the grain, sulcus margin raised a little; faint granulate to scabrate; exine ca. 1 μm .

Dimensions: 10(18)27 x 27(37)46 μm (5 specimens).

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Genus *Entylissa* Naumova 1939 ex Ishchenko 1952

Type species: *Entylissa caperatus* (Luber) Potonie & Kremp 1954.

***Entylissa* sp.**

Plate 18, Fig. 6

Pollen grain free; elliptical, monosulcate, furrow broadens at both ends, scabrate to fine granulate; exine ca. 2.5 μm .

Dimensions: 27(29)32 x 45(51)57 μm (4 specimens).

Occurrence: Highway 4 Clay Pit.

Genus *Monosulcites* Cookson, 1947, ex Couper, 1953

Type species: *Monosulcites minimus* Cookson, 1947.

***Monosulcites* sp. 1**

Plate 18, Fig. 7

Pollen grain free; elliptical, monosulcate, sulcus extending full length of grain, sulcus becoming narrow at ends, scabrate to granulate; exine ca. 2 μm .

Dimensions: 30(36)44 x 45(57)67 μm (3 specimens).

Remarks: *Monosulcites* sp. 1 differs from *Monosulcites* sp. 2 in that the ornamentation of the latter is rugulate to verrucate; in addition the sulcus of *Monosulcites* sp. 2 does not become narrow at the ends. It differs from *Monosulcites* sp. 3 in that its size is much smaller than *Monosulcites* sp. 3 (79 x 100 μm). *Monosulcites* sp. 4 is smaller and has thinner exine compared with *Monosulcites* sp. 1.

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

***Monosulcites* sp. 2**

Plate 18, Fig. 8

Pollen grain free; elliptical, monosulcate, sulcus extending full length of grain, granulate, rugulate to verrucate; exine two layered, sexine alveolate, exine 1.2-2.5 μm .

Dimensions: 32(39)48 x 47(54)63 μm (5 specimens).

Remarks: It differs from other three *Monosulcites* species in this chapter in its regulate to verrucate ornamentation.

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Monosulcites sp. 3

Plate 18, Fig. 9

Pollen grain free; elliptical, monosulcate, sulcus extending full length of grain, scabrate to granulate; exine two layered, ca. 3 μm .

Dimensions: 79 x 100 μm (1 specimen).

Remarks: It differs from other three *Monosulcites* species in this chapter in its large grain size.

Occurrence: Ochs Clay Pit.

Monosulcites sp. 4

Plate 18, Figs. 10, 11

Pollen grain free; elliptical, monosulcate, sulcus extending full length of grain, sulcus often folded, granulate; exine 0.5 μm .

Dimensions: 15(20)23 x 24(26)30 μm (3 specimens).

Remarks: It differs from other three *Monosulcites* species in this chapter in its small grain size and thin exine.

Occurrence: Ochs Clay Pit.

Genus *Sabalpollenites* Thiergart, in Raatz, 1938

Type species: *Sabalpollenites convexus* Thiergart, in Raatz, 1938.

Sabalpollenites scabrous (Brenner) Wingate, 1980

Plate 18, Fig. 12

Pollen grain free; subcircular to circular, monosulcate, sulcus extending full length of grain, granulate to regulate; exine two layered, sexine alveolate, exine 2 μm .

Dimensions: 35(40)45 μm (2 specimens).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: Albian to lower Cenomanian, Maryland (Brenner 1963); Cenomanian, New Jersey and New York (Kimyai 1966, 1970); middle Cenomanian, Louisiana and Mississippi (Phillips and Felix 1972b); upper Albian, Oklahoma (Wingate 1980), and lower to middle Cenomanian, northwestern Iowa and northeastern Nebraska (Ravn and Witzke 1995).

Turma **POROSSES** Naumova emend. Potonie, 1960

Subturma **MONOPORINES** Naumova 1939

Genus *Bacumonoporites* Pierce, 1961

Type species: *Bacumonoporites baculatus* Pierce, 1961

Bacumonorites baculatus Pierce, 1961

Plate 18, Fig. 13

Pollen grain free; subcircular to circular; monoporate, aperture circular, ca. 16-35 μm in diameter, granulate, baculate to regulate; exine 1.5-4 μm .

Dimensions: 27(43)65 x 27(49)74 μm (4 specimens).**Occurrence:** Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.**Distribution:** ? Cenomanian, Minnesota (Pierce 1961).Genus ***Classopollis*** Pflug, 1953 emend. Pocock and Jansonius, 1961

Type species: ***Classopollis classoides*** Pflug, 1953 emend. Pocock and Jansonius, 1961.

Classopollis torosus (Reissinger) Couper 1958

Plate 18, Fig. 14

Pollen grain free; circular, monoporate, aperture circular to triangular, ca. 11 μm in diameter; microreticulate to granulate, with equatorial circular ornament; exine 1.5 μm .

Dimensions: 24(25)28 μm (3 specimens).**Occurrence:** Courtland Clay Pit, Highway 4 Clay Pit.

Distribution: Albian to lower Cenomanian, Maryland (Brenner 1963); ? lower to upper Cenomanian, northwestern Iowa and northeastern Nebraska (Ravn and Witzke 1995).

Genus ***Exesipollenites*** Balme, 1957Type species: ***Exesipollenites tumulus*** Balme, 1957***Exesipollenites* sp.**

Plate 18, Fig. 15

Pollen grain free; circular, monoporate, pore circular, ca. 3 μm in diameter, differentially thickened areas present around the pore, scabrate; exine ca. 1.5 μm .

Dimensions: 32 μm (1 specimen).**Occurrence:** Courtland Clay Pit.Subturma **POLYSACCITES** Cookson 1947Genus ***Punctamultivesiculites*** Pierce, 1961Type species: ***Punctamultivesiculites inchoatus*** Pierce, 1961***Punctamultivesiculites* cf. *inchoatus*** Pierce, 1961

Plate 18, Fig. 16

Pollen grain free, heteropolar; vesiculate, multisaccate; corpus elliptical, granulate; sacci small and numerous, ca. 30, sacci granulate to verrucate, exine ca. 2 μm .

Dimensions: 43 x 51 μm (1 specimen).**Remarks:** The holotype only has ca. 10 small sacci.**Occurrence:** Ochs Clay Pit.

Spores

Anteturma **SPORITES** Potonie, 1893

Turma **TRILETES**, Reinsch emend. Dettmann 1963

Subturma **AZONOTRILETES** Luber emend. Dettmann 1963

Infraturma **LAEVIGATI** Bennie & Kidston emend. Potonie 1956

Genus *Biretisporites* Delcourt & Sprumont emend. Delcourt, Dettmann, & Hughes
1963

Type species: *Biretisporites potoniaei* Delcourt & Sprumont, 1955.

Biretisporites sp.1

Plate 18, Fig. 17

Spores tetrahedral, trilete, amb subtriangular; laesurae long and straight, extending full distance of spore radius, laesurae slightly raised and gaping sometimes; sides convex, apices rounded; sculpture scabrate, densely small pits present; spore wall of uniform thickness, about 1.2µm thick.

Dimensions: 28(35)42µm (5 specimens)

Occurrence: Courtland Clay Pit.

Biretisporites sp.2

Plate 18, Fig. 18

Spores tetrahedral, trilete, amb triangular; laesurae extending full distance of spore radius, laesurae distinct and raised; sides straight; sculpture scabrate; small folds along interradiial edge; spore wall of uniform thickness, thin, less than 1 µm thick.

Dimensions: 27 µm (1 specimen)

Remarks: It differs from *Biretisporites* sp. 1 in its absence of pits for the ornamentation.

Occurrence: Courtland Clay Pit.

Genus *Cyathidites* Couper 1953

Type species: *Cyathidites australis* Couper, 1953.

Cyathidites australis Couper 1953

Plate 18, Fig. 19

Spore tetrahedral, trilete, amb triangular; laesurae extending 2/3 of spore radius, laesurae gapping; sides concave, apices well-rounded; sculpture scabrate, with densely small fovea; spore wall of uniform thickness, about 1.2 µm thick.

Dimensions: 57(58)60 µm (3 specimens)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Distribution: Jurassic and Cretaceous, worldwide.

Cyathidites minor Couper 1953

Plate 18, Fig. 20

Spore tetrahedral, trilete, amb triangular; laesurae nearly extending full distance of spore radius, laesurae gapping; sides slightly concave, apices rounded; sculpture scabrate; spore wall of uniform thickness, about 1.2 μm thick.

Dimensions: 24(26)28 μm (4 specimens)

Occurrence: Courtland Clay Pit.

Distribution: Jurassic and Cretaceous, worldwide.

Cyathidites punctatus (Delcourt and Sprumont 1955) Delcourt, Dettmann, and Hughes, 1963

Plate 19, Fig. 1

Spore tetrahedral, trilete, amb subtriangular; laesurae extending full distance of spore radius, laesurae gapping; sides concave, apices well-rounded; sculpture scabrate to granulate; spore wall thinner at apices (ca. 1.5 μm) and thicker at interradial areas (ca. 2.5 μm).

Dimensions: 51(52)53 μm (2 specimens)

Occurrence: Courtland Clay Pit.

Distribution: Wealden and Aptian, England (Couper 1958); Upper Mesozoic, southeastern Australia (Dettmann 1963); and Cenomanian, Oklahoma (Hedlund 1966).

Genus *Deltoidospora* Miner emend. Potonie

Type species: *Deltoidospora hallii* Miner, 1935

Deltoidospora hallii Miner 1935

Plate 19, Fig. 2

Spore tetrahedral, trilete, amb triangular; laesurae extending full distance of spore radius, laesurae distinct; sides convex, apices well-rounded; sculpture scabrate; spore wall of uniform thickness, ca. 1.5 μm thick.

Dimensions: 32 μm (1 specimen)

Occurrence: Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: Throughout much of the upper Mesozoic, worldwide.

Deltoidospora sp.

Plate 19, Fig. 3

Spore tetrahedral, trilete, amb subtriangular; laesurae extending nearly full of spore radius, laesurae distinct and raised; sides convex; sculpture scabrate; spore wall ca. 1 μm .

Dimensions: 77 μm (1 specimen)

Occurrence: Highway 4 Clay Pit, Ochs Clay Pit.

Genus *Undulatisporites* Pflug in Thomson & Pflug 1953

Type species: *Undulatisporites microcutis* Pflug in Thomson & Pflug, 1953.

Undulatisporites sp.

Plate 19, Fig. 4

Spore tetrahedral, trilete, amb subcircular; laesurae sinuous, extending 2/3 of spore radius; sides convex, apices well-rounded; sculpture scabrate to psilate; spore wall of uniform thickness, ca. 1 μm thick.

Dimensions: 37 μm (1 specimen)

Occurrence: Ochs Clay Pit.

Genus *Dictyophyllidites* Couper emend.

Type species: *Dictyophyllidites harrisii* Couper, 1958.

Dictyophyllidites impensus (Hedlund) Singh, 1983

Plate 19, Fig. 5

Spore tetrahedral, trilete, amb subtriangular; laesurae distinct and raised, laesurae nearly extending full distance of spore radius; sides convex; sculpture psilate; spore wall ca. 2 μm thick.

Dimensions: 53 μm (1 specimen)

Remarks: This type of spore is similar to that from *Goolangia minnesotensis* and may have affinity to Marattiaceae.

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay pit.

Dictyophyllidites sp.1

Plate 19, Fig. 6

Spore tetrahedral, trilete, amb triangular; laesurae extending full distance of spore radius, laesurae distinct and gapping; arcuate thickening at interradian areas; sides slightly convex, apices rounded; sculpture scabrate; spore wall of uniform thickness, thin, less than 1 μm thick.

Dimensions: 25(26)27 μm (2 specimens)

Occurrence: Courtland Clay Pit.

Genus *Stereisporites* Pflug 1953

Type species: *Stereisporites stereoides* (Potonie & Venitz) Pflug 1953.

Stereisporites sp.

Plate 19, Fig. 7

Spore tetrahedral, trilete, amb subtriangular; cingulum present (ca. 2 μm); laesurae short and only half of spore radius, laesurae gapping; sides convex, apices rounded; sculpture scabrate; spore wall thickened at apices, ca. 1.5 μm .

Dimensions: 33(39)44 μm (2 specimens)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Genus *Auritulasporites* Nilsson 1958

Type species: *Auritulasporites scanicus* Nilsson, 1958.

? *Auritulasporites* sp.

Plate 19, Fig. 8

Spores tetrahedral, trilete, amb triangular; laesurae extending full distance of spore radius, laesurae distinct and thickened; distinctly thickened "lips" delineate a triangular area around the laesurae; sides concave; sculpture scabrate; spore wall of uniform thickness, ca. 1.5-2 μm thick.

Dimensions: 48(48)49 μm (3 specimens)

Occurrence: Ochs Clay Pit, Highway 4 Clay Pit.

Infraturma **APICULATI** Bennie & Kidston emend. Potonie 1956

Genus *Concavissimisorites* Delcourt & Sprumont emend. Delcourt, Dettmann, & Hughes 1963

Type species: *Concavissimisorites verrucosus* Delcourt & Sprumont, 1955.

? *Concavissimisorites* sp.

Plate 19, Fig. 10

Spore tetrahedral, trilete, amb triangular; laesurae extending 2/3 of spore radius; sides concave or slight convex, apices well-rounded; sculpture granulate, verrucate to rugulate; spore wall thin, less than 1 μm thick.

Dimensions: 24(32)39 μm (4 specimens)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Genus *Baculatisporites* Thomson & Pflug 1953

Type species: *Baculatisporites primaries* (Wolff) Thomson & Pflug 1953

Baculatisporites comaumensis (Cookson) Potonie 1956

Plate 19, Fig. 9

Spores tetrahedral, trilete, amb subtriangular; laesurae distinct and raised, laesurae extending full distance of spore radius; sides convex; sculpture baculate to verrucate; baculae ca. 2.5 μm high, dense on distal side and reduced on proximal side.

Dimensions: 34 μm (1 specimen)

Occurrence: Courtland Clay Pit.

Distribution: Late Triassic to Cretaceous, worldwide.

Baculatisporites sp.

Plate 19, Fig. 11

Spores tetrahedral, trilete, amb elliptical to circular; laesurae gapping; sides convex, apices rounded; sculpture baculate and baculae size 1.2 x 1.0 μm ; spore wall of uniform thickness, about 1.8 μm thick.

Dimensions: 34 μm (1 specimen)

Occurrence: Courtland Clay Pit.

Genus *Converrucosisporites* Potonie & Kremp 1954

Type species: *Converrucosisporites triquetrus* (Ibrahim) Potonie & Kremp, 1954.

Converrucosisporites sp.

Plate 19, Figs. 12, 13

Spore tetrahedral, trilete, amb triangular; laesurae extending full of spore radius, laesurae gapping; sides concave; verrucate, baculate and coni, evenly distributed; spore wall about 0.8 μm thick (excluding ornamentation).

Dimensions: 39(44)48 μm (2 specimens)

Occurrence: Ochs Clay Pit.

Genus *Neoraistrickia* Potonie 1956

Type species: *Neoraistrickia truncatus* (Cookson) Potonie 1956.

***Neoraistrickia* sp.**

Plate 19, Fig. 14

Spore tetrahedral, trilete, amb triangular; laesurae difficult to observe due to ornamentation; sides straight or convex; sculpture baculate, baculae ca. 0.5 μm high and 2.5-3.5 μm wide, baculae denser at apices on distal view; spore wall of uniform thickness, about 3 μm thick.

Dimensions: 47 μm (1 specimen)**Occurrence:** Courtland Clay Pit.Genus *Ceratosporites* Cookson & Dettmann 1958Type species: *Ceratosporites equalis* Cookson & Dettmann 1958.**? *Ceratosporites* sp.**

Plate 19, Fig. 15

Spore tetrahedral, trilete, amb triangular; laesurae not clear because of ornamentation; sides convex; sculpture echinate on distal side, echinae ca. 3 x 5 μm , small pits on the surface of echinae; sculpture psilate on proximal side; spore wall thick (ca. 5 μm)

Dimensions: 34 μm (1 specimen)**Occurrence:** Courtland Clay pit, Highway 4 Clay Pit.Genus *Impardecispora* Venkatachala, Kar & Raza 1969

Type species: *Impardecispora apiverrucata* (Couper) Venkatachala, Kar & Raza, 1969.

***Impardecispora* sp.1**

Plate 19, Fig. 16

Spore tetrahedral, trilete, amb triangular; laesurae distinct and raised, laesurae extending 2/3 of spore radius; sides convex; sculpture verrucate, big verrucae at apices region on distal side; proximal side reduced and relatively smooth.

Dimensions: 34 μm (1 specimen)**Occurrence:** Courtland Clay Pit.Genus *Verrucosisorites* Ibrahim emend. Smith & Butterworth 1967Type species: *Verrucosisorites verrucosus* (Ibrahim) Ibrahim, 1933.***Verrucosisorites* sp.**

Plate 19, Fig. 17

Spore tetrahedral, trilete, amb subtriangular; laesurae extending ca. 2/3 distance of spore radius, laesurae gapping; sides concave; sculpture verrucate; spore wall of uniform thickness, about 1 μm thick.

Dimensions: 27(36)51 μm (2 specimens)**Occurrence:** Courtland Clay Pit, Ochs Clay Pit.Genus *Granulatisporites* Ibrahim 1933Type species: *Granulatisporites granulatus* Ibrahim 1933.

? *Granulatisporites* sp.

Plate 19, Fig. 18

Spore tetrahedral, trilete, amb subtriangular; laesurae extending full distance of spore radius, laesurae not straight; sides convex, apices rounded; a distinct triangular depression on the proximal surface; sculpture scabrate to granulate; granules connect each other to form dense regulate structure; spore wall of uniform thickness, about 1.2 μm thick.

Dimensions: 38(38)39 μm (3 specimens)**Occurrence:** Courtland Clay Pit.**Genus *Punctatriletes* Pierce 1961**Type species: *Punctatriletes punctus* Pierce, 1961.***Punctatriletes punctus* Pierce, 1961**

Plate 19, Fig. 19

Spore tetrahedral, trilete, amb triangular; laesurae extending more than 2/3 of spore radius, laesurae distinct and straight; sides convex; sculpture granulate; spore wall of uniform thickness, ca. 2 μm thick.

Dimensions: 48(50)51 μm (2 specimens)**Occurrence:** Highway 4 Clay Pit, Ochs Clay Pit.**Distribution:** ? Cenomanian, Minnesota (Pierce 1961).**Genus *Phaeoceros*****cf. *Phaeoceros* form A Jarzen, 1979**

Plate 19, Figs. 20, 21

Spore tetrahedral, trilete, amb sub circular to triangular; laesurae sinuous and bifurcating when reaching the spore wall, extending nearly full distance of spore radius; sides slightly convex, apices rounded; baculate, ca. 3 μm high and 1 μm wide, baculae dense and big on distal surface and rare and small on proximal surface; spore wall 1.5-3 μm , uneven.

Dimensions: 56 μm (1 specimen)**Occurrence:** Ochs Clay Pit.Infraturma **MURORNATI** Potonie & Kremp 1954Genus *Lycopodiacidites* Couper 1953Type species: *Lycopodiacidites bullerensis* Couper, 1953.***Lycopodiacidites* sp.1**

Plate 19, Figs. 22, 23

Spore tetrahedral, trilete, amb triangular; laesurae extending full distance of spore radius, laesurae distinct and slightly sinuous; sides convex; sculpture regulate.

Dimensions: 25 μm (1 specimen)**Occurrence:** Courtland Clay Pit.***Lycopodiacidites* sp.2**

Plate 19, Figs. 24, 25

Spore tetrahedral, trilete, amb subtriangular to circular; laesurae distinct and straight, laesurae extending full distance of spore radius; sides convex; sculpture rugulate, rugulae dense and delicate (less than 1 μm wide); spore wall ca. 1 μm thick.

Dimensions: 36(42)47 μm (2 specimens)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Genus *Foveotriletes* van der Hammen ex Potonie 1956

Type species: *Foveotriletes scrobiculatus* (Ross) Potonie 1956.

***Foveotriletes* sp.**

Plate 19, Fig. 26

Spore tetrahedral, trilete, amb triangular; laesurae nearly extending full distance of spore radius, laesurae slightly raised; sides straight or slightly convex; sculpture foveolate, fovea rounded, 1.5-2 μm .

Dimensions: 46 μm (1 specimen)

Occurrence: Courtland Clay Pit.

? *Foveotriletes* sp.

Plate 19, Figs. 27, 28

Spores tetrahedral, trilete, amb triangular; laesurae extending full distance of spore radius, laesurae distinct, laesurae circled by distinctive thickening areas; sides straight or slightly concave; sculpture granulate with small pits; spore wall of uniform thickness, ca. 1.5 μm thick.

Dimensions: 29(37)45 μm (2 specimen)

Remarks: It differs from *Foveotriletes* sp. in its ornamentation that is granulate with small pits. Also it has distinct thickening areas around laesurae.

Occurrence: Courtland Clay Pit.

Genus *Foveosporites* Balme 1957

Type species: *Foveosporites canalis* Balme 1957.

***Foveosporites* sp.**

Plate 20, Fig. 1

Spore tetrahedral, trilete, amb triangular; laesurae distinct and straight, laesurae extending 2/3 of spore radius; sides convex to concave; sculpture foveolate, fovea irregular.

Dimensions: 35 μm (1 specimen)

Remarks: It differs from *Foveotriletes* sp. in its irregular fovea. The fovea is rounded for *Foveotriletes* sp.

Occurrence: Courtland Clay Pit.

Genus *Lycopodiumsporites* Thiergart ex Delcourt & Sprumont 1955

Type species: *Lycopodiumsporites agathoecus* (Potonie) Thiergart, 1938.

***Lycopodiumsporites marginatus* Singh, 1964**

Plate 20, Figs. 2, 3

Spore tetrahedral, trilete, amb subcircular; laesurae raised, extending nearly full distance of spore radius; psilate and with several irregular ridges on proximal surface; reticulate on distal surface, lumina 15-26 μm , muri polygonal at the areas of 3 lumina connecting, muri ca. 1 μm wide in other areas, forming a 9 μm high membrane layer.

Dimensions: 61 (73)79 μm (3 specimens)

Remarks: The lumina are 9-14 μm on the holotype.

Occurrence: Ochs Clay Pit.

Distribution: Middle Albian, east-central Alberta (Singh 1964); Albian to ? Cenomanian, central Alberta (Norris 1967); Albian, Oklahoma (Hedlund and Norris 1968); and middle to late Albian, northwestern Alberta (Singh 1971).

***Lycopodiumsporites* sp. 1**

Plate 20, Fig. 4

Spore tetrahedral, trilete, amb triangular; laesurae extending full distance of spore radius, laesurae slightly raised; sculpture reticulate, muri membrane like (ca. 4 μm high), thickness even, muri polygonal, ca. 8 μm in diameter.

Dimensions: 35 μm (1 specimen)

Occurrence: Courtland Clay Pit.

Genus *Klukisporites* Couper 1958

Type species: *Klukisporites variegatus* Couper, 1958.

***Klukisporites* sp.1**

Plate 20, Fig. 5

Spore tetrahedral, trilete, amb subtriangular; laesurae not clear; sides straight to slightly convex; sculpture foveolate, fovea irregular, ca. 2.5-4 μm long; spore wall ca. 2.5 μm thick.

Dimensions: 28 μm (1 specimen)

Occurrence: Courtland Clay Pit.

***Klukisporites* sp.2**

Plate 20, Fig. 6

Spore tetrahedral, trilete, amb subtriangular; laesurae distinct; sides straight to slightly convex; sculpture foveolate on distal side, fovea irregular, size 9 x 13 μm to 9 x 23 μm ; sculpture proximal side scabrate, with small pits; spore wall ca. 4 μm thick.

Dimensions: 61 μm (1 specimen)

Remarks: It differs from *Klukisporites* sp. 1 in its large spore size and large fovea size, and from ? *Klukisporites* sp. in its absence of thickened apices and tori on proximal surface.

Occurrence: Courtland Clay Pit.

? *Klukisporites* sp.

Plate 20, Figs. 7, 8

Spore tetrahedral, trilete, amb subcircular; laesurae extending 2/3 of spore radius, sinuous and slightly raised; sides convex, apices thickened, ca. 7 μm thick; sculpture

reticulate (?), lumina 21 μm and 36 μm on distal surface, muri 12 μm wide, a tori exist on proximal surface; spore wall ca. 3.5 μm thick.

Dimensions: 89 μm (1 specimen)

Remarks: It differs from other *Klukisporites* in its thickened apices and tori on proximal surface.

Occurrence: Ochs Clay Pit.

Genus *Taurocusporites* Stover 1962

Type species: *Taurocusporites segmentatus* Stover, 1962.

Taurocusporites segmentatus Stover 1962

Plate 20, Fig. 9

Spore tetrahedral, trilete, amb subtriangular; zonate, zona with concentric annular crassitudes; laesurae extending full distance of spore radius, laesurae distinct and thickened, laesurae do not reach into zona; sides convex; sculpture verrucate.

Dimensions: 37(42)51 μm (6 specimens)

Occurrence: Courtland Clay Pit.

Distribution: Neocomian to Cenomanian, North America and Europe (Ravn and Witzke, 1995).

Genus *Januasporites* Pocock 1962

Type species: *Januasporites reticularis* Pocock 1962

? *Januasporites* sp.

Plate 20, Fig. 10

Spore tetrahedral, trilete, amb triangular; zonate, zona membrane like and with wide base blunt spines on surface; laesurae extending full distance of spore radius, laesurae distinct; sides convex, apices well-rounded; spore wall ca. 1.5 μm thick.

Dimensions: 42(54)65 μm (including zona) (2 specimens)

Occurrence: Ochs Clay Pit.

Genus *Cicatricosisporites* Potonie & Gelletich 1933

Type species: *Cicatricosisporites dorogensis* Potonie & Gelletich 1933.

Cicatricosisporites coconinoensis Agasie, 1969

Plate 20, Fig. 11

Spore tetrahedral, trilete, amb circular to subcircular; laesurae distinct and raised, extending nearly full distance of spore radius; sides convex, apices rounded; relative wide (ca. 2 μm) and dense ridges on distal surface and nearly smooth on proximal surface; spore wall 2 μm .

Dimensions: 30(40)50 μm (2 specimens)

Occurrence: Highway 4 Clay Pit.

Distribution: Cenomanian, northeastern Arizona (Agasie 1969).

Cicatricosisporites crassiterminatus Hedlund, 1966

Plate 20, Figs. 12, 13

Spore tetrahedral, trilete, amb triangular to subtriangular; laesurae raised and nearly extending to equator; sculpture cicatricose, ridge dense and relatively wide (ca. 1.5-3 μm wide), 1 μm apart from each other, interconnected ridges enclose circular to elongate lumina, 2-2.5 μm .

Dimensions: 39 (44) 48 μm (2specimen)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Distribution: Cenomanian, North America (Hedlund 1966, Kimyai 1966, Agasie 1969, Romans 1975, May and Traverse 1973, and Singh 1983).

Cicatricosisporites cf. crassiterminatus Hedlund, 1966

Plate 20, Figs. 14, 15

Spore tetrahedral, trilete, amb subtriangular; laesurae slightly raised and nearly extending to equator; sculpture cicatricose, ridge wide (6-8 μm wide) and width uneven, interconnected ridges enclose elongate or rounded lumina; spore wall 5-8 μm , uneven.

Dimensions: 91 μm (1specimen)

Remarks: The holotype is only 56 μm . Also there are no thickened areas at apices for this species. Ridge width is wider and the thickness of spore wall is thicker than that of holotype.

Occurrence: Ochs Clay Pit.

Cicatricosisporites hallei Delcourt and Sprumont 1955

Plate 20, Fig. 16

Spore tetrahedral, trilete, amb triangular; laesurae extending to equator, laesurae straight and distinct; sculpture cicatricose, ridge delicate and relatively narrow (less than 1 μm wide).

Dimensions: 25 μm (1 specimen)

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit.

Distribution: Middle Albian, east-central Alberta (Singh 1964); Albian to ? Cenomanian, central Alberta (Norris 1967); Albian and Cenomanian, Oklahoma (Hedlund 1966; Hedlund and Norris 1968); and middle to late Albian (Singh 1971).

Cicatricosisporites hughesi Dettmann 1963

Plate 20, Figs. 17, 18

Spore tetrahedral, trilete, amb triangular to subtriangular; laesurae nearly extending full of the spore radius; sculpture cicatricose, ridge sinuous and wide (4-6 μm wide), 3-7 μm apart, there are 3 ridges in each interradian area, which are nearly parallel to each other and to the side of spore.

Dimensions: 30 (39) 48 μm (2 specimens)

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Distribution: Aptian, Albian, and ? Cenomanian, southeastern Australia (Dettmann 1963); Albian to ? Cenomanian, central Alberta (Norris 1967); Maastrichtian and Danian, California (Drugg 1967); and middle to late Albian, northwestern Alberta (Singh 1971).

Cicatricosisporites sp.1

Plate 20, Fig. 19

Spore tetrahedral, trilete, amb subtriangular; laesurae nearly extending to equator, laesurae distinct and raised; sculpture cicatricose, ridge dense (ca. 1.5-2 μm wide).

Dimensions: 37(39)40 μm (2 specimens)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

***Cicatricosisporites* sp.2**

Plate 20, Fig. 20

Spore oblique, trilete, trilete mark not clear; sculpture cicatricose, ridge dense and delicate; spore wall ca. 1 μm .

Dimensions: 43 μm (1 specimen)

Remarks: It differs from *Cicatricosisporites hallei* in its larger size, and from other *Cicatricosisporites* in this chapter in its dense and delicate ridges.

Occurrence: Highway 4 Clay Pit.

***Cicatricosisporites* sp. 4**

Plate 20, Figs. 21, 22

Spore tetrahedral, trilete, amb subtriangular; laesurae not clear because of ridges; sculpture cicatricose, ridge dense and wide (2.5 μm wide), small pits on the ridges.

Dimensions: 47 μm (1 specimen)

Remarks: It differs from other *Cicatricosisporites* in this chapter in its dense and wide ridges with pits.

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Genus *Costatoperforosporites* Deak 1962

Type species: *Costatoperforosporites fistulosus* Deak, 1962.

***Costatoperforosporites* sp.**

Plate 21, Fig. 1

Spore tetrahedral, trilete, amb triangular; laesurae slightly sinuous, extending nearly full distance of spore radius; sides slightly convex, apices rounded; wide (ca. 6-7 μm) and dense ridges evenly distributed, with small fovea on the ridges; spore wall 2.5-5 μm , uneven.

Dimensions: 52(72)90 μm (4 specimens)

Occurrence: Ochs Clay Pit.

Genus *Ischyosporites* Balme 1957

Type species: *Ischyosporites crateris* Balme, 1957

? *Ischyosporites* sp.

Plate 21, Figs. 2, 3

Spore subtriangular, trilete; laesurae sinuous and raised, extending nearly full of spore radius; psilate to scabrate on proximal surface and faint reticulate on distal surface, lumina 2-7 μm , muri ca. 1 μm wide, irregular; spore wall ca. 2 μm .

Dimensions: 51(57)63 μm (2 specimens)

Occurrence: Ochs Clay Pit.

Genus *Retitriletes* van der Hammen ex Pierce emend. Doring et al., in Krutzsch 1963

Type species: *Retitriletes globosus* Pierce, 1961.

***Retitriletes* sp.1**

Plate 21, Fig. 4

Spore tetrahedral, trilete, amb circular to subcircular; laesurae extending 2/3 distance of spore radius, laesurae not straight; sculpture reticulate, lumina polygonal (ca. 5µm in diameter) and muri thickness not even.

Dimensions: 27(29)31 µm (2 specimens)

Occurrence: Courtland Clay Pit.

***Retitriletes* sp.2**

Plate 21, Figs. 5, 6

Spore tetrahedral, trilete, amb triangular; laesurae nearly extending full distance of spore radius; sides convex, apices rounded; sculpture reticulate, lumina shape irregular (1.5-3 µm in diameter) and muri thickness not even; spore wall of uniform thickness, about 1.2 µm thick.

Dimensions: 29 µm (1specimen)

Remarks: It differs from *Retitriletes* sp.1 in its smaller and irregular lumina, and from ? *Retitriletes* sp. in its smaller size.

Occurrence: Courtland Clay Pit.

? *Retitriletes* sp.

Plate 21, Figs. 7, 8

Spore tetrahedral, trilete, trilete mark not clear, amb nearly circular; sides convex; sculpture reticulate, lumina polygonal, 3-6 µm in diameter.

Dimensions: 40 µm (1 specimen)

Remarks: It differs from other *Retitriletes* in this chapter in its larger size.

Occurrence: Highway 4 Clay Pit.

Genus *Stoverisporites* Burger in Norvick & Burger 1975

Type species: *Stoverisporites microverrucatus* Burger, 1975.

? *Stoverisporites* sp.

Plate 21, Fig. 9

Spore tetrahedral, trilete; laesurae raised, with thick “lips” or “arcuate”; incomplete fovea on distal surface and psilate on proximal surface; spore wall thick, ca. 5 µm.

Dimensions: 73(78)83 µm (2 specimens)

Occurrence: Highway 4 Clay Pit.

Infraturma **TRICRASSATI** Dettmann 1963

Genus *Gleicheniidites* Ross ex Delcourt & Sprumont emend. Dettmann 1963

Type species: *Gleicheniidites senonicus* Ross 1949.

Gleicheiidites senonicus Ross emend. Skarby 1964

Plate 21, Fig. 10

Spore tetrahedral, trilete, amb triangular; laesurae extending full distance of spore radius, laesurae long and raised; sides concave with interrarial crassitudes, crassitude ca. 4 μm wide; sculpture psilate; spore wall of uniform thickness, less than 1 μm thick.

Dimensions: 19(22)25 μm (3 specimens)**Occurrence:** Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.**Distribution:** upper Mesozoic, Southeastern Australia (Dettmann 1963).**? *Gleichiidites* sp.**

Plate 21, Fig. 11

Spore tetrahedral, trilete, amb triangular; laesurae extending full of spore radius, laesurae thickened and raised; sides concave; sculpture scabrate; spore wall ca. 0.5 μm .

Dimensions: 21(24)26 μm (2 specimens)**Remarks:** There are no interrarial crassitudes for this species.**Occurrence:** Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.Genus ***Sestrosporites*** Dettmann 1963Type species: ***Sestrosporites irregulatus*** Dettmann 1963***Sestrosporites* sp. 1**

Plate 21, Fig. 12

Spore tetrahedral, trilete, amb subtriangular; laesurae extending full distance of spore radius, laesurae distinct and sinuous slightly; sides convex with thicker (ca. 2.5 μm) interrarial crassitudes and crassitude membrane like; sculpture foveolate; hilate on distal view.

Dimensions: 41 μm (1 specimen)**Occurrence:** Courtland Clay Pit.***Sestrosporites* sp. 2**

Plate 21, Figs. 13, 14

Spore tetrahedral, trilete, amb subtriangular; zonate, zona membranous, ca. 4 μm thick; laesurae extending full distance of spore radius, laesurae slightly sinuous; sides convex; sculpture foveolate, fovea irregular, elongate, ca. 1 μm ; spore wall ca. 3 μm .

Dimensions: 53(56)59 μm (excluding zona) (2 specimens)**Remarks:** It differs from *Sestrosporites* sp. 1 in its uniform thick zona and larger size.**Occurrence:** Ochs Clay Pit.Genus ***Camarozonosporites*** Pant ex Potonie emend. Klaus, 1960Type species: ***Camarozonosporites cretaceous*** (Weyland & Krieger) Potonie, 1956.***Camarozonosporites* sp.1**

Plate 21, Fig. 15

Spores tetrahedral, trilete, amb elliptical to circular; laesurae extending nearly full distance of spore radius, laesurae gapping; crassitude present at interrarial areas; sides convex; sculpture regulate, dense and delicate, ca. 1-2 μm wide.

Dimensions: 27(29)30 μm (2 specimens)

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

***Camarozonosporites* sp.3**

Plate 21, Figs. 16, 17

Spores tetrahedral, trilete, amb circular to subcircular; zonate, crassitude thicker at interrarial areas (7 μm wide) than that at apical areas (2.5 μm wide); laesurae raised and slightly sinuous, extending full distance of spore radius; sides convex; sculpture regulate on distal surface, rugulae thick and wide, ca. 5 μm wide, smooth and psilate on proximal surface.

Dimensions: 50(57)61 μm (3 specimens)

Occurrence: Ochs Clay Pit.

Suprasubturma **PERINOTRILITES** Erdtman

Genus *Crybelosporites* Dettmann, 1963

Type species: *Crybelosporites striatus* Dettmann, 1963.

***Crybelosporites* sp.**

Plate 21, Figs. 18, 19

Spore subcircular, trilete, laesurae ragged and raised, extending nearly full of spore radius; scabrate to granulate; with perine, perine membrane like, with hair like process on the surface, hair ca. 3.5 μm long; spore wall ca. 2.5 μm .

Dimensions: 47(54)62 μm (excluding perine) (5 specimens)

Remarks: This species probably shares affinity with the Salviniaceae (Hall, 1964).

Occurrence: Ochs Clay Pit.

Turma **MONOLETES** Ibrahim 1933

Subturma **AZONOMONOLETES** Luber 1935

Infraturma **LAEVIGATOMONOLETI** Dybova & Jachowicz 1957

Genus *Laevigatosporites* Ibrahim 1933

Type species: *Laevigatosporites vulgaris* (Ibrahim) Ibrahim, 1933.

Laevigatosporites ovatus Wilson and Webster 1946

Plate 21, Fig. 20

Spore monolete; aperture about half spore length; sculpture psilate to scabrate; spore wall thin and less than 1 μm .

Dimensions: 19(22)24 x 30(34)36 μm (6 specimens)

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: Upper Mesozoic, Australia (Dettmann 1963); middle Albian, east-central Alberta (Singh 1964).

Laevigatosporites cf. irroratus Hedlund 1966

Plate 21, Fig. 21

Spore monolete; oval to elliptical, aperture about 2/3 of spore length; sculpture fine granulate; spore wall thin, ca. 0.6 μm .

Dimensions: 22(24)25 x 27(28)28 μm (2 specimens)**Occurrence:** Highway 4 Clay Pit.*Laevigatosporites sp.2*

Plate 21, Fig. 22

Spore monolete; aperture long; scabrate, with fine granules occasionally; spore wall ca. 1 μm .

Dimensions: 32 x 61 μm (1 specimen)**Occurrence:** Courtland Clay Pit.Genus *Microfoveolatosporis* Krutzsch 1959Type species: *Microfoveolatosporis pseudodentatus* Krutzsch 1959*Microfoveolatosporis pseudoreticulatus* (Hedlund) Singh, 1963

Plate 21, Fig. 23

Spore monolete; elongate bean shaped; aperture not clear; sculpture granulate to microfoveolate; spore wall about 1.2 μm .

Dimensions: 21(23)25 x 50(53)56 μm (3 specimens)**Occurrence:** Courtland Clay Pit, Ochs Clay Pit.

Distribution: Cenomanian, southern Oklahoma (Hedlund 1966); Albian, southern Oklahoma (Hedlund and Norris 1968); middle Cenomanian, northwestern Alberta (Singh, 1983); and middle Cenomanian, northwestern Iowa and northeastern Nebraska (Ravn and Witzke, 1995).

Turma **HILATES** Dettmann, 1963Genus *Aequitriradites* Delcourt & Sprumont emend. Cookson & Dettmann 1961

Type species: *Aequitriradites dubius* Delcourt & Sprumont emend. Delcourt, Dettmann & Hughes 1963.

Aequitriradites spinulosus (Cookson and Dettmann) Cookson and Dettmann 1961

Plate 21, Fig. 24

Spores tetrahedral, trilete, amb subtriangular; zonate, zona with small pits, ca. 12 μm thick; laesurae extending full distance of spore radius and extending to the margin of the zona; sculpture baculate, one thinning area (hilate) present; spore wall of uniform thickness, about 1.5 μm thick.

Dimensions: 38(40)41 μm (excluding zona); 64 μm (including zona)(2 specimens)**Occurrence:** Courtland Clay Pit.

Distribution: Lower Cretaceous, eastern Australia (Cookson and Dettmann 1958a); and middle Albian, east-central Alberta (Singh 1964).

Genus *Triporoletes* Mtchedlishvili emend. Playford 1971

Type species: *Triporoletes singularis* Mtchedlishvili, in Mtchedlishvili & Samoilovich, 1960.

Triporoletes involucratus (Chlonova) Playford, 1971

Plate 21, Fig. 25

Spore elliptical to circular, aperture absent; zonate, zona thin and membranous; spore central body undulate; 4 convex projections and 4 concave embayments present; fine closely spaced, radially arranged, sinuous wrinkles on distal side.

Dimension: 35 μm (1 specimen)

Occurrence: Courtland Clay Pit.

Distribution: Albian, Saskatchewan and Manitoba (Playford 1971); and Cenomanian, northwestern Alberta (Singh 1983).

Triporoletes reticulatus (Pocock) Playford 1971

Plate 21, Figs. 26, 27

Spores tetrahedral, trilete mark absent, amb subtriangular; zonate, zona very thin, ca. 1 μm thick at the apices; sculpture reticulate on distal surface, lumina 5-11 μm , psilate to scabrate on proximal surface; spore wall ca. 2 μm .

Dimensions: 36 (44) 49 μm (3 specimens)

Remarks: The *Zlivisporis* has a distinct trilete mark which reaches up to the equator. Zona is absent and reticulum is arranged into a sparse net on the distal side.

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: Albian to Cenomanian, worldwide.

Triporoletes sp.1

Plate 22, Fig. 1

Spores tetrahedral, trilete, amb subtriangular; zonate, zona membranous like; laesurae extending full distance of spore radius and extending to the margin of the zona, slightly sinuous; sides convex, apices rounded; sculpture scabrate; spore wall of uniform thickness, about 1.2 μm thick.

Dimensions: 34(36)38 μm (excluding zona) (3 specimens)

Remarks: *Densoisporites* with interrational thickenings situated near the proximal pole. For *Triporoletes*, the proximal aperture is not clear or absent, and the zona have a flask-shaped to conical invagination at each radial position of the equator.

Occurrence: Courtland Clay Pit.

Triporoletes sp.2

Plate 22, Figs. 2, 3

Spores tetrahedral, trilete, amb subtriangular; zonate, zona membranous; laesurae extending full distance of spore radius and extending to the margin of the zona and laesurae branching in zona, laesurae sinuous; sides convex, apices rounded; sculpture scabrate on proximal side and reticulate on distal side, lumina polygonal and 11-13 μm in diameter, muri ca. 1 μm ; spore wall of uniform thickness, about 1.5 μm thick.

Dimensions: 42(44)45 μm (4 specimens)

Remarks: It differs from *Triporoletes reticulates* in its clear trilete mark, from *Triporoletes* sp.1 in its reticulate feature on distal side, from *Triporoletes* sp.3 in its sinuous laesurae and smaller size.

Occurrence: Courtland Clay Pit.

***Triporoletes* sp.3**

Plate 22, Fig. 4

Spores tetrahedral, trilete, amb triangular; zonate, zona membranous, usually not complete and broken; laesurae extending full distance of spore radius and extending onto zona, laesurae distinct and relatively straight; sides convex, apices rounded; sculpture scabrate; spore wall of uniform thickness, about 1.2 μm thick.

Dimensions: 49(51)52 μm (excluding zona) (3 specimens)

Remarks: It differs from *Triporoletes reticulatus* in its clear trilete mark, from *Triporoletes* sp.1 and *Triporoletes* sp.2 in its straight laesurae and larger size.

Occurrence: Courtland Clay Pit.

Genus *Chomotriletes* Naumova 1939 ex 1953

Type species: *Chomotriletes vedugensis* Naumova, 1953.

***Chomotriletes* sp.**

Plate 22, Fig. 5

Spore elliptical, inaperture; nearly concentric thin (less than 0.5 μm) ridges on spore surface.

Dimensions: 35 μm (1 specimen)

Occurrence: Courtland Clay Pit.

Spore type 1

Plate 22, Figs. 6, 7

Spores tetrahedral, trilete (?), amb subtriangular; laesurae not clear because of splitting; hilate in distal view; sculpture scabrate, granulate to regulate.

Dimensions: 40(43)46 μm (2 specimens)

Occurrence: Courtland Clay Pit.

Subturma **ZONOTRILETES** Waltz

Infraturma **AURICULATI** Schopf emend. Dettmann

Genus *Appendicisporites* Weyland & Krieger 1953

Type species: *Appendicisporites tricuspидatus* Weyland & Krieger, 1953.

***Appendicisporites auritus* Agasie 1969**

Plate 22, Fig. 8

Spores tetrahedral, trilete, amb triangular; laesurae not clear because of ridges; sculpture cicatricose, ridge wide (2-6 μm wide), with wide and blunt appendages.

Dimensions: 81 μm (1 specimen)

Occurrence: Ochs Clay Pit.

Distribution: Cenomanian, Arizona (Agasie 1969; Romans 1975); and Cenomanian, northwestern Alberta (Singh 1983).

Appendicisporites matesovae (Bolkhovitina) Norris 1967

Plate 22, Fig. 9

Spore subtriangular, aperture not clear; dense ridges on surface (ca. 1.5 μm wide); sparse baculae on ridges, baculae 6 μm high and 2 μm wide.

Dimensions: 37 μm (excluding baculae) (1 specimen).

Occurrence: Courtland Clay Pit.

Distribution: Albian to ? Cenomanian, central Alberta (Norris 1967); Cenomanian, Oklahoma (Hedlund 1966); and middle to late Albian (Singh 1971).

Appendicisporites cf. matesovae (Bolkhovitina) Norris 1967

Plate 22, Fig. 10

Spore subtriangular, aperture not clear; with ridges on surface (ca. 4 μm wide), 2.5 μm apart from each other; baculae on apices and distal surface, baculae 15 μm high and 4 μm wide, unclear for proximal surface.

Dimensions: 56 μm (excluding baculae) (1 specimen)

Remarks: The baculae in the holotype (3-8 μm long and 2-4 μm wide) are shorter than those of this species.

Occurrence: Ochs Clay Pit.

Appendicisporites potomacensis Brenner 1963

Plate 22, Figs. 11, 12

Spores tetrahedral, trilete, amb triangular; laesurae not clear because of ridges; sculpture cicatricose, ridge wide (2-2.5 μm wide), ridges fused before projecting spore outline.

Dimensions: 44(50)56 μm (2 specimens)

Occurrence: Courtland Clay Pit.

Distribution: Barremian to Albian, Maryland (Brenner 1963); Albian to ? Cenomanian, central Alberta (Norris 1967); middle Albian, east-central Alberta (Singh 1964); and middle to late Albian (Singh 1971).

Appendicisporites problematicus (Burger) Singh, 1971

Plate 22, Figs. 13, 14

Spores tetrahedral, trilete, amb triangular; spore with appendages at apices, appendage ca. 12 μm high and 6 μm wide; laesurae extending nearly full of spore radius; sculpture cicatricose; ridge wide, ca. 3 μm , ridges sinuous, 2 μm apart from each other; ridges on distal surface parallel to spore sides and forming a triangle in the center.

Dimensions: 58(76)90 μm (4 specimens)

Occurrence: Ochs Clay Pit.

Distribution: middle to late Albian, northwestern Alberta (Singh 1971).

Genus ***Plicatella*** Maljavkina 1949 emend. Potonie 1960

Type species: ***Plicatella trichacantha*** Maljavkina 1949.

Plicatella fucosa (Vavrdova) Davies 1985

Plate 22, Fig. 15

Spore tetrahedral, trilete, amb triangular; laesurae not clear because of ridges; sculpture cicatricose, ridge wide (2.5-3 μm), ridges fused outside of the outline of spore.

Dimensions: 45(48)50 μm (2 specimens)

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: ? lower to middle Cenomanian, northwestern Iowa and northeastern Nebraska (Ravn and Witzke 1995).

Plicatella witzkei Ravn 1995

Plate 22, Fig. 16

Spore tetrahedral, trilete, amb triangular; laesurae not clear because of ridges; sculpture cicatricose, ridge dense and relatively narrow (1-2 μm wide), ridges fused outside of the outline of spore, tiny pits present on some ridges.

Dimensions: 44(44)45 μm (3 specimens)

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit.

Distribution: middle to upper Albian, Alberta (Norris 1967); and upper Albian, Wyoming (Ravn 1995)

Plicatella sp.1

Plate 22, Fig. 17

Spore tetrahedral, trilete, amb subtriangular to elliptical; laesurae extending ca. half of the radius, gapping; sculpture cicatricose, ridge dense and wide (2.5 μm wide), ridges apart from each other ca. 0.5 μm , ridges fused outside of the outline of spore.

Dimensions: 32 μm (1 specimen)

Occurrence: Courtland Clay Pit.

Plicatella sp.2

Plate 22, Figs. 18, 19

Spore tetrahedral, trilete, amb subtriangular; laesurae extending more than 2/3 of the spore radius, laesurae gapping; sculpture cicatricose, ridge dense and wide (6 μm wide), ridges fused outside of the outline of spore; appendage small and short.

Dimensions: 48 μm (1 specimen)

Occurrence: Courtland Clay Pit.

Genus ***Trilobosporites*** Pant ex Potonie 1956

Type species: ***Trilobosporites hannonicus*** (Delcourt & Sprumont) Potonie 1956

Trilobosporites purverulentus (Verbitskaya) Dettmann, 1963

Plate 22, Fig. 20

Spore tetrahedral, trilete, amb triangular; laesurae extending 2/3 of spore radius, distinct and straight; sides concave, apices well-rounded; sculpture scabrate to foveolate, fovea (ca. 1.5-3 μm) on apices region and other part of surface scabrate; spore wall ca. 2 μm thick.

Dimensions: 43(48)52 μm (2 specimens)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Distribution: Aptian and Albian, southeastern Australia (Dettmann 1963); middle Albian, Oklahoma (Hedlund and Norris 1968); Albian, Saskatchewan and Manitoba

(Playford 1971); Cenomanian, Louisiana (Phillips and Felix, 1972a); and Cenomanian (Singh 1983).

Algal, Fungal and Megaspore

Genus *Laevigatasporites* Potonie & Gelletich 1933

Type species: *Laevigatasporites magnus* (Potonie) Potonie & Gelletich 1933

Laevigatasporites sp.

Plate 23, Fig. 1

Spore large, subcircular; inaperture, psilate to scabrate, full of folds on surface; spore wall very thin, ca. 0.5 μm .

Dimensions: 81 μm (1 specimen).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit.

Genus *Oedogonium* Link 1820

Type species: *Oedogonium cretaceum* Zippi, 1998

Oedogonium cretaceum Zippi, 1998

Plate 23, Fig.2

Oospore, spherical to subspherical; thick outer wall surrounding a solid porous body.

Dimensions: 24 μm (1 specimen).

Remarks: Modern species of *Oedogonium* are distributed in fresh water throughout the world (Tiffany, 1930; Fritsch, 1961) and can indicate slow moving or still shallow fresh water (Zippi, 1998).

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Distribution: Albian, Ontario (Zippi 1998).

Genus *Ovoidites* Potonie 1951 ex Thomson and Pflug 1953 emend. Krutzsch 1959

Type species: *Ovoidites ligneolus* Potonie ex Krutzsch, 1959.

Ovoidites grandis (Pocock) Zippi, 1998

Plate 23, Fig. 3

Spore elliptical; splitting equatorially into two elongate sections, psilate; spore wall ca. 1 μm .

Dimensions: 58(74)89 x 125(152)178 μm (2 specimens).

Occurrence: Ochs Clay Pit.

Distribution: Cenomanian, Oklahoma (Hedlund 1966); Albian, Ontario (Zippi 1998).

Ovoidites sp.

Plate 23, Fig. 4

Spore elliptical; splitting equatorially into two halves, psilate to scabrate; spore wall ca. 1 μm .

Dimensions: 16(19)24 x 30(39)54 μm (4 specimens).

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

? *Ovoidites* sp. 1

Plate 23, Fig. 5

Spore elliptical; aperture wide, splitting equatorially into two halves; reticulate, lumina uneven, 0.5-4 μm , muri uneven, 0.5-1 μm ; spore wall 1-2 μm .

Dimensions: 48 x 80 μm (1 specimen).

Occurrence: Highway 4 Clay Pit.

? *Ovoidites* sp. 2

Plate 23, Fig. 6

Spore elliptical; aperture wide, splitting equatorially into two halves; verrucate to baculate; spore wall 1 μm .

Dimensions: 48 x 80 μm (1 specimen).

Occurrence: Ochs Clay Pit.

Genus *Palambages* O. Wetzel 1961

Palambages sp.

Plate 23, Fig. 7

Algal colony, individual cell ca. 15 μm ; ca. 16 cells in colony; the cell wall is psilate to scabrate; there are folds on cell surface.

Dimensions: colony 38 x 54 μm (1 specimen)

Occurrence: Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.

Genus *Pediastrum* Meyen 1829

Pediastrum sp.

Plate 23, Fig. 8

Algal colony; with spines, spines connected each other, spine point blunt.

Dimensions: colony 28 x 35 μm (1 specimen)

Occurrence: Courtland Clay Pit.

Genus *Schizosporis* Cookson and Dettmann emend. Pierce 1976

Type species: *Schizosporis reticulatus* Cookson and Dettmann, 1959.

Schizosporis reticulatus Cookson and Dettmann, 1959

Plate 23, Figs. 9, 10

Probable algal colony; individual cell ca. 5 x 8 μm .

Dimensions: 107 x 117 μm (1 specimen).

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Distribution: Berriasian to Cenomanian (? Early Turonian) in North America, Australia, and Europe (Zippi, 1998).

Genus *Tetraporina* Naumova emend. Lindgren 1980

Type species: *Tetraporina antique* Naumova, 1950.

***Tetraporina* sp.**

Plate 23, Fig. 11

Spore quadrate; sides concave, surface psilate to scabrate.

Dimensions: 47 μm (1 specimen).**Remarks:** *Tetraporina* is similar to several genera of the modern Zygnemataceae (Jarzen, 1979) based on the characteristics such as size, wall thickness and overall quadrate morphology.**Occurrence:** Courtland Clay Pit, Ochs Clay Pit.**Fungal spore type 1**

Plate 23, Fig. 12

Individual cell square to rectangular; cell wall ca. 0.5 μm , each cell with an opening to connect each other.**Dimensions:** cell 7 x 8 μm (1 specimen).**Occurrence:** Courtland Clay Pit, Highway 4 Clay Pit, Ochs Clay Pit.**Fungal spore type 2**

Plate 23, Fig. 13

Individual cell (?), ovate; psilate, cell wall thin, ca. 0.5 μm , thinning area present on the center of the cell.**Dimensions:** 32 x 53 μm (1 specimen).**Occurrence:** Highway 4 Clay Pit.**Fungal spore type 3**

Plate 23, Fig. 14

Individual cell (?), irregular, central body elliptical.

Dimensions: 12 x 25 μm (1 specimen).**Occurrence:** Highway 4 Clay Pit.**Fungal spore type 4**

Plate 23, Fig. 15

Individual cell irregular elongate, at least 9 individual cells link together.

Dimensions: cell 4 x 22 μm (1 specimen).**Occurrence:** Courtland Clay Pit, Highway 4 Clay Pit.**Fungal spore type 5**

Plate 23, Fig. 16

Individual cell square to rectangular; cell wall ca. 1 μm , cells may be linked together by a central "canal".**Dimensions:** cell 12 x 12 to 11 x 16 μm (1 specimen).**Occurrence:** Highway 4 Clay Pit, Ochs Clay Pit.**Fungal spore type 6**

Plate 23, Fig. 17

Individual cell (?), ovate to elliptical; wall ca. 2.5 μm .

Dimensions: 18 x 28 μm (1 specimen).
Occurrence: Highway 4 Clay Pit.

Fungal fruiting body of the family Microthyriaceae

Plate 23, Fig. 18

Fruiting body circular, with radiating rows of cells; cells square to elongate, 5 to 9 μm long and 3 to 6 μm wide; there is a hole in the center of the body.

Dimensions: body diameter 59 μm (1 specimen)

Remarks: This is the same as the specimen Singh (1971) described. It is similar to the species of *Microthallites* described by Dilcher (1965).

Occurrence: Courtland Clay Pit.

Distribution: Late Albian, northwestern Alberta (Singh 1971).

Megaspore type 1

Plate 24, Fig. 1

Spore circular; probably scabrate to fine granulate; proximally surmounted by a prominent trifoliate acrolamella, echinae (ca. 4 μm long) evenly distributed on surface of acrolamella.

Dimensions: Spore body: 62 μm ; overall length of the body and acrolamella: 136 μm (1 specimen).

Occurrence: Highway 4 Clay Pit.

Genus *Balmeisporites* Cookson and Dettmann 1958

Type species: *Balmeisporites holodictyus* Cookson and Dettmann, 1958.

Balmeisporites glenelgensis Cookson and Dettmann

Plate 23, Figs. 2, 3

Spore circular; reticulate, lumina 8-18 μm , muri ca. 3 μm , with acrolamella; spore wall ca. 5 μm .

Dimensions: Spore body: 156 μm ; overall length of the body and acrolamella: 190 μm (1 specimen).

Occurrence: Ochs Clay Pit.

Distribution: Upper Cretaceous, Victoria, Australia (Cookson and Dettmann 1958b); Cenomanian, Oklahoma (Hedlund 1966); Cenomanian, Arizona (Agasie 1969; Romans 1975); middle to upper Cenomanian, northwestern Iowa and northeastern Nebraska (Ravn and Witzke 1995).

Dinoflagellate Cysts and Acritarchs

Dinoflagellate Cysts

Genus *Oligosphaeridium* Davey and Williams 1966

Type species: *Oligosphaeridium complex* (White) Davey and Williams, 1966.

Oligosphaeridium reniforme (Tasch) Davey, 1969

Plate 25, Figs. 1, 2

Central body elliptical, with apical archaeopyle; with funnel-shaped processes that expanded gradually from base to the distal ends, the extremities of the processes are flat with short (ca. 2 μm) hair like spines.

Dimensions: Size of central body: 50 x 55 μm ; length of processes: 17-22 μm ; width of processes at base: 2-6 μm ; width of processes at distal ends: 18-22 μm . (1 specimen)

Occurrence: Ochs Clay Pit.

Distribution: Albian to Cenomanian, Saskatchewan (Davey 1969).

? *Oligosphaeridium* sp.

Plate 25, Figs. 3-6

Central body elliptical; with funnel-shaped processes whose width is smallest at middle of the processes, the extremities of the processes are serrate.

Dimensions: size of central body: 59 x 68 μm ; length of processes: 10-17 μm ; width of processes at base: 1-3 μm ; width of processes at distal ends: 4-9 μm . (1 specimen)

Remarks: The processes are slender for this species compared with those of *Oligosphaeridium reniforme*.

Occurrence: Ochs Clay Pit.

Genus *Nyktericysta* Bint, 1986

Type species: *Nyktericysta davisii* Bint, 1986

***Nyktericysta* cf. *pentagona* (Singh, 1983) Bint, 1986**

Plate 25, Figs. 7, 8; Plate 26, Fig. 1

Cyst proximate, pentagonal shape; two layered, epiphragm membrane, wrinkled, epiphragm is appressed to endophragm except for at horns; one apical, two lateral and two antapical horns; there is a small appendage on the tip of apical and antapical horns; cingulum and tabulation are not clear.

Dimension: 50(57)64 x 79(81)83 μm (4 specimens)

Remarks: Compared with the specimens from middle Cenomanian that Singh described in 1983 (75 x 111 μm), the specimens described here are smaller. Also, the reticulate structures are not clear on endophragm.

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Genus *Canningia* Cookson & Eisenack 1960a

Type species: *Canningia reticulata* Cookson & Eisenack 1960a

? *Canningia* sp.

Plate 26, Fig. 2

Proximate cyst, with an apical archeopyle; having evenly distributed processes, tip of process branching, ca. 4 μm long.

Dimension: 40 x 61 μm (1 specimen)

Occurrence: Courtland Clay Pit.

Genus *Coronifera* Cookson and Eisenack emend. Davey 1974
 Type species: *Coronifera oceanica* Cookson and Eisenack, 1958.

Coronifera oceanica Cookson and Eisenack, 1958

Plate 26, Figs. 3-5

Central body elliptical; granulate to scabrate, with spines, spine simple, not furcating; antapical process present, extremities of antapical process serrate.

Dimensions: size of central body: 36(41)45 x 42(46)49 μm ; length of processes: 9-12 μm ; antapical process 7(8)9 x 10 μm . (2 specimens)

Occurrence: Ochs Clay Pit.

Distribution: Upper Aptian, Germany (Eisenack 1958); Albian, Australia (Cookson and Eisenack 1958); Albian to Cenomanian, England (Cookson and Hughes 1964; Davey 1969); and Albian, Saskatchewan (Davey 1969).

Genus *Cyclonephelium* Deflandre & Cookson emend. Stover & Evitt 1978

Type species: *Cyclonephelium compactum* Deflandre & Cookson 1955

Cyclonephelium cf. *vannophorm* Davey, 1969

Plate 26, Figs. 6, 7

Shell subcircular; with apical prominence and two reduced antapical horns; with apical archaeopyle; granular shell wall with short processes which bifurcating sometimes, process shape irregular; a wide sulcus present from antapical horn to archaeopyle margin.

Dimension: overall length of shell (including operculum): 74(81)88 μm ; overall width of shell: 66(69)72 μm ; length of processes: 4 μm . (2 specimens)

Remarks: The processes are shorter than those of the holotype (up to 8 μm).

Occurrence: Ochs Clay Pit.

? *Cyclonephelium* sp.

Plate 26, Figs. 8, 9

Shell elliptical, operculum probably gone, antapical horns not clear; psilate to scabrate; with short funnel shaped processes, extremities of processes serrate.

Dimension: overall length of shell: 88(93)98 μm ; overall width of shell: 62(73)84 μm ; length of processes: 2-5 μm . (2 specimens)

Occurrence: Ochs Clay Pit.

Genus *Odontochitina* Deflandre emend. Davey 1970

Type species: *Odontochitina operculata* Deflandre & Cookson, 1955.

cf. *Odontochitina* sp.

Plate 26, Fig. 10

Single isolated horn; regulate to scabrate; one circular (8 μm in diameter) thinning area in the middle of the horn, another thinning area (ca.3 μm in diameter) at the tip of the horn.

Dimension: 63 x 26 μm for entire specimen and 44 x 11 μm for horn (width in middle of horn) (1 specimen)

Occurrence: Courtland Clay Pit.

Genus *Pterodinium* Eisenack 1958

Type species: *Pterodinium aliferum* Eisenack, 1958.

cf. *Pterodinium cingulatum* subsp. *cingulatum*

Plate 26, Fig. 11

Cyst proximochorate, subcircular shape; subspherical body with high parasutural septa, septa membrane; there are pits on central body surface; cingulum and tabulation are not clear.

Dimension: 31(38)44 μm (2 specimens)

Remarks: The holotype specimen (50-54 μm) is larger than specimens found here.

Occurrence: Courtland Clay Pit.

Genus: *Subtilisphaera* Jain & Millepied 1973

Type species: *Subtilisphaera senegalensis* Jain & Millepied 1973

***Subtilisphaera deformans* (Davey and Verdier) Stover and Evitt, 1978**

Plate 26, Fig. 12

Cyst proximate; pericyst forming a prominent, broad-based conical apical horn, two uneven antapical horns; left antapical horn is nearly as long as apical horn, right antapical horn is vestigial; pericyst membranous, both pericyst and endocyst fine granulate, endocyst appressed laterally to one side of pericyst, tabulation not clear.

Dimensions: pericyst size: 48 x 87 μm ; endocyst size: 44 x 50 μm (1 specimen)

Occurrence: Ochs Clay Pit.

Distribution: middle Albian, France (Davey and Verdier 1971); Albian, eastern Canada (Bujak and Williams 1978); and Albian to middle Cenomanian, northwestern Canada (Singh 1983).

Genus *Geiselodinium* Krutzsch 1962

Type species: *Geiselodinium geiseltalense* Krutzsch 1962

cf. *Geiselodinium* sp.

Plate 27, Fig. 1

Cyst cavate, heart shape; periphragm psilate and endophragm with fine granules; tip of apical horn and antapical horns blunt; cingulum and sulcus present but tabulation is not clear.

Dimension: 36(43)47 x 47(48)50 μm (3 specimens)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Genus *Trithyrodinium* Drugg emend. Lentin & Williams 1976

Type species: *Trithyrodinium evittii* Drugg, 1967.

? *Trithyrodinium* sp.

Plate 27, Figs. 2, 3

Cyst proximate; two layered, with a short apihorn, ca. 9 μm long; two antapihorn may exist, periphragm psilate and endophragm hairy, tabulation not clear.

Dimensions: 48(52)58 x 65(69)73 μm (3 specimens)

Occurrence: Ochs Clay Pit.

Dino cyst type A

Plate 27, Fig. 4

Cyst single wall, thin; elliptical shape; psilate; a lot of folds on the surface; tabulation are not clear.

Dimension: 34(36)39 x 48(49)50 μm (3 specimens)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Dino cyst type B

Plate 27, Fig. 5

Cyst proximochorate; subcircular to elliptical shape; subspherical body with membrane-like short parasutural septa; cingulum and tabulation are not clear.

Dimension: 42(43)44 μm (3 specimens) for subcircular shape; 38(41)43 x 45(47)48 μm for elliptical shape (2 specimens).

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Dino cyst type C

Plate 27, Fig. 6

Cyst single wall, thin; subcircular shape; microgranulate; a lot of folds on the surface; tabulation are not clear.

Dimensions: 39 μm (1 specimen)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Dino cyst type D

Plate 27, Fig. 7

Cyst single wall, very thin; subcircular shape; dense hair-like processes on surface, ca. 3 μm long; a lot of folds on the surface; tabulation are not clear.

Dimensions: 31(33)35 x 36(37)37 μm (2 specimens)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Dino cyst type H

Plate 27, Fig. 8

Cyst single wall, thin; subcircular shape; short hair-like short processes on surface and tip of process branching; a lot of folds on the surface; tabulation are not clear.

Dimensions: 29 x 30 μm (1 specimen)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Dino cyst type I

Plate 27, Fig. 9

Cyst two layered, subcircular; both epicyst and endocyst with granules, granule size uneven, 0.2-0.6 μm .

Dimensions: 41 μm (1 specimen)

Occurrence: Ochs Clay Pit.

Acritarchs

Genus *Micrhystridium* Deflandre 1937

Type species: *Micrhystridium inconspicuum* Deflandre, 1937.

Micrhystridium singulare Firtion, 1952.

Plate 27, Fig. 10

Central body polygonal; processes more than 10 on surface, processes fluffy and sinuous, hollow, ca. 14-16 μm long; test wall very thin and psilate.

Dimensions: diameter of central body ca. 25 μm ; maximum length of process ca. 16 μm . (1 specimen)

Remark: The process is longer than the central body for the holotype.

Occurrence: Courtland Clay Pit.

Distribution: Albian to Cenomanian, England (Davey 1969).

Micrhystridium sp.1

Plate 27, Fig. 11

Central body nearly circular; sparse processes on surface, processes rigid and strong, tip is very sharp, ca. 7-12 μm long; test wall very thin and psilate.

Dimensions: diameter of central body ca. 24 μm ; maximum length of process ca. 12 μm . (1 specimen)

Remark: The processes have broad bases and taper gradually.

Occurrence: Courtland Clay Pit.

Micrhystridium sp.2

Plate 27, Fig. 12

Central body subcircular to elliptical; sparse short processes on surface, processes curled at the tip, and sharp, ca. 5-7 μm long; test wall membrane like, psilate.

Dimensions: diameter of central body ca. 34(35)35 x 41(42)42 μm ; maximum length of process ca. 7 μm . (2 specimens)

Remark: The processes are without broad bases.

Occurrence: Courtland Clay Pit.

Micrhystridium sp.3

Plate 27, Fig. 13

Central body irregular; dense hair like processes on surface, long, ca. 13-17 μm ; processes curled and tip of processes sharp; test wall thin and psilate.

Dimensions: diameter of central body ca. 24(27)30 x 30(34)37 μm ; maximum length of process ca. 17 μm . (2 specimens)

Remark: The processes are without broad bases.

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Micrhystridium sp.4

Plate 27, Fig. 14

Central body circular; thick and stiff processes uniformly distributed, long, ca. 11-17 μm ; processes tapering distally but tip is blunt; test wall thin and scabrate.

Dimensions: diameter of central body ca. 30 μm ; maximum length of process ca. 17 μm . (1 specimen)

Remark: Compared with *M. sp.1*, the processes of this species are thicker and longer.

Occurrence: Courtland Clay Pit.

Micrhystridium sp.5

Plate 27, Figs. 15, 16

Central body circular; with rare and sharp processes, process ca. 4-5 μm long, less than 1 μm wide at base; test wall thin and scabrate.

Dimensions: diameter of central body ca. 11(12)12 μm ; maximum length of process ca. 5 μm . (2 specimens)

Occurrence: Courtland Clay Pit, Ochs Clay Pit.

Genus *Pterospermella* Eisenack 1972

Type species: *Pterospermella aureolata* (Cookson & Eisenack) Eisenack 1972

Pterospermella australiensis (Deflandre & Cookson) S.K. Srivastava, 1984

Plate 27, Fig. 17

Overall subcircular and central body nearly circular; central body opaque; the flank scabrate.

Dimensions: overall diameter ca. 23 μm ; central body ca. 11 μm . (1 specimens)

Remark: This species is relatively smaller compared to other species.

Occurrence: Courtland Clay Pit.

Distribution: Barremian, France (Srivastava 1984)

Genus *Veryhachium* Deunff emend. Downie & Sarjeant 1963

Veryhachium reductum Deunff 1961

Central body triangular; bearing a process at each corner; the process hollow and tapering distally to a fine point; test wall thin and psilate to scabrate.

Dimensions: diameter of central body 20(29)38 μm ; length of process ca. 10(12)13 μm . (2 specimens)

Occurrence: Ochs Clay Pit, Courtland Clay Pit.

Distribution: Ordovician, Silurian, Permian, Triassic, Jurassic and lower Cretaceous, France and England (Davey 1969).

Veryhachium cf. reductum Deunff

Plate 27, Fig. 18

Central body triangular; bearing a process at each corner; the process hollow and tapering distally to a fine point; test wall thin and psilate to scabrate.

Dimensions: diameter of central body 46 μm ; maximum length of process ca. 21 μm . (1 specimen)

Remark: It is bigger than the holotype (12(16)21 μm).

Occurrence: Courtland Clay Pit.

***Veryhachium* sp.1**

Plate 27, Fig. 19

Central body slightly inflated; at least 6 curved processes present; processes hollow, tip of processes blunt; test wall very thin and scabrate.

Dimensions: diameter of central body ca. 19 μm ; maximum length of process ca. 24 μm . (1 specimen)

Remark: The processes are not circular in cross section

Occurrence: Courtland Clay Pit.

***Veryhachium* sp.2**

Plate 27, Fig. 20

Central body triangular; 3 curved processes radiated from central body; processes hollow, tip of processes sharp; test wall thin and granulate.

Dimensions: diameter of central body ca. 18 μm ; maximum length of process ca. 30 μm . (1 specimen)

Occurrence: Courtland Clay Pit.

***Veryhachium* sp.3**

Plate 27, Fig. 21

Central body nearly rectangular; bearing a process at each corner; the processes hollow and tapering distally to a fine point; processes wide based and 11-15 μm long; test wall very thin and scabrate to psilate.

Dimensions: diameter of central body ca. 11x18 μm ; maximum length of process ca. 15 μm . (1 specimen)

Occurrence: Courtland Clay Pit.

Acritarch type A

Plate 27, Fig. 22

Central body circular; hollow processes uniformly distributed; processes acuminate, bifid or branched-bifid; test wall thin and psilate.

Dimensions: diameter of central body ca. 19(20)21 μm ; maximum length of process ca. 11 μm . (2 specimens)

Occurrence: Courtland Clay Pit.

Acritarch type B

Plate 27, Fig. 23

Central body irregular or elliptical; hollow processes uniformly distributed; processes long and acuminate, bifid or branched-bifid; test wall thin and psilate.

Dimensions: diameter of central body ca. 9 x 15 μm ; maximum length of process ca. 18 μm . (1 specimen)

Remark: The shape is different from acritarch type A.

Occurrence: Courtland Clay Pit.

Acritach type C

Plate 28, Figs. 1, 2

Central body elliptical; dense processes uniformly distributed; processes long and bifurcating; test wall thin and fine granulate.

Dimensions: diameter of central body ca. 59 x 68 μm ; length of process ca. 10-13 μm . (1 specimen)

Occurrence: Ochs Clay Pit.

? Acritarch type 1

Plate 28, Fig. 3

Cyst single wall; subcircular shape; reticulate or regulate; folds on the surface; tabulation are not clear.

Dimensions: 27 x 30 μm (2 specimens)

Occurrence: Courtland Clay Pit.

? Acritarch type 2

Plate 28, Fig. 4

Cyst single wall, relatively thick, ca. 1 μm ; elliptical shape; scabrate, a lot of folds on surface; tabulation are not clear.

Dimensions: 37 x 59 μm (1 specimen)

Occurrence: Courtland Clay Pit.

? Acritarch type 3

Plate 28, Fig. 5

Cyst single wall, thin; subcircular to elliptical shape; sparse granules on surface and there is a pit on each granule, a lot of folds on the surface; tabulation are not clear.

Dimensions: 35 μm for subcircular shape (1 specimen); 21 x 31 μm for elliptical shape (1 specimen)

Occurrence: Courtland Clay Pit.

? Acritarch type 4

Plate 28, Fig. 6

Cyst single wall, thin; subcircular to circular shape; fur-like short processes on surface, a lot of folds on the surface; tabulation are not clear.

Dimensions: 26(30)30 μm (2 specimens)

Occurrence: Courtland Clay Pit.

? Acritarch type 5

Plate 28, Fig. 7

Cyst single wall, very thin membrane-like, subcircular shape; a lot of folds on the surface; tabulation are not clear.

Dimensions: 28(31)34 x 35(36)37 μm (2 specimens)

Occurrence: Courtland Clay Pit.

CHAPTER 5 GEOLOGICAL SETTING: REGIONAL AND STUDY AREA

Regional

During the early Cretaceous, two epicontinental seas, the Boreal in the north and the Gulf in the south, were present on continental North America, with the Boreal Sea advancing southward and the Gulf Sea northward (Obradovich and Cobban, 1975). These two seas joined together to form the Western Interior Seaway, a continuous sea extending from the Arctic to the Gulf of Mexico across the North America continent, which was present by the Late Albian age (Witzke and Ludvigson, 1996) (Figure 5-1). The Western Interior Seaway was transgressive during the Late Albian to the Cenomanian (Kauffman, 1977) and was bordered on the west by the Cordilleran thrust belt and on the east by the cratonic platform (Dyman, et al., 1994). Because of variable rates of subsidence related to tectonic and sediment loading, an asymmetric sedimentary basin with thick Cretaceous sediments in the west and thin sediments in the east, was formed (Dyman, et al., 1994).

The type area of the Dakota Formation is located in northeastern Nebraska and northwestern Iowa along the Missouri River (Ravn and Witzke, 1995). “Dakota” is used as a lithostratigraphic unit across a vast area of central and west-central North America (Ravn and Witzke, 1995) (Figure 5-2). However, this name often has been used without consideration of the relationship to the type Dakota, either lithostratigraphically or chronostratigraphically (Witzke, et al., 1983). So the age and lithology of the Dakota

Formation are probably not the same from the west margin to the east margin of the Western Interior Seaway.

The Dakota Formation, a sequence of nonmarine to marginal marine facies, is the oldest Cretaceous sediment in southwestern Minnesota (Witzke and Ludvigson, 1994). The Dakota Formation in southwestern Minnesota includes two units, the lower sandstone lithostratigraphic unit, which is similar to the Nishnabotna Member, and the upper mudstone lithostratigraphic unit, which is similar to the Woodbury Member of the Dakota Formation in age and lithology (Setterholm, 1994) (Figure 5-3). Currently, the age of the Dakota Formation in southwest Minnesota is thought to be Cenomanian (Setterholm, 1994). However this suggestion for Cenomanian age is mainly based upon the interpretation of Lesquereux (1895) and Pierce (1961). The interpretations of megafossils by Lesquereux (1895) and microfossils by Pierce (1961) all need reexamination and reinterpretation (Upchurch and Dilcher, 1990; Wang H., 2002, Hu et al., 2004). The age of the Dakota Formation in southwest Minnesota is uncertain at this time and will be addressed in this dissertation.

Stratigraphy and Sedimentary Environments in Study Area

Courtland Clay Pit

The sediments at Courtland Clay Pit are dominated by laminated mudstone (Figure 5-4 and Figure 5-5). Hajek et al. (2002) interpreted the sedimentary environment as a large lake based upon the mm- to cm-scale laminae, scattered well-preserved leaves, and siderite concretions. Lake Drummond in Virginia is a typical coastal lake and may be a good analogy of the large Cretaceous lake at Courtland Clay Pit (Figure 5-6).

Highway 4 Clay Pit

The sediments at Highway 4 Clay Pit consist predominantly of tabular cross-bedded sandstone and carbonaceous siltstone (Figure 5-7 and Figure 5-8). Hajek et al. (2002) interpreted the sedimentary environment as a tidally influenced meandering river system based on the inclined heterolithic stratification (IHS) and tabular cross-bedded fine-grained sandstone. Oxbow lake, ridge and swale, and levee are important environments associated with a meandering river system (Figure 5-9).

Ochs Clay Pit

The sediments at Ochs Clay Pit are dominated by silty mudstone and siltstone (Figure 5-10). Sloan (1964) indicated that the sediments below the lignite layer probably represent the lacustrine environment based on the varved mudstone and abundant leaf fossils, and the sediments above the lignite layer probably represent the estuarine environment based upon the silty and sandy mudstone and several vertebrae of sharks. The lignite layer extended broadly and its thickness is relatively constant. The ash content of the lignite is 32%-41%. This kind of lignite is probably not from the peat accumulation in close association with active clastic depositional environments such as on the floodplain of meandering rivers, in coastal mires close to active beach barrier systems, in interdistributary bays and even levees of delta tops (McCabe, 1987). The lignite in the locality may represent the distal side of the coastal swamp, which is not close to the active beach barrier systems. According to Walther's Law (Boggs, 2001), the lignite probably represented a coastal swamp. The Dismal swamp in Virginia and North Carolina is a typical coastal swamp associated with the bar-built estuaries and lakes, and may be a good analogy of the Cretaceous coastal swamp at Ochs Clay Pit (Figure 5-6). Twenhofel (1932) suggested that the ideal lacustrine sequence for a low-

energy lake (Figure 5-11) is one in which the lacustrine mud deposits are overlain by peat deposits of swamps. For a high-energy lake the ideal sequence has sediments that coarsen upwards (Visher, 1965) (Figure 5-11). According to these ideas, the top lacustrine sediments at Ochs Clay Pit seem to represent a low-energy lake paleoenvironment.

The Stratigraphic Relationships of the Localities

The Cretaceous sediments at the three clay pits studied here in southwestern Minnesota were isolated from each other. It is very difficult to make correlations between these three clay pits based upon their lithology. Megafossils are not satisfactory for comparative dating between these localities because even numbers of leaves are available in our collections and a stratigraphic sequence of leaf species have not been worked out yet for the Dakota Formation leaf fossils. However, plant microfossils are abundant in the sediments at these three clay pits. Pollen has been successfully used for Dakota Formation stratigraphic zonations of other areas (Brenner et al. 2000). Based upon the common occurrence of *Liliacidites reticulatus*, *Tricolpites cf. vulgaris*, *Phimopollenites striolata* and *Fraxinoipollenites constrictus* in sample 036710 at Courtland Clay Pit, in sample 046517 at Highway 4 Clay Pit, and in sample 046522 at Ochs Clay pit, I suggest that the sediments from which these samples were collected represented time equivalent deposits (Figure 5-12). Thus it is possible to make some stratigraphic comparisons between these three clay pits. The pollen studies also provide a framework for paleoenvironmental interpretations of localities.

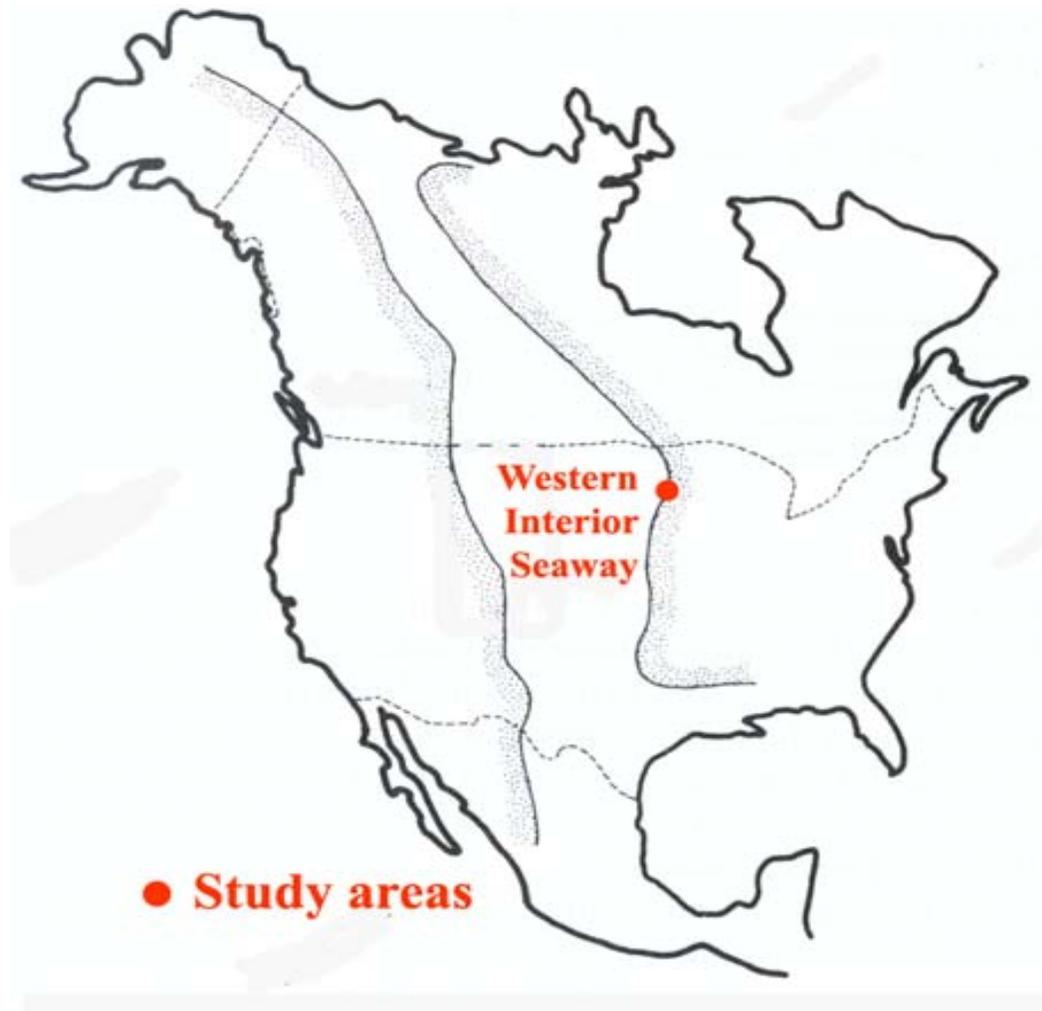


Figure 5-1. Map of North America with the location of Western Interior Seaway during the Cenomanian (early Late Cretaceous). Modified from Parrish, et al., 1984, Parrish, et al. modified from Ziegler et al., 1983.

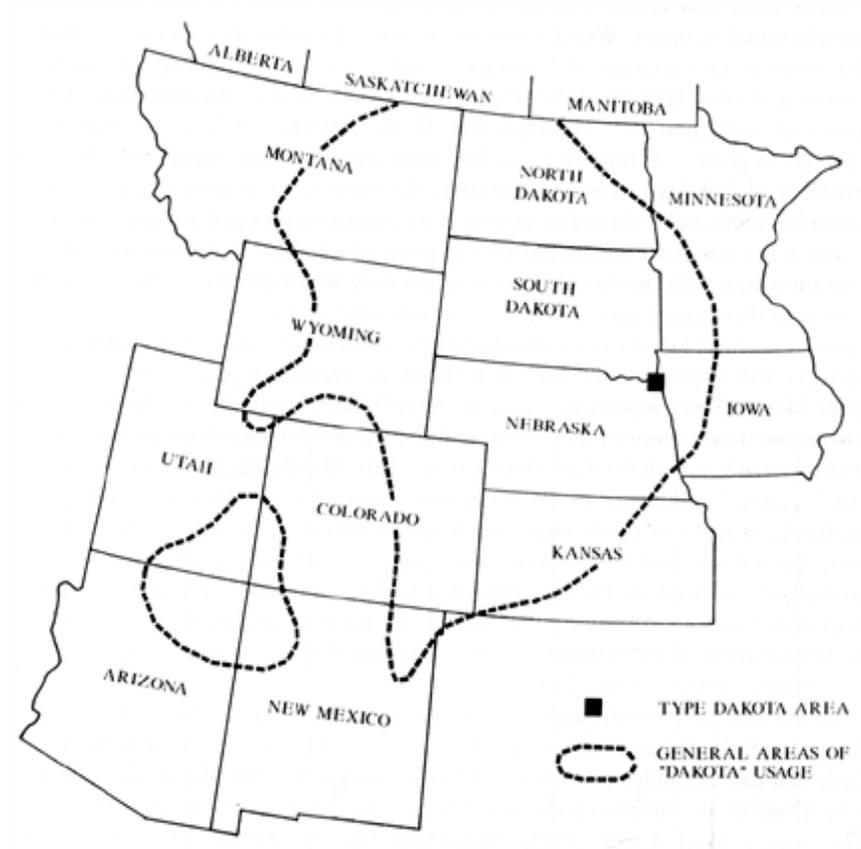


Figure 5-2. Area of west-central United States in which the lithostratigraphic name “Dakota” is used. (from Ravn et al., 1995).

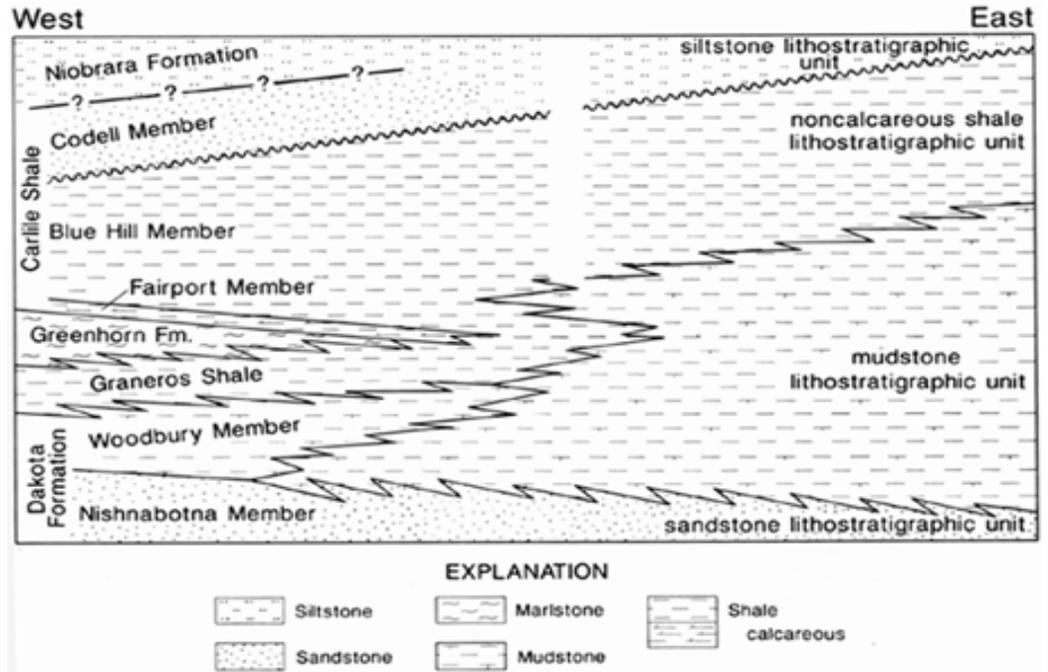
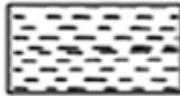


Figure 5-3. Schematic cross section of lower Upper Cretaceous sediments in southwestern Minnesota. (from Setterholm, 1994)

	Thickness (cm)	Lithological description	Samples	Sedimentary environments
	280	massive yellowish gray mudstone, with limonitic concretions	036707 036704 036702	lacustrine (based upon the present study and Hajek et al., 2002)
		dark gray mudstone, intercalated with thin organic rich layers	036699 036694 036690	
	127.5	pale green siltstone, grain sizes decrease upward		
	8	grayish green sandstone with rounded pyrite concretions		
	15			

Explanation



mudstone

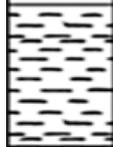
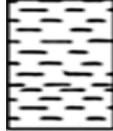


siltstone



fine sandstone

Figure 5-4. Detailed stratigraphic columnar section of lower section at Courtland Clay Pit.

	Thickness (cm)	Lithological description	Samples	Sedimentary environments
	120	light gray silty mudstone, with charcoals	036710	lacustrine (based upon the present study and Hajek et al., 2002)
	110	massive dark gray mudstone, with limonitic concretions	036709 036708	

Explanation



mudstone

Figure 5-5. Detailed stratigraphic columnar section of upper section at Courtland Clay Pit.

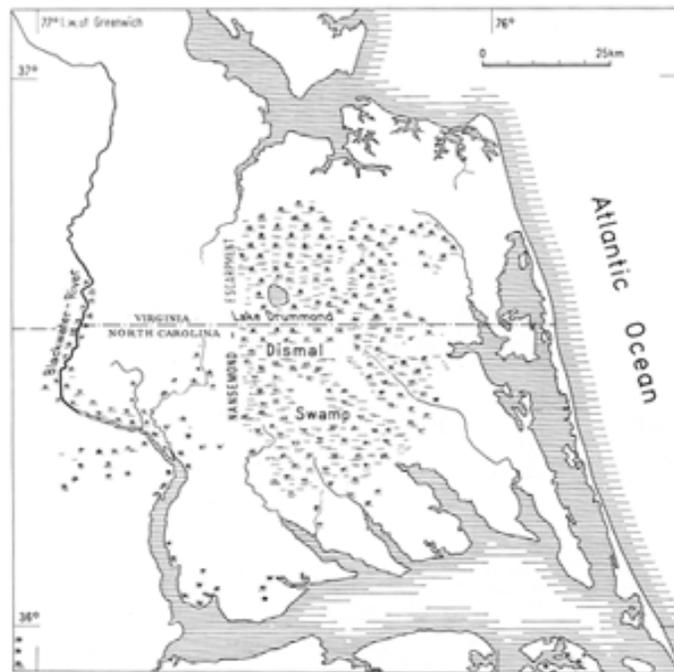
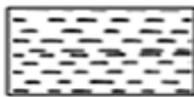


Figure 5-6. Sketch map of the Dismal Swamp, USA; an example of a coastal swamp and coastal lake developed along the coastal areas. (in Stach et al., 1982, after Teichmeuler, 1962).

	Thickness (cm)	Lithological description	Samples	Sedimentary environments
	35	medium yellowish sandstone, with mudstone pebbles		meandering river system (based upon the present study and Hajek et al., 2002)
	110	silty gray mudstone		
	70	carbonaceous sandy siltstone, with charcoal and pebbles.	046519 046518 046517	
	180	light gray to yellowish coarse sandstone, with lens of organic debris	046515	

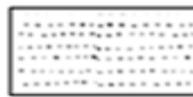
Explanation



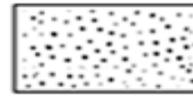
mudstone



siltstone



medium sandstone

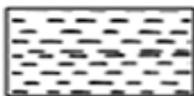


coarse sandstone

Figure 5-7. Detailed stratigraphic columnar section of SW section at Highway 4 Clay Pit.

	Thickness (cm)	Lithological description	Samples	Sedimentary environments
	6	medium sandstone, with mudstone pebbles		meandering river system (based upon the present study and Hajek et al., 2002)
	25	gray and dark gray mudstone, with charcoal	036717 036716	
	23	carbonaceous sandy siltstone, with charcoal and pebbles; bioturbated	036715	
	190	medium yellowish sandstone, with lens of organic debris	048292	

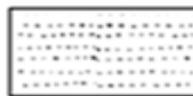
Explanation



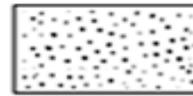
mudstone



siltstone



medium sandstone



coarse sandstone

Figure 5-8. Detailed stratigraphic columnar section of NE section at Highway 4 Clay Pit.

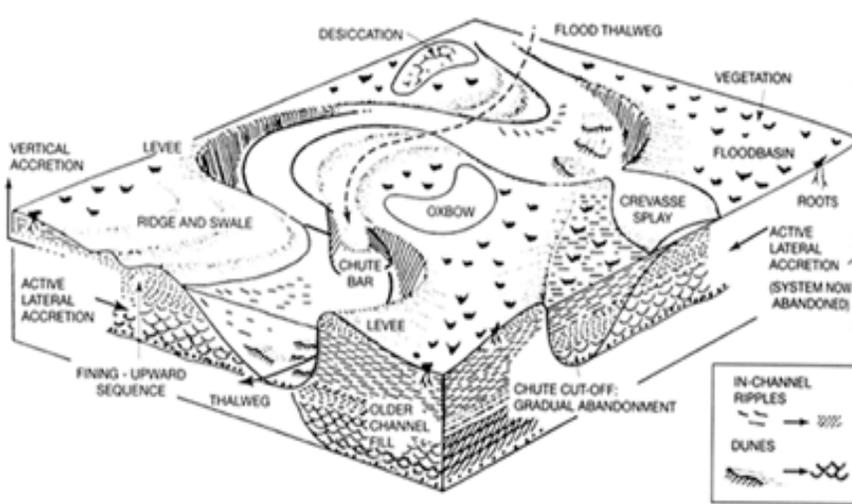
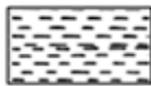


Figure 5-9. The morphological elements of a meandering river system. (from Walker and Cant, 1984)

	Thickness (cm)	Lithological description	Samples	sedimentary environments
	25	gray silty mudstone (weathered)		estuarine (based upon the present study and Sloan, 1964)
	30	fine white sandstone		
	45	fine sandstone and silty mudstone interbedded	046545	
	12	siltstone, well-cemented		
	200	silty mudstone, intercalated with thin irregular siltstone on top	046540	coastal swamps (present study)
	28	lignite, black	046536 046535	
	50	siltstone, brown, with charcoals and concretions	046533	lacustrine (based upon the present study and Sloan, 1964)
	220	silty mudstone and siltstone interbedded, siltstone increase from bottom to top		
	110	massive mudstone, becoming silty mudstone from bottom to top	046526	
	75	mudstone intercalated with irregular silty mudstone, containing coarse sand and gravel on top (5 cm)		
	60	siltstone and silty mudstone interbedded, laminae 1-20mm	046522	

Explanation



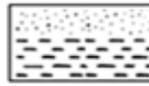
mudstone



siltstone



interbedded mudstone and siltstone



interbedded mudstone and fine sandstone



fine sandstone



lignite

Figure 5-10. Detailed stratigraphic columnar section at Ochs Clay Pit.

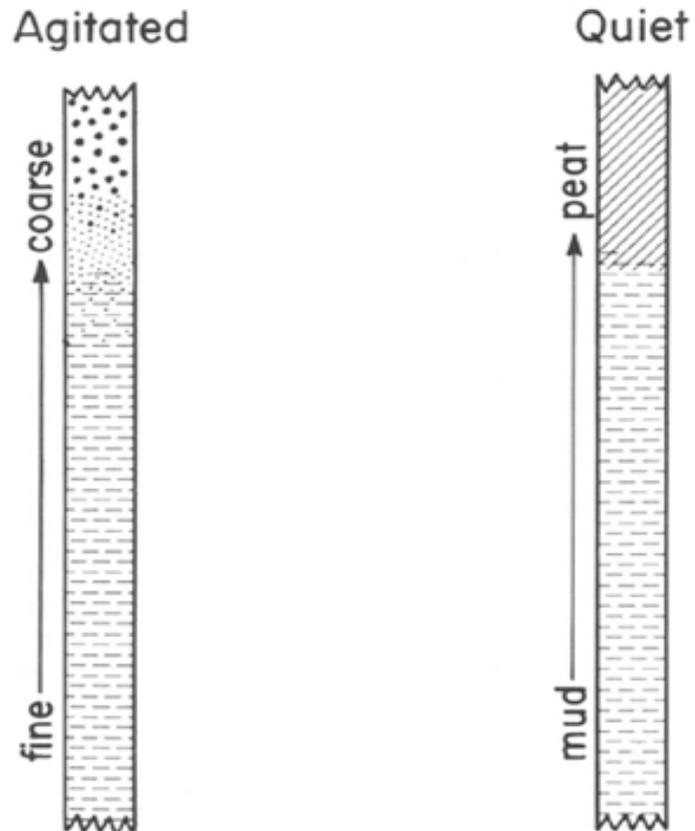


Figure 5-11. Ideal sequence of lacustrine deposits. After Visher (1965) and Twenhofel (1932). (from Picard and High, 1981)

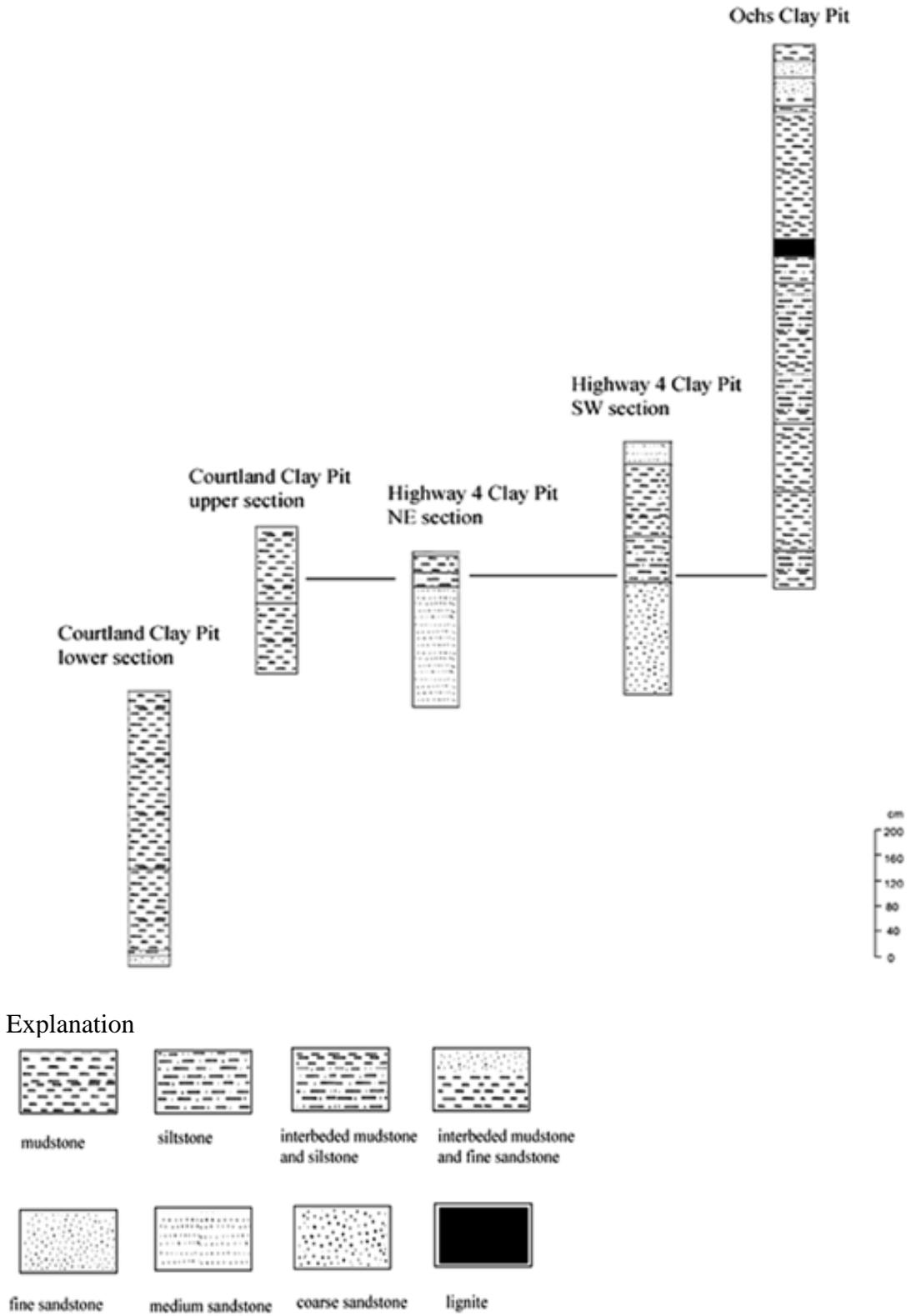


Figure 5-12. Inferred stratigraphic relationships, outcrop sections in study areas. (Solid line indicates the time equivalent level.)

CHAPTER 6 THE AGE OF THE DAKOTA FORMATION IN MINNESOTA

Based upon fossil leaves, Lesquereux (1895) assigned some Cretaceous sediments that outcropped in Minnesota to the “Dakota group” and related them to the Cenomanian. Pierce (1961) also indicated that the Cretaceous deposits of the Dakota Formation in Minnesota are of Cenomanian age based upon a palynological investigation. Later, Austin (1972) proposed that the nonmarine Cretaceous sediments (above the weathered residuum of the Precambrian and Paleozoic basement rocks) in the Minnesota River Valley are about middle Cenomanian based upon clay mineralogy. Setterholm (1994) suggested that the thick mudstone unit adjacent to the Minnesota River Valley resembles the Woodbury Member of the Dakota Formation in age and lithology. But Setterholm (1994) proposed that the upper mudstone unit may be equivalent to Graneros Shale which is placed in late Cenomanian in Minnesota. So it is obvious the accurate age assignment for the Dakota Formation in Minnesota is not clear due to the absence of marine fossils. Palynological investigations have been completed in Alberta (Singh, 1983), the Rocky Mountain Region (Nichols, 1994), and northwestern Iowa and northeastern Nebraska (Ravn and Witzke, 1995). Therefore, pollen and spores may be used as a tool to determine the age of mid-Cretaceous nonmarine sediments in the Western Interior Seaway.

Both *Liliacidites giganteus* and *Dictyophyllidites impensus* occur first in the upper Shaftesbury Formation of the Peace River area in northwestern Alberta, Canada. Based upon a “Fish-scale” marker bed and its comparison with marine fauna, the age of the

upper Shaftesbury Formation was assumed to be Cenomanian (Singh, 1983). Therefore, the dark gray clay sediments in Courtland Clay Pit from which *Liliacidites giganteus* and *Dictyophyllidites impensus* were recovered is here considered to represent Cenomanian age sediments in Minnesota. Moreover, both *Cicatricosisporites crassiterminatus* and *Stellatopollis largissimus* recovered from the Courtland Clay Pit and *Artiopollis indivisus*, *Appendicisporites auritus* and *Cicatricosisporites crassiterminatus* recovered from the Ochs Clay Pit all appear in Cenomanian or younger sediments in North America such as northwestern Alberta (Singh, 1983) and Arizona (Agasie, 1969). Based upon the pollen data, it appears that the Cretaceous sediments in south central Minnesota probably are Cenomanian in age.

The megaspore *Balmeisporites glenelgensis* was found only in the lignite of Ochs Clay pit. This species also occurs in the Cenomanian sediments in the Peace River area of northwestern Alberta, Canada (Singh, 1983). *Balmeisporites glenelgensis* also occurs in the Sergeant Bluff lignite and the Stone Park lignite that outcrop in northwestern Iowa and northeastern Nebraska. The age of these lignites was placed as middle and upper Cenomanian (Ravn and Witzke, 1995). Again, based upon the common occurrence of *Balmeisporites glenelgensis*, the lignite layer at the Ochs Clay Pit can be correlated with the Sergeant Bluff lignite and Stone Park lignite, suggesting that the age of the lignite layer and the sediments above the lignite layer at Ochs Clay Pit are probably middle to upper Cenomanian

Witzke et al. (1996) and Brenner et al. (2000) also indicated that the first occurrence of *Dictyophyllidites impensus* and *Cicatricosisporites crassiterminatus* probably represent the middle Cenomanian. *Dictyophyllidites impensus* occurs at

Courtland Clay Pit, Ochs Clay Pit and Highway 4 Clay Pit and *Cicatricosisporites crassiterminatus* occurs at Courtland Clay Pit and Ochs Clay Pit. So the sediments exposed at Courtland Clay Pit, Ochs Clay Pit and Highway 4 Clay Pit are all probably middle Cenomanian.

Nichols (1994) made a revision of the palynostratigraphic zonation for the upper Cretaceous nonmarine sediments in the Rocky Mountain Region. This palynostratigraphic zonation is based upon a comparison with marine ammonite zones. He stated that the first occurrence of the psilate tricolporate pollen type (such as *Nyssapollenites* sp.) and the obligate tetrads (such as *Artiopollis indivisus*) are representative of middle Cenomanian age. Both *Nyssapollenites* sp. and *Artiopollis indivisus* occur in Ochs Clay Pit and *Nyssapollenites* sp. occurs in Courtland Clay Pit. Because the exposed sediments in Courtland Clay Pit, Highway 4 Clay Pit and Ochs Clay Pit contain typical middle Cenomanian marker pollen, they are best considered as middle Cenomanian in age.

This middle Cenomanian age is in conflict with other pollen data that has been published. The angiosperm pollen types which occur in upper Zone III, Atlantic coastal plain, Potomac Group sediments (Doyle and Robbins, 1977) included “*Foveotricolporites*” *rhombohedralis*, *Retimonocolpites* sp. A, *Striatopollis* sp. B, cf. *Tricolpites barrandei*, and *Tricolpites nemejci*. The sediments at the Courtland Clay Pit contain very similar pollen such as *Foveotricolporites rhombohedralis*, *Retimonocolpites dividuus*, *Striatopollis paraneus*, *Tricolpites* cf. *vulgaris*, and *Tricolpites nemejci*. The age of the Potomac Group Zone III was suggested to be lower Cenomanian ? (Doyle and Robbins, 1977). However, based upon typical pollen from several pollen studies (Singh,

1983; Ravn and Witzke, 1995; Nichols, 1994), the age of the sediments at the Courtland Clay Pit probably are middle Cenomanian rather than “lower Cenomanian?”. This suggests that a revision in age may be in order for the pollen Zone III established for the Atlantic coastal plain, Potomac Group.

Doyle and Robbins (1977) mentioned that Zone IV “have not yet been studied in detail”. Also the samples from which pollen were recovered were from outcrops, not from cores of wells. Considering that the first *Normapolles* triporate type pollen occurs in Zone IV and they are absent in the middle Cenomanian sediments in northwestern Iowa and northeastern Nebraska (Ravn and Witzke 1995), and northwestern Alberta (Singh 1983), the middle Cenomanian to lower Turonian age of the Zone IV may be doubtful. So defining the age of the middle Cenomanian by the occurrence of *Normapolles* triporate pollen probably should be open to question.

Considering the comparison with Singh (1983), Nichols (1994), Ravn and Witzke (1995), Witzke et al. (1996), and Brenner et al. (2000), the age of Cretaceous sediments exposed in Courtland Clay Pit, Highway 4 Clay Pit and Ochs Clay Pit is probably middle Cenomanian.

CHAPTER 7
IMPLICATION OF POLLINATION BIOLOGY AND EARLY LATE CRETACEOUS
COASTAL VEGETATION

**Implications for Pollination Biology of the Early Late Cretaceous Angiosperm
Pollen**

During the past 30 years early angiosperm pollination biology has been understood substantially through the research on Cretaceous fossil flowers (Dilcher et al. 1976, Dilcher 1979, Crepet 1979, Friis and Skarby 1981, Dilcher and Crane, 1984, Crane and Dilcher, 1984, Crane, et al., 1986; Drinnan, et al., 1990; Friis, et al., 1999, 2000a, 2000b, Dilcher, 2001). It was a widely accepted hypothesis that the dominant angiosperm pollination modes were insect-pollination in early Cretaceous (Crepet and Friis 1987, Friis et al., 1999; Field and Arens, 2005; Wing and Boucher, 1998). Even some ancient relatives of extant wind-pollinated taxa were insect-pollinated during the Cretaceous, such as Late Albian insect-pollinated flowers of *Platanus*-like plants (Crane, et al., 1986) and Campanian (Late Cretaceous) insect-pollinated Fagaceous flowers (Herendeen, et al., 1995). During Cenomanian a showy flower that is bisexual from Dakota Formation in Nebraska implied insect pollination (Basinger and Dilcher, 1984). Also Drinnan et al. (1990) described a lauraceous flower which was probably insect-pollinated based upon the modified stamens that may have served as pollinator rewards. For the rosids, magnoliids, and hamamelids, insect pollination probably was important (Crepet et al., 1991) by Cenomanian time. It seems that insect pollination was very common during Cenomanian. Dilcher (1979), on the other hand, presents evidence to support the presence of wind pollination by mid-Cretaceous times. Dilcher (1979) also proposed the

hypothesis that the independent lineages of some anemophilous flowers may have developed separately from entomophilous flowers from a common bisexual ancestral stock. Moreover Dilcher (2000) indicated that wind pollination along with insect pollination mechanisms is also important for Cretaceous angiosperms. But Whitehead (1969) indicated that anemophily may evolve secondly in angiosperms. He wrote this at a time when *Magnolia* was considered to represent the characters of the ancestor of modern flowers and when insects were thought to have been important in the evolution of angiosperms. So perhaps more studies need to be done for a better understanding the role of pollination in the evolution of early angiosperms. The palynological data may provide new evidence about the diversity and nature of pollination profiles of angiosperms during the Cenomanian.

Generally the pollen types of wind-pollinated plant might be overrepresented in some paleoenvironments (Cohen, 1975). On the other hand the pollen of insect-pollinated plants could be very rare or absent in areas some distance from the zoophilous plants (Faegri and Iversen, 1989; Friis, et al., 1999). But some insect-pollinated angiosperms often produce large amounts of pollen as reward for their pollinators (Faegri and van der Pijl, 1979). Lupia et al. (2002) described a new insect pollinated angiosperm flower (Santonian), which produced large quantities of pollen. But there is no indication that this abundantly produced pollen was dispersed any distance from the plant that produced it or that it was likely to become incorporated into sediments. Faegri and van der Pijl (1979) indicated that the large number of pollen grains produced by insect-pollinated flowers may result in some accidental wind pollination. Retallack and Dilcher (1981) suggested that some early angiosperms were probably generalists, pollinated by

insects and wind. It is possible that the generalists may produce large numbers of pollen grains for wind-pollination while also being visited by insects that might serve as accidental pollinators.

Understanding the modes of angiosperm pollination is very important for reconstructing angiosperm diversity in different habitats based upon palynological data obtained from dispersed pollen in Cretaceous age sediments. The presence and the relative abundance of angiosperm pollen combined with the pollination modes of parent plants should indicate which kinds of angiosperm pollen were autochthonous. Doyle and Hickey (1976) indicated that *Clavatipollenites*, *Retimonocolpites* and *Liliacidites* are probably insect-pollinated pollen based upon their well-developed reticulate exine sculpture. Friis et al. (1999) indicated that the majority of pollen forms from early angiosperm flowers are monosulcate, which may be recognized as dispersed pollen as *Clavatipollenites*, *Retimonocolpites* and *Liliacidites*. The discrepancy between the rareness of dispersed angiosperm pollen types and the richness of *in situ* pollen types from angiosperm reproductive organs may indicate widespread insect pollination (Friis et al., 1999). The only reliable wind-pollinated angiosperm pollen probably is *Asteropollis*-type pollen based upon the floral organs and *in situ* pollen which are closely comparable to extant wind-pollinated *Hedyosmum* (Friis et al., 1999) of the Chloranthaceae. Pedersen et al. (1991) describes a new earliest Cenomanian fruit *Couperites mauldinensis* from West Mauldin Mountain locality in Maryland and the *in situ* pollen adhering to the sessile stigma is of the *Clavatipollenites* type. Although *in situ* pollen is comparable to extant chloranthaceous genus *Ascarina*, which is wind-pollinated, this *Clavatipollenites* type pollen probably is from insect-pollinated plants based upon the presence of probable

pollenkitt in *Couperites* in combination with an unelaborated stigmatic area (Pedersen et al., 1991). Friis et al. (2000a) described a staminate structure with *in situ* monosulcate *Liliacidites*-type or *Retimonocolpites*-type pollen. Based upon the same type pollen in the insect coprolite, the fossil flowers with in-situ *Liliacidites*-type or *Retimonocolpites*-type pollen were thought to be insect-pollinated. Also, insects very probably dispersed very small pollen (9-17 μm) because of deflection around the stigma by boundary layers of air flow (Retallack and Dilcher, 1981).

The methods I used for pollination interpretation are as follows:

1. Use former researchers' results about the pollination interpretation.
2. Analyze taxa which have no pollination data from references based upon the criteria for pollination interpretation (table 7-1).
3. Consider the clump as the first factor when analyzing pollen characteristics. Pollen in pollen clumps consisting of more than 10 grains (or tetrads) will be considered to be insect-pollinated.
4. Consider size as the second factor. If the average pollen diameter is less than 20 μm or more than 40 μm , the pollen will be considered to be insect-pollinated.

According to the methods for pollination interpretation proposed above it is possible that the modes of angiosperm pollination during early Late Cretaceous can be partially decoded. Twenty-six angiosperm pollen taxa were recovered from the Courtland Clay Pit (Table 7-2). Of these, twenty taxa appear to be insect-pollinated, which accounted for 77% of total angiosperm assemblage, and six taxa appear to have been wind-pollinated, accounting for 33% (Table 7-2). The maximum relative abundance of *Tricolpites cf. vulgaris* accounted for 16% (for a total of 52 pollen grains out of 318 palynomorphs counted); the maximum relative abundance of *Cupuliferoidaepollenites* sp. accounted for 10% (for a total of 30 pollen grains out of 304 palynomorphs counted); the maximum relative abundance of *Tricolpites labeonis*

accounted for 9% (for a total of 27 pollen grains out of 304 palynomorphs counted); the maximum relative abundance of *Rousea cf. delicipollis* accounted for 9% (for a total of 26 pollen grains out of 302 palynomorphs counted); and the maximum relative abundance of *Dryadopollis minnesotensis* accounted for 7% (for a total of 21 pollen grains out of 318 palynomorphs counted). Moreover the pollen clumps of *Tricolpites cf. vulgaris* (15+), *Tricolpites labeonis* (30+), *Rousea cf. delicipollis* (10+), *Dryadopollis minnesotensis* (10+, plate 13, fig. 11) were recovered from the lacustrine sediments at the Courtland Clay Pit. Based upon the occurrence of these pollen clumps which were from insect-pollinated plants, these pollen taxa should be from local. Considering that the maximum relative abundance of these insect-pollinated pollen taxa is all greater than 5%, I propose that 5% of the maximum relative abundance is considered as an acceptable limit to define a local lake flora apart from a non-local lake flora. Therefore the plants releasing pollen grains such as *Tricolpites cf. vulgaris*, *Cupuliferoidaepollenites* sp., *Tricolpites labeonis*, *Rousea cf. delicipollis*, and *Dryadopollis minnesotensis* probably inhabited coastal lake areas during the middle Cenomanian. However, because of the rare or low abundance of the other pollen types that probably were insect-pollinated (15 types) it is not possible to determine their source plants (Table 8-3). Drinnan et al. (1991) suggested that Early Cenomanian flower *Spanomera mauldinensis* were probably insect-pollinated. And the *in situ* pollen from *Spanomera mauldinensis* is comparable to *Striatopollis paraneus* (Drinnan et al. 1991). Considering that the stamens of *Spanomera mauldinensis* show abundant *in situ* pollen (Drinnan et al. 1991), the low relative abundance of *Striatopollis paraneus*, which is 2% (for a total of six pollen grains out of

302 palynomorphs counted), may imply that the source plants of *Striatopollis paraneus* were probably not *in situ*, but transported for a short distance (maybe regional).

Pollen taxa such as *Fraxinoipollenites constrictus*, which appear to be wind-pollinated and its relative abundance of 7% (for a total of 20 pollen grains out of 302 palynomorphs counted), may have grown also around lake areas because all other types with wind-pollinated pollen morphology were rare or low abundance (Table 7-2). Inasmuch as the wind-pollinated flowers usually produce large amounts of pollen, it is probable that the plants releasing *Fraxinoipollenites constrictus* pollen inhabited areas near the coastal lakes. At Ochs Clay Pit, 29 angiosperm pollen types were recovered. There are 20 taxa that appear to be insect-pollinated, which accounted for 69% of total angiosperm assemblage, and 9 taxa appear to have been wind-pollinated, which accounted for 31% (Table 7-3). Moreover some types of insect-pollinated angiosperm taxa had high relative abundance among the angiosperm pollen group in some samples. In the lacustrine deposits the maximum relative abundance of *Tricolpites labeonis* accounted for 53% (for a total of 164 pollen grains out of 310 palynomorphs counted); the maximum relative abundance of *Tricolpites cf. vulgaris* accounted for 20% (for a total of 59 pollen grains out of 295 palynomorphs counted); and the maximum relative abundance of *Cupuliferoideaepollenites* sp. accounted for 11% (for a total of 31 pollen grains out of 295 palynomorphs counted). The lignite considered here to represent coastal swamps has a very different pollen profile. The maximum relative abundance of *Artiopollis indivisus* accounted for 17% (for a total of 50 pollen grains out of 301 palynomorphs counted). In the estuarine deposits the maximum relative abundance of *Artiopollis indivisus* accounted for 37% (for a total of 113 pollen grains out of 306

palynomorphs counted). This situation may indicate that the parent plants of *Tricolpites labeonis*, *Tricolpites cf. vulgaris*, *Cupuliferoideaepollenites* sp. probably grew in close proximity to the coastal lake areas. At the same time the parent plants of *Artiopollis indivisus* may have inhabited the coastal swamps.

The pollen clumps of *Artiopollis indivisus* (plate 9, figs. 5-7, the largest clump including more than 100 tetrads) were only recovered from the lignite samples. And the pollen clumps of *Cupuliferoideaepollenites* sp. (plate 10, fig. 4, ca 10 pollen grains), *Tricolpites labeonis* (plate 11, figs. 13-15, ca 200 pollen grains), and *Psilatricolporites subtilis* (plate 16, fig. 4, more than 100 pollen grains) were discovered only from the lacustrine sediments at the Ochs Clay Pit. Pollen clumps is almost never found during routine pollen counts of the slides. Most pollen clumps are located by scanning the entire slide under low power objective and then studying the clumps one by one under higher magnification to identify the specific type of pollen comprising the clump. These pollen clumps may imply that the parent plants were probably local and not so far from the depositional sites. So the parent plants of *Artiopollis indivisus*, *Cupuliferoideaepollenites* sp., *Tricolpites labeonis*, and *Psilatricolporites subtilis* probably inhabited coastal areas during early Late Cretaceous. In view of the relatively high percentages the parent plants of *Tricolpites cf. vulgaris* may also have grown in coastal areas. Also swamps were relatively closed environments and most of the pollen/spores recovered from lignite can be considered as autochthonous (Traverse, 1988). Other insect-pollinated pollen recovered from lignite, such as *Liliacidites sinuatus*, *Liliacidites* sp. 3, *Liliacidites* sp. 4, *Nyssapollenites* sp., *Doyleipollenites robbinsiae*, *Clavatipollenites* sp. 2, and *Tricolpate* sp.11 may have grown in swamps.

For wind-pollinated pollen taxa (9 taxa total), the relative abundance is relatively low in all three environments. *Tricolpites nemejci* and *Fraxinoipollenites constrictus* have the highest relative abundance among the wind-pollinated pollen group. The maximum relative abundance of *Tricolpites nemejci* and *Fraxinoipollenites constrictus* both accounted for 2% (for a total of six pollen grains out of 295 palynomorphs counted) in the lacustrine sediments. So wind-pollinated pollen probably were not from local at Ochs Clay Pit.

In the Highway 4 Clay Pit, seven angiosperm pollen taxa were recovered from sediments representing a meandering river environment (Table 7-4). Six of these pollen taxa were from insect-pollinated plants (accounting for 86% of the angiosperm pollen taxa) and one type was from a wind-pollinated plant (accounting for 14% of the angiosperm pollen taxa). The maximum relative abundance of *Phimopollenites striolata* accounted for 62% (for a total of 188 pollen grains out of 303 palynomorphs counted). For *Tricolpites cf. vulgaris* the maximum relative abundance accounted for 15% (for a total of 45 pollen grains out of 303 palynomorphs counted). Also pollen clumps of *Phimopollenites striolata* (plate 14, figs. 19-21, ca 50 grains) and *Tricolpites cf. vulgaris* (plate 12, fig. 7, ca 10 grains) were discovered from this locality. It is possible that the parent plants of *Phimopollenites striolata* and *Tricolpites cf. vulgaris* may have inhabited areas along a meandering river. Because of the rare occurrence and low abundance for other insect-pollinated pollen types (Table 7-4), it is not possible to determine if they represent local or regional vegetation. The relative abundance of *Fraxinoipollenites constrictus*, which is wind-pollinated, accounted for 5% (for a total of 14 pollen grains

out of 303 palynomorphs counted). So wind-pollinated plants which released *Fraxinoipollenites constrictus* probably have grown in meandering areas.

In conclusion, based upon the analysis of angiosperm pollen types from the Courtland Clay Pit, Ochs Clay Pit, and Highway 4 Clay Pit, the pollen types that appear to be insect-pollinated accounted for 77% of all pollen types on average, and the pollen types which appear to be wind-pollinated accounted for 23% of all pollen types. It seems that the wind-pollination was not dominant by the middle Cenomanian. Also, the pollen, because of the characteristics of the pollen grains as discussed previously, such as *Artiopollis indivisus*, *Cupuliferoideaepollenites* sp., *Tricolpites labeonis*, and *Psilatricolporites subtilis*, *Tricolpites* cf. *vulgaris*, *Rousea* cf. *delicipollis*, and *Dryadopollis minnesotensis* all appear to be insect-pollinated. The plants producing these pollen forms probably inhabited coastal areas during early Late Cretaceous based upon their relatively high relative abundance and the presence of pollen in clumps. At the same time, the pollen, such as *Phimopollenites striolata* and *Tricolpites* cf. *vulgaris*, both appear to be insect-pollinated, suggesting that the parent plants probably inhabited meandering river areas during the early Late Cretaceous based upon their relatively high relative abundance and the presence of pollen in clumps. It seems that the parent plants of *Tricolpites* cf. *vulgaris* had a wide range of distribution. Also wind-dispersed pollen by early angiosperms may not have been a well developed syndrome of their pollination biology until middle to late Cenomanian.

Angiosperm, Fern and Gymnosperm Diversity in Coastal Areas during Early Late Cretaceous

Ochs Clay Pit is used as a case study of diversity of the coastal areas during early Late Cretaceous. In this pit sediments from lake, swamp and estuary environments are

preserved. The question of species abundance and the relative abundance of the different elements in the floras of these environments is addressed here.

There are 29 types of angiosperm pollen recovered from the sediments representing coastal lakes, coastal swamps, and estuaries (Table 7-5). The pollen recovered from coastal lake environments, contains 21 types and is the most diverse. There are 15 types of angiosperm pollen recovered from the swamp sediments. There are 16 types of angiosperm pollen recovered from estuarine sediments.

A total of 15 types of angiosperm pollen types were recovered from the lignitic sediments of the coastal swamp (Table 7-5). *Liliacidites sinuatus* was present only in the coastal swamps. It is possible that the plant releasing *Liliacidites sinuatus* pollen could grow only in coastal swamp environments. *Artiopollis indivisus* is distributed in the coastal lake, swamp and estuary environments. However the relative abundance was different in each environment (Figure 7-1). Its relative abundance changes from 5% in coastal lake environment to 55% in the coastal swamp environment. This may indicate that the plant releasing *Artiopollis indivisus* pollen was growing in the swamp and the pollen clumps (plate 9, figs. 5-7; plate 10, figs. 1-3) were dropped and incorporated into the swamp sediments. Only dispersed pollen of this type was found in the lake sediments.

There are only eight types (38%) of pollen in coastal lake sediments that overlapped with coastal swamp pollen. In the same way there are only nine types (43%) of pollen in coastal lakes that overlapped with estuarine pollen. This is because plants inhabiting other environments besides lakesides and coastal swamps may have increased the pollen diversity within the lake sediments. However, there are 11 types of pollen

(accounting for 79% of pollen types from coastal swamps and 69% of pollen types from estuaries respectively) shared by coastal swamps and estuaries. This situation may indicate that the pollen from plants inhabiting coastal swamps or adjacent areas were the major input of the estuaries.

A total of 32 types of ferns and fern allies spores were recovered from the coastal lake sediments of Ochs Clay Pit (Table 7-6). In contrast, the spores recovered from coastal swamps and estuaries were in both cases, 16 types. There were 13 types (41%) of spores in coastal lakes which overlapped with coastal swamp spores. At the same time, there were 12 types (38%) of spores in coastal lakes which overlapped with estuarine spores. However the shared spores between coastal swamp and estuaries were 11 (69%). So the patterns of spore distribution were similar to those of angiosperms (Figure 7-2). The spore data support the premise that the major botanical input of estuaries come from coastal swamp and adjacent areas. The spore diversity recovered from coastal swamps indicates the diversity of ferns and fern allies in these coastal swamps. The diversity of ferns and fern allies (16 types) was slightly higher than that of angiosperms (15 types) in coastal swamps.

Because *Trilobosporites purvernlentus* was only recovered from lignite, the ferns releasing this type of spore may have grown in coastal swamps. But its relative abundance is just 1% among the spore group of ferns and fern allies suggesting that the fern and fern ally that released *Trilobosporites purvernlentus* was not a dominant member of the coastal swamp community. From relative abundance analysis of selected spores of ferns and allies at Ochs Clay Pit (Figure 7-3), the dominant ferns and fern allies in coastal

swamps were the ferns and fern allies which produced *Glechiidites senonicus* (31%) and ? *Glechiidites* sp. (42%) because their relative abundance was high among coastal lakes, coastal swamps, and estuaries. Moreover, *Deltoidospora hallii*, ? *Auritulinasporites* sp., *Laevigatosporites ovatus* were important elements in the coastal swamps and adjacent areas because of their relatively high abundance in coastal lakes, coastal swamps, and estuaries. One type of megaspore *Balmeisporites glenelgensis* was only recovered from lignite. It is probable that the habitat of the plant releasing *Balmeisporites glenelgensis* may have been restricted to coastal swamps.

There were 28 types of gymnosperm pollen in the coastal lake environments (Table 7-7). 21 types of gymnosperm pollen were recovered from coastal swamps and 18 types of gymnosperm pollen recovered from estuaries. The coastal lake environments had the most diverse gymnosperm pollen, coastal swamps second, and the estuaries least (Figure 7-2).

Among the gymnosperm pollen recovered from coastal swamps 14 types (67%) are bisaccate pollen. The pollen count data indicate that the relative abundance of all 14 bisaccate pollen types was not higher than 5% (Figure 7-4). Traverse (1988) suggested that most pollen (including bisaccate pollen) fall as the "pollen rain" very near the parent plants and "at least 95% of all pollen has normally settled down well within a kilometer of the source plant". Because wind-pollinated plants are producers of a great number of pollen grains (Faegri and Iversen, 1989), the low relative abundance of bisaccate pollen in coastal swamps probably indicates that the plants releasing these bisaccate pollen types did not grow in the coastal areas. The bisaccate pollen in coastal lake environments showed the same pattern (Figure 7-5) and did not exceed 5% relative abundance.

Bisaccate pollen became especially rare in estuaries (Table 7-8). Except for *Cedripites cretaceous* (accounting for 1%), *Rugubivesiculites cf. reductus* (accounting for 3%), other bisaccate pollen taxa were not found when the pollen count was made. The infrequent to rare occurrence of bisaccate pollen in the coastal lake environment and estuaries may support the inference that the plants releasing bisaccate pollen did not inhabit coastal areas (Retallack and Dilcher, 1981).

Other non-bisaccate pollen types such as ? *Eucommiidites* sp., *Araucariacites australis*, *Bacumonoporites baculatus*, *Inaperturopollenites* sp., *Monosulcites*. sp.2, *Sabalpollenites scabrous*, *Taxodiaceapollenites hiatus* may have grown in coastal swamps or adjacent areas. Among them ? *Eucommiidites* sp. was only recovered from coastal swamps and the plant releasing this type of pollen may have been restricted to coastal swamps. Six other types of non-bisaccate pollen occurred in all three different environments. The plants releasing pollen *Inaperturopollenites* sp., *Sabalpollenites scabrous*, and *Taxodiaceapollenites hiatus* may have been dominant among the gymnosperm plants in coastal swamps and adjacent areas because of their higher percentage among the gymnosperm groups in different environments (Figure 7-6). Considering that the relative abundance of *Sabalpollenites scabrous* was the highest in coastal swamps among coastal lakes, coastal swamps, and estuaries it is probable that the plants releasing *Sabalpollenites scabrous* may have been more prosperous in coastal swamps than in other environments.

Species diversity analysis suggests that gymnosperm pollen is most diverse (21 types), spores of ferns and allies second (16 types), and angiosperm pollen least (14 types) in coastal swamps. The species diversity of ferns and allies, and angiosperm was

similar. Considering that baccate pollen may not be local and that gymnosperm species diversity may be seven types at most, that is far below the diversity of ferns and fern allies, and angiosperms. On the other hand the relative abundance data show that angiosperm and gymnosperm had the same abundance (31%). But the ferns and fern allies had a higher abundance (38%). This result may suggest that although angiosperms became important in the view of species diversity the ferns and allies may still have been important in the ecosystem. This result supports the conclusion suggested by Farley and Dilcher (1986), Coe et al (1987), and Skog and Dilcher (1994).

Comparison with Other Late Cretaceous Assemblages Recovered from Coal Bearing Sequences

Agasie (1969) studied the late Cretaceous (Cenomanian) palynomorphs from northeastern Arizona. The most productive samples of that study, were black shales and the least productive were coals. This situation differs from Ochs Clay Pit where the lignite was very productive. Agasie indicated that the plants in coal swamps are composed primarily of ferns and angiosperms with a minor number of gymnosperms. This swamp plant composition in general was similar to the coastal swamps recovered from Ochs Clay Pit. Although detailed sedimentary environment interpretation were not provided, the author implied that the areas probably consisted of the low-lying coastal plains or swampy areas that were covered by ferns and angiosperm trees according to the occurrence of microplankton. While spores of ferns and fern allies dominated in both localities, the dominant elements were different. The most abundant genera were *Appendicisporites* and *Cicatricosisporites* in northeastern Arizona while *Glechiidites* and *Deltoidospora* were dominant genera at Ochs Clay Pit. For angiosperm pollen, the general pattern was similar for both localities in dominance of tricolpate pollen, absence

of triporate pollen, and small size of non-monosulcate pollen. Significant differences are obvious in gymnosperm pollen between these two localities. Bisacate pollen types were dominant in northwestern Arizona while inaperturate pollen types (such as *Inaperturopollenites*) were dominant at the Ochs Clay Pit.

Ravn and Witzke (1995) studied the early Late Cretaceous (middle Cenomanian) palynomorphs in northwestern Iowa and northeastern Nebraska. The most productive samples are lignite in these areas. One lignite sample from Sergeant Bluff was examined in detail. The authors pointed out that angiosperm pollen was more diverse in the lignite although it was still subordinate to the spores of ferns and fern allies. Unfortunately the authors did not make a detailed analysis for the diversity of angiosperms and ferns and fern allies making further comparisons impossible. Key angiosperm elements from Sergeant Bluff lignite sample, *Doyleipollenites robbinsiae*, *Artiopollis indivisus*, *Tricolpites nemejcii*, are also present in the lignite representing coastal swamps at Ochs Clay Pit. The common spores of ferns and fern allies include *Gleicheniidites senonicus*, *Deltoidospora hallii*, *Dictyophyllidites impensus*, *Microfoveolatosporis pseudoreticulatus*, which were recovered from the lignite samples from northwestern Iowa and northeastern Nebraska, and Ochs Clay Pit. Gymnosperm pollen included *Pristinupollenites pannosus* and *Rugubivesiculites convolutes* in these two lignite samples from northwestern Iowa and northeastern Nebraska and Ochs Clay Pit. Moreover, the megaspore, *Balmeisporites glenelgensis*, occurs in both lignite samples. So probably the lignite assemblages from northwestern Iowa and northeastern Nebraska, and Ochs Clay Pit represent similar swamps.

Farley and Dilcher (1986) examined the palynoflora of the Linnenberger Ranch lignite in Kansas. They suggested that the lignite represents a swamp environment. However, earlier Farley (1982) indicated that the locality was tidally influenced and the proximity of the sea was obviously based upon the Dakota Graneros contact, which is only a few meters above the Linnenberger Ranch locality. Thus it is possible that the swamp that Farley and Dilcher (1986) studied represents a coastal swamp. Spores of ferns and fern allies (17 types) were most diverse; gymnosperm pollen (10 types) was second; and the pollen of angiosperms (9 types) was third. At the same time the spores of ferns and fern allies were most abundant; the pollen of angiosperm was second; and the pollen of gymnosperm was least abundant. Bisaccate pollen was absent in the lignite and *Araucariacites* was the only abundant gymnosperm pollen. The authors suggested the ferns and fern allies constituted the understory beneath angiosperms and rarer gymnosperms.

Therefore based on the comparison with palynological assemblages recovered from coal or lignite from northwestern Arizona, northwestern Iowa and northeastern Nebraska, and central Kansas, it is possible that the characteristic floristic features in the coastal swamps during the early Late Cretaceous were diverse angiosperms, dominant ferns and fern allies, and a relative low abundance of gymnosperms.

Table 7-1. Criteria for pollination interpretation

	Insect-pollinated pollen	Wind-pollinated pollen
Surface feature	ornamental, sticky and oily surface	smooth and dry surface
Pollen size	varies, small to large size	20-40 μm in diameter
Dispersal method	large clumps	individually or in small groups
Pollen production	varies, small to large quantities	large quantities

(From Whitehead, 1969, Frankel and Galun, 1977; Retallack and Dilcher, 1981, Traverse, 1988; Faegri and Iversen, 1989; Dafni, 1992, Proctor et al., 1996)

Table 7-2. Inferred mode of pollination for angiosperm pollen taxa from Courtland Clay Pit. (“Abundance” equals the numbers of angiosperm pollen found in 3 counts of around 300 each which included all palynomorphs)

Taxa	Unit	Aperture	Ornamentation	Dimensions	Pollination	Abundance
<i>Clavatipollenites tenellis</i>	monad	monosulcate	reticulate	28μ (1 grain) 20 (24) 28μ	insect-pollinated	0
<i>Clavatipollenites</i> sp.2	monad	monosulcate	reticulate	(2 grains)	insect-pollinated	0
<i>Doyleipollenites robbinsiae</i>	monad	monosulcate	reticulate to foveolate	22 (27) 34μ (7 grains)	insect-pollinated	2
<i>Liliacidites giganteus</i>	monad	monosulcate	reticulate	48 X 76 μ (1 grain)	insect-pollinated	0
<i>Liliacidites</i> cf. <i>reticulatus</i>	monad	monosulcate	reticulate	19 (20) 23 X 22 (24) 28 (5 grains)	insect-pollinated	0
<i>Stellatopollis largissimus</i>	monad	monosulcate	reticulate	64 X 123μ (1 grain). 38 X 53 μ (1 grain).	insect-pollinated	0
<i>Stellatopollis</i> sp.	monad	monosulcate	reticulate	32 (35) 38μ	insect-pollinated	0
<i>Retimonocolpites dividuus</i>	monad	monosulcate	reticulate	(2 grains)	insect-pollinated	0
<i>Cupuliferoideaepollenites</i> sp.	monad	tricolpate	scabrate	7 (11) 17 X 10 (16) 19μ (10 grains) 11 (14) 19 X	insect-pollinated	79
<i>Tricolpites</i> cf. <i>vulgaris</i>	monad	tricolpate	reticulate	16 (20) 24μ (5 grains) 6 (10) 14 X 9 (14) 19μ	insect-pollinated	145
<i>Tricolpites labeonis</i>	monad	tricolpate	reticulate	(14 grains)	insect-pollinated	48

Table 7-2—continued.

Taxa	Unit	Aperture	Ornamentation	Dimensions	Pollination	Abundance (count)
				11 (17) 21 X		
				17 (22) 25μ		
Tricolpate sp.4	monad	tricolpate	reticulate	(5 grains)	insect-pollinated	13
				17 (18) 18μ		
Tricolpate sp.7	monad	tricolpate	microfoveolate	(2 grains)	insect-pollinated	0
			reticulate to	11 (12) 12 X		
				14 (15) 16μ		
				(2 grains); 11		
				(13) 14μ (2		
Tricolpate sp.11	monad	tricolpate	foveolate	grains)	insect-pollinated	0
<i>Phimopollenites</i>				12 (14) 19 X		
				16 (19) 21 μ		
				(10 grains),		
				15 (18) 24 μ		
<i>striolata</i>	monad	tricolporoidate	microreticulate	(7 grains)	insect-pollinated	0
<i>Dryadopollis</i>				8 (15) 19 μ X		
				15 (19) 23 μ		
				(5 grains), 16		
				(17) 19 μ (13		
<i>minnesotensis</i>	monad	tricolporate	microreticulate	grains)	insect-pollinated	24

Table 7-2—continued.

Taxa	Unit	Aperture	Ornamentation	Dimensions	Pollination	Abundance (count)
<i>Dryadopollis minutus</i>	monad	tricolporate	microreticulate	8 X 10 μ (1 grain), 9 (10) 10 μ (2 grains)	insect-pollinated	1
<i>Nyssapollenites</i> sp.	monad	tricolporate	microfoveolate reticulate to	9 (11) 14 X 11 (14) 17μ (7 grains); 11 (14) 15μ (3 grains)	insect-pollinated	3
<i>Rousea</i> cf. <i>delicipollis</i>	monad	tricolpate	foveolate	14 X 23 μ (1 grain), 16 (23) 35 μ (7 grains)	insect-pollinated	26
<i>Satishia</i> sp.	monad	tricolpate	microreticulate	28 μ (1 grain).	wind-pollinated (?)	0
<i>Striatopollis paraneus</i>	monad	tricolpate	striato-reticulate	15 X 18μ (1 grain); 21 μ (1 grain).	insect-pollinated	6
<i>Fraxinoipollenites constrictus</i>	monad	tricolpate	microfoveolate	18 (24) 34 X 28 (38) 48 μ (11 grains),	wind-pollinated	20

Table 7-2—continued.

Taxa	Unit	Aperture	Ornamentation	Dimensions	Pollination	Abundance (count)
<i>Foveotricolporites</i>				20 (27) 31 X 31 (34) 39μ (4 grains); 42 (47) 51μ (3 grains)	wind-pollinated	2
<i>rhombohedralis</i>	monad	tricolporate	foveolate	19 X 30μ (1 grain); 27 μ		
<i>cf. Foveotricolporites</i> sp.	monad	tricolporate	foveolate	(1 grain) 17 (19) 21 X 22 (27) 35μ (10 grains); 21 (26) 31μ	wind-pollinated	0
<i>Tricolpites nemejci</i>	monad	tricolpate	microreticulate	(4 grains)	wind-pollinated (?)	1
? <i>Spinizonocolpites</i> sp.	monad	monosulcate	scabrate	25μ (1 grain).	wind-pollinated (?)	0

Table 7-3. Inferred mode of pollination for angiosperm pollen taxa from Ochs Clay Pit. (“Abundance” for lacustrine equals the numbers of angiosperm pollen found in 3 counts of around 300 each which included all palynomorphs; “Abundance” for swamps or estuarine equals the numbers of angiosperm pollen found in 2 counts of around 300 each).

Taxa	Unit	Aperture	Ornamentation	Dimensions	Pollination	Abundance			Total
						Lacustrine	Swamps	Estuarine	
<i>Artiopollis indivisus</i>	tetrad	tricolpate	microreticulate	17 (21) 27μ (whole tetrad), 9 (13) 15μ (individual grain)(7 tetrads)	insect pollinated	23	90	145	258
<i>Retimonocolpites dividuus</i>	monad	monosulcate	reticulate	32 (35) 38μ (2 grains)	insect pollinated	6	0	0	6
<i>Clavatipollenites tenellis</i>	monad	monosulcate	reticulate	28μ (1 grain)	insect pollinated	1	0	0	1
<i>Clavatipollenites</i> sp.2	monad	monosulcate	reticulate	20 (24) 28μ (2 grains)	insect pollinated	0	1	1	2
<i>Liliacidites</i> sp.2	monad	monosulcate	reticulate	21μ (1 grain)	insect pollinated	0	0	0	0
<i>Liliacidites</i> sp.3	monad	monosulcate	reticulate	15 (21) 31 X 19 (30) 43μ (11 grains)	insect pollinated	0	20	7	27
<i>Liliacidites</i> sp.4	monad	monosulcate	reticulate	29 (37) 48μ (9 grains)	insect pollinated	0	4	2	6
<i>Liliacidites</i> cf. <i>reticulatus</i>	monad	monosulcate	reticulate	19 (20) 23 X 22 (24) 28 (5 grains)	insect pollinated	0	0	0	0
<i>Liliacidites sinuatus</i>	monad	monosulcate	reticulate	18 (22) 25 X 33 (34) 34μ (2 grains)	insect pollinated	0	8	0	8
<i>Doyleipollenites robbinsiae</i>	monad	trichotomosulcate	reticulate to foveolate	22 (27) 34μ (7 grains)	insect pollinated	0	2	2	4
<i>Tricolpites labeonis</i>	monad	tricolpate	reticulate	6 (10) 14 X 9 (14) 19μ (14 grains)	insect pollinated	171	11	22	204
<i>Cupuliferoidaepollenites</i> sp.	monad	tricolpate	scabrate	7 (11) 17 X 10 (16) 19μ (10 grains)	insect pollinated	42	9	24	75
<i>Tricolpites</i> cf. <i>vulgaris</i>	monad	tricolpate	reticulate	11 (14) 19 X 16 (20) 24μ (5 grains)	insect pollinated	99	0	1	100
<i>Tricolpate</i> sp.4	monad	tricolpate	reticulate	11 (17) 21 X 17 (22) 25μ (5 grains)	wind pollinated	31	1	0	32

Table 7-3—continued.

Taxa	Unit	Aperture	Ornamentation	Dimensions	Pollination	Abundance			
						Lacustrine	Swamps	Estuarine	Total
Tricolpate sp.7	monad	tricolpate	microfoveolate	17 (18) 18 μ (2 grains)	insect pollinated	4	0	0	4
			reticulate to	11 (12) 12 X 14 (15)					
Tricolpate sp.11	monad	tricolpate	foveolate	16 μ (2 grains); 11 (13) 14 μ (2 grains)	insect pollinated	0	2	2	4
				13 (16) 18 X 15 (19) 22 μ (2 grains); 14 μ (1 grain)					
Tricolpate sp.12	monad	tricolpate	reticulate	9 (11) 13 X 15 (18)	insect pollinated	0	0	21	21
				20 μ (3 grains)					
Tricolpate sp.14	monad	tricolpate	microfoveolate	13 (16) 19 X 16 (19)	insect pollinated	0	0	8	8
				23 μ (6 grains)					
<i>Phimopollenites striolata</i>	monad	tricolporoidate	microreticulate	11 X 14 μ (1 grain); 11	insect pollinated	17	0	0	17
<i>Psilatricolporites subtilis</i>	monad	tricolporoidate	scabrate	(12) 12 μ (2 grains)	insect pollinated	2	0	0	2
				9 (11) 14 X 11 (14)					
<i>Nyssapollenites</i> sp.	monad	tricolporate	microfoveolate	17 μ (7 grains); 11 (14)	insect pollinated	12	2	6	20
<i>Fraxinoipollenites</i>				15 μ (3 grains)					
				18 (24) 34 X 28 (38)	wind pollinated	7	0	0	7
<i>constrictus</i>	monad	tricolpate	microfoveolate	48 μ (11 grains), 30					
				(35) 38 μ (5 grains)	wind pollinated	0	4	6	10
			reticulate to	14 (21) 32 X 19 (29)					
Tricolpate sp.10	monad	tricolpate	foveolate	40 μ (9 grains); 46 μ (1 grain)	wind pollinated	0	4	6	10
				30 (33) 35 X 36 (38)					
<i>Foveotricolpites</i> sp.	monad	tricolpate	scabrate	40 μ (2 grains)	wind pollinated	3	0	0	3

Table 7-3—continued.

Taxa	Unit	Aperture	Ornamentation	Dimensions	Pollination	Abundance			
						Lacustrine	Swamps	Estuarine	Total
<i>Foveotricolporites</i>				20 (27) 31 X 31 (34) 39 μ (4 grains); 42 (47)					
<i>rhombohedralis</i>	monad	tricolporate	foveolate	51 μ (3 grains)	wind pollinated	4	0	0	4
? <i>Clavatipollenites</i> sp.3	monad	monosulcate	microfoveolate	24 (27) 29 μ (4 grains) 17 (18) 19 X 19 (25) 30 μ (2 grains), 15	wind pollinated (?)	0	6	2	8
Tricolporate sp.2	monad	tricolporate	striate	(17) 19 μ (2 grains) 17 (19) 21 X 22 (27) 35 μ (10 grains); 21	wind-pollinated (?)	0	0	0	0
<i>Tricolpites nemejci</i>	monad	tricolpate	microreticulate	(26) 31 μ (4 grains)	wind pollinated (?)	8	5	11	24
Tricolpate sp.8	monad	tricolpate	scabrate	23 (26) 28 μ (2 grains)	wind pollinated (?)	2	0	0	2

Table 7-4. Inferred mode of pollination for angiosperm pollen taxa from Highway 4 Clay Pit. (“Abundance” equals the numbers of angiosperm pollen found in 3 counts of around 300 each which included all palynomorphs)

Taxa	Unit	Aperture	Ornamentation	Dimensions	Pollination	Abundance (count)
<i>Liliacidites</i> cf. <i>inaequalis</i>	monad	monosulcate	reticulate	15 (16) 18 X 22 (24) 26 μ (3 grains)	insect-pollinated	3
<i>Liliacidites</i> cf. <i>reticulatus</i>	monad	monosulcate	reticulate	19 (20) 23 X 22 (24) 28 μ (5 grains)	insect-pollinated	2
<i>Liliacidites</i> sp.5	monad	monosulcate	reticulate	20 (23) 25 X 23 (24) 25 μ (2 grains)	insect-pollinated	1
<i>Phimopollenites</i> <i>striolata</i>	monad	tricolporoidate	microreticulate	12 (14) 19 X 16 (19) 21 μ (10 grains), 15 (18) 24 μ (7 grains)	insect-pollinated	219
<i>Tricolpites</i> cf. <i>vulgaris</i>	monad	tricolpate	reticulate	11 (14) 19 X 16 (20) 24 μ (5 grains)	insect-pollinated	63
<i>Rousea</i> cf. <i>delicipollis</i>	monad	tricolpate	reticulate to foveolate	14 X 23 μ (1 grain), 16 (23) 35 μ (7 grains)	insect-pollinated	0
<i>Fraxinoipollenites</i> <i>constrictus</i>	monad	tricolpate	microfoveolate	18 (24) 34 X 28 (38) 48 μ (11 grains), 30 (35) 38 μ (5 grains)	wind-pollinated	14

Table 7-5. Angiosperm pollen distribution in three different environments in Ochs Clay Pit.

Taxa	Lacustrine	Coastal swamps	Estuarine
<i>Clavatipollenites tenellis</i>	†		
<i>Foveotricolpites</i> sp.	†		
<i>Foveotricolporites rhombohedrali</i>	†		
<i>Fraxinoipollenites constrictus</i>	†		
<i>Liliacidites reticulatus</i>	†		
<i>Liliacidites</i> sp.2	†		
<i>Phimopollenites striolata</i>	†		
<i>Psilatricolporites subtilis</i>	†		
<i>Retimonocolpites dividuus</i>	†		
Tricolpate sp.7	†		
<i>Liliacidites sinuatus</i>		†	
Tricolpate sp.12			†
Tricolpate sp.14			†
<i>Artiopollis indivisus</i>	†	†	†
<i>Cupuliferoideaepollenites</i> sp.	†	†	†
<i>Nyssapollenites</i> sp.	†	†	†
<i>Tricolpites labeonis</i>	†	†	†
<i>Tricolpites nemejci</i>	†	†	†
<i>Liliacidites</i> sp.3	†	†	
Tricolporate sp.2	†	†	
<i>Doyleipollenites robbinsiae</i>	†	†	†
<i>Tricolpites</i> cf. <i>vulgaris</i>	†		†
Tricolpate sp.4	†	†	†
Tricolpate sp.8	†		†
<i>Clavatipollenites</i> sp.2		†	†
? <i>Clavatipollenites</i> sp.3		†	†
<i>Liliacidites</i> sp.4		†	†
Tricolpate sp.10		†	†
Tricolpate sp.11		†	†

Table 7-6. Fern spore distribution in three different environments at Ochs Clay Pit

Taxa	Lacustrine	Coastal swamps	Estuarine
<i>Appendicisporites</i> cf. <i>auritus</i>	†		
<i>A.</i> cf. <i>matesovae</i>	†		
<i>Cicatricosisporites</i> cf. <i>crassiterminatus</i>	†		
<i>C. hughesi</i>	†		
<i>C. crassiterminatus</i>	†		
<i>Concavissimisporites</i> sp.	†		
? <i>Concavissimisporites</i> sp.	†		
<i>Costatoperforosporites</i> sp.	†		
<i>Crybelosporites</i> sp.	†		
<i>Deltoidospora</i> sp.	†		
? <i>Januasporites</i> sp.	†		
? <i>Klukisporites</i> sp.	†		
cf. <i>Phaeoceros</i> form A	†		
<i>Plicatella fucosa</i>	†		
<i>Triporoletes reticulatus</i>	†		
<i>Undulatisporites</i> sp.	†		
<i>Trilobosporites purvernlentus</i>		†	
<i>Verrucosisporites</i> sp.			†
<i>Lycopodiacidites</i> sp.2			†
<i>A. problematicus</i>	†	†	†
? <i>Auritulinasporites</i> sp.	†	†	†
<i>Camarozonosporites</i> sp.1	†	†	†
<i>C.</i> sp.3	†	†	†
<i>Deltoidospora hallii</i>	†	†	†
<i>Dictyophyllidites impensus</i>	†	†	†
<i>Gleichiidites senonicus</i>	†	†	†
? <i>Gleichiidites</i> sp.	†	†	†
<i>Laevigatosporites ovatus</i>	†	†	†
<i>Converrucosisporites</i> sp.	†	†	
<i>Ischyosporites</i> sp.	†	†	
<i>Lycopodiumsporites marginatus</i>	†	†	
<i>Punctatriletes punctus</i>	†	†	
<i>Cicatricosisporites</i> . sp.4	†		†
<i>Cyathidites australis</i>	†		†
<i>Stereisporites</i> sp.1	†		†
<i>Microfoveolatosporis pseudoreticulatus</i>		†	†
<i>Sestrosporites</i> sp.2		†	†

Table 7-7. Gymnosperm pollen distribution in three different environments at Ochs Clay Pit

Taxa	Lacustrine	Coastal swamps	Estuarine
<i>Cycadopites</i> sp.	†		
<i>Equisetosporites</i> sp.1	†		
<i>Eucommiidites</i> sp. 1	†		
<i>Monosulcites</i> sp.1	†		
M. sp.3	†		
<i>Pristinupollenites microsaccus</i>	†		
<i>P. canadensis</i>	†		
<i>P.</i> sp.	†		
<i>Punctamultivesiculites</i> cf. <i>inchoatus</i>	†		
? <i>Eucommiidites</i> sp.		†	
<i>Monosulcites</i> sp.4			†
<i>Alisporites rotundus</i>	†	†	†
<i>Araucariacites australis</i>	†	†	†
<i>Bacumonoporites baculatus</i>	†	†	†
<i>Cedripites cretaceus</i>	†	†	†
<i>C.</i> sp.	†	†	†
<i>Inaperturopollenites</i> sp.	†	†	†
<i>Monosulcites</i> . sp.2	†	†	†
<i>Pristinupollenites pannosus</i>	†	†	†
<i>Parvisacites radiatus</i>	†	†	†
<i>Rugubivesiculites rugosus</i>	†	†	†
<i>R. convolutus</i>	†	†	†
<i>Sabalpollenites scabrus</i>	†	†	†
<i>Taxodiaceapollenites hiatus</i>	†	†	†
? <i>Pityosporites constrictus</i>	†	†	
<i>Pristinupollenites sulcatus</i>	†	†	
<i>Podocarpidites minisculus</i>	†	†	
<i>Punctabivesiculites parvus</i>	†	†	
<i>Pristinupollenites inchoatus</i>	†		†
<i>Pityosporites constrictus</i>	†	†	†
<i>Rugubivesiculites</i> cf. <i>multiplex</i>		†	†
<i>R.</i> cf. <i>reductus</i>		†	†

Table 7-8. Relative abundance of bisaccate pollen in estuaries at Ochs Clay Pit

Taxa	Percentage (%)
<i>Alisporites rotundus</i>	0%
<i>Cedripites cretaceus</i>	1%
<i>Cedripites</i> sp.	0%
<i>Pristinupollenites pannosus</i>	0%
<i>Parvisacites radiatus</i>	0%
<i>Rugubivesiculites rugosus</i>	1%
<i>R. convolutus</i>	0%
<i>Pristinupollenites inchoatus</i>	0%
<i>Pityosporites constrictus</i>	0%
<i>Rugubivesiculites</i> cf. <i>multiplex</i>	0%
<i>R.</i> cf. <i>reductus</i>	3%

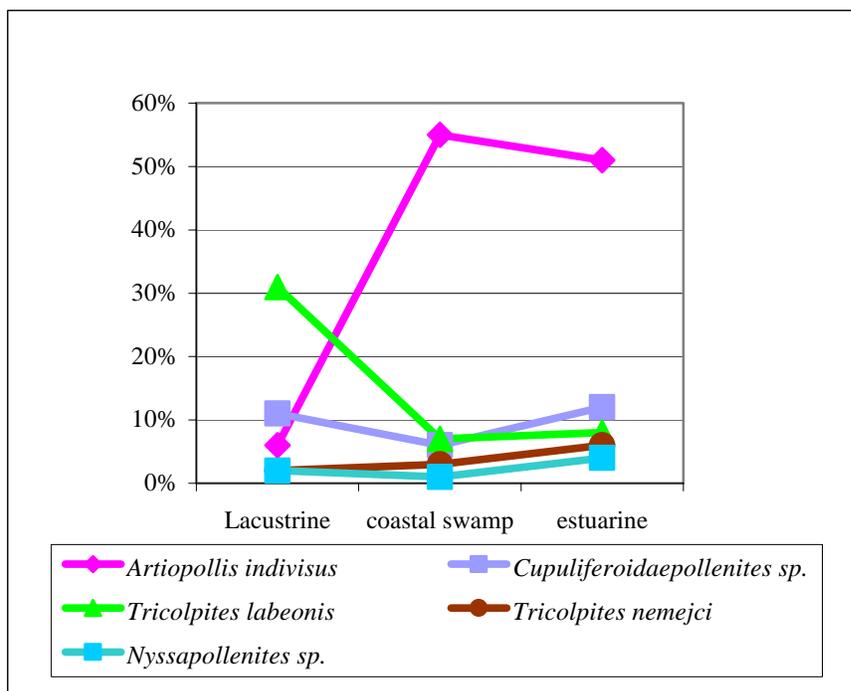


Figure 7-1. Selected angiosperm pollen relative abundance analysis in three different environments at Ochs Clay Pit

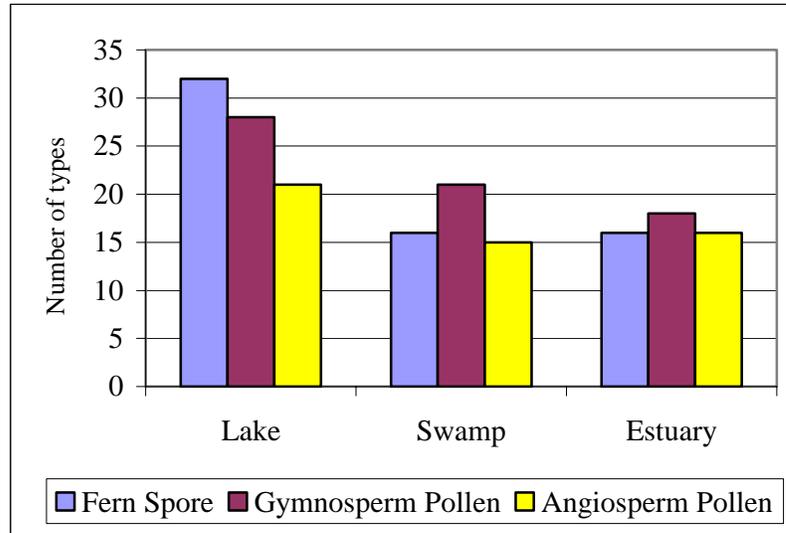


Figure 7-2. The distribution of terrestrial palynomorphs in lake, swamp, and estuarine sediments at the Ochs Clay Pit

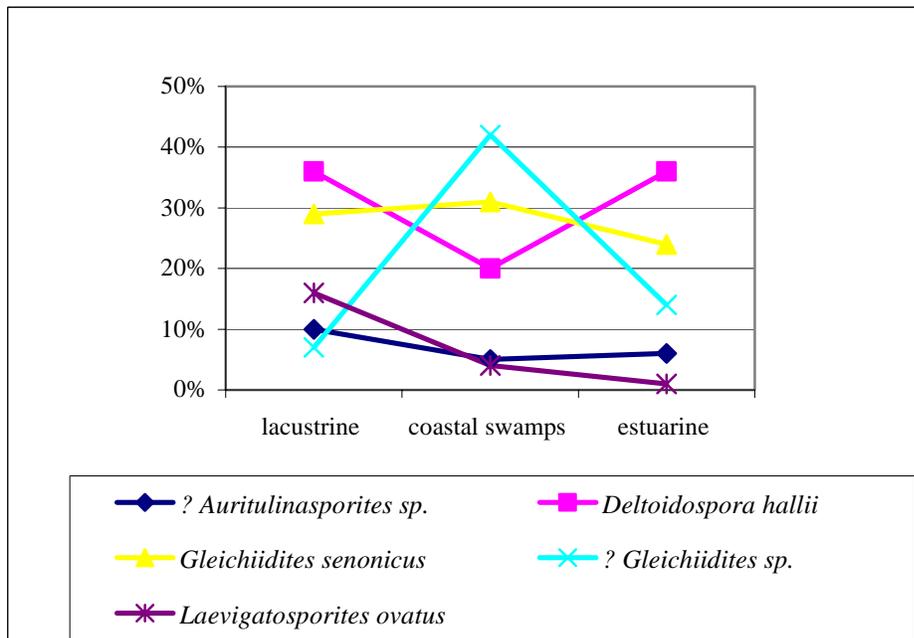


Figure 7-3. Relative abundance analysis of selected spores of ferns and allies at Ochs Clay Pit

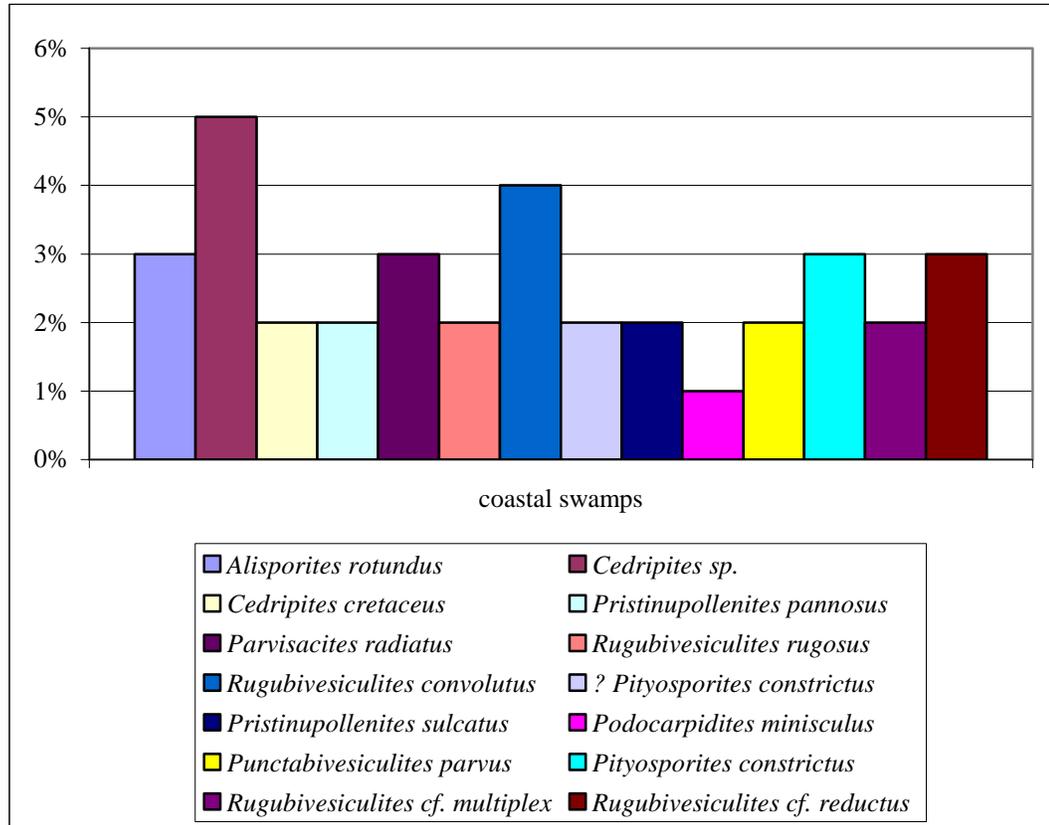


Figure 7-4. Relative abundance of bisaccate pollen in coastal swamps at Ochs Clay Pit

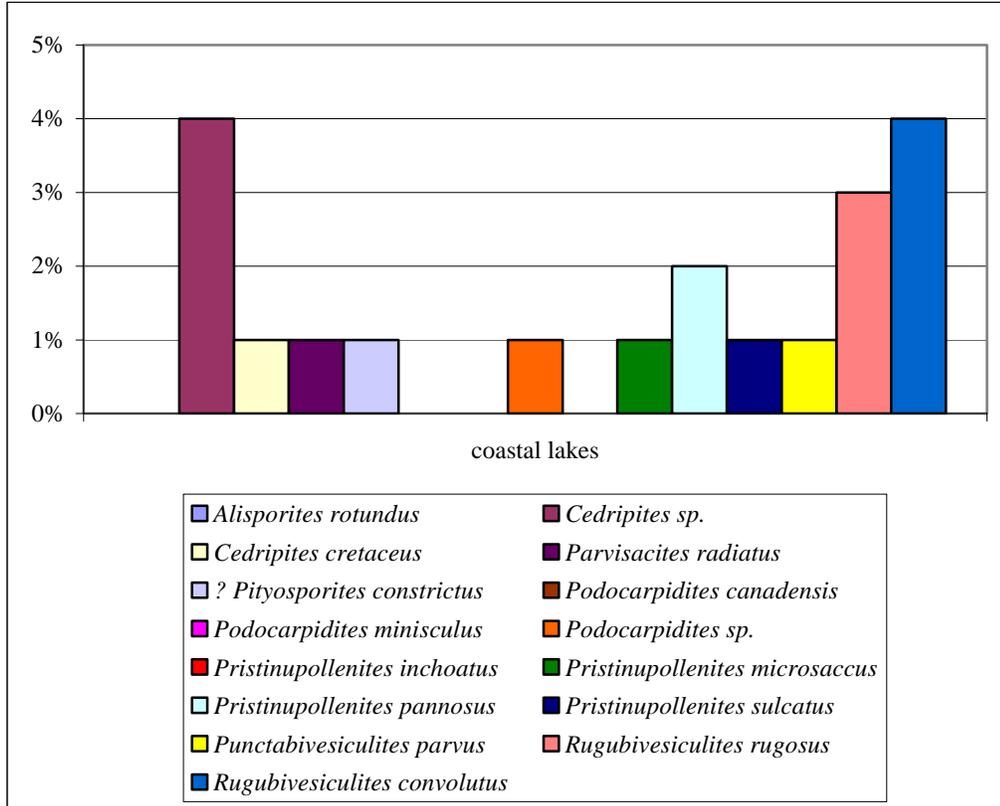


Figure 7-5. Relative abundance of bisaccate pollen in coastal lake environments at Ochs Clay Pit

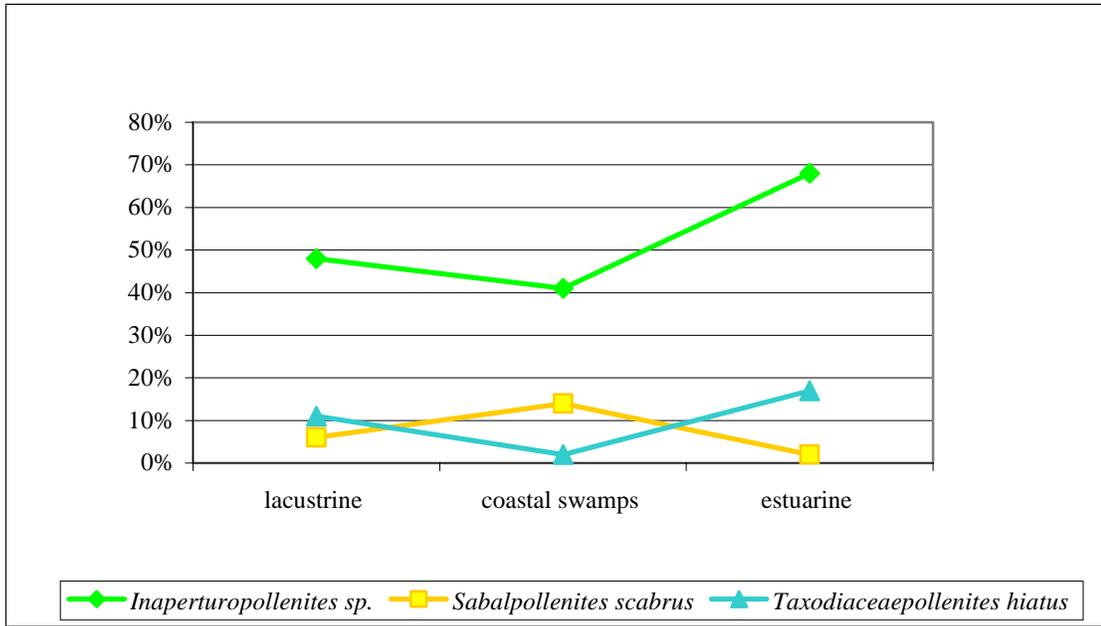


Figure 7-6. Relative abundance analysis of dominant non-bissacate gymnosperm pollen in three different environments

CHAPTER 8
COMPARISONS BETWEEN ANGIOSPERM MEGAFOSSIL AND MICROFOSSIL
RECORDS

Wang H. (2002) undertook research on the megafossil angiosperm leaves of Courtland Clay Pit. He described 13 genera and 23 species of angiosperms based upon leaf fossils. Although none of Wang's fossils were assigned to extant genera, the extant orders Magnoliales, Laurales, Proteales, and Saxifragales and similar extant families Lauraceae, Cercidiphyllaceae, Chloranthaceae, and Platanaceae were identified. Among them the Lauraceae with four genera and nine species had the highest diversity. The Cercidiphyllaceae and Platanaceae both with one genus and one species, respectively, had the lowest diversity. The Lauraceae also had the highest species abundance (102 specimens) while the Platanaceae had the second highest species abundance (36 specimens).

There were 26 pollen taxa recovered from the sediments at Courtland Clay Pit. *Tricolpites cf. vulgaris* (145 pollen grains found as a result of 3 counts of around 300 palynomorphs in each count), *Cupuliferoidaepollenites* sp. (79 pollen grains), *Tricolpites labeonis* (48 pollen grains), *Rousea cf. delicipollis* (26 pollen grains), *Dryadopollis argus* (24 pollen grains), *Fraxinoipollenites constrictus* (20 pollen grains), and *Tricolpate* sp.4 (13 pollen grains) were the most abundant species. *Tricolpites labeonis* was similar to *Tricolpites minutus* in pollen size and ornamentation. *Tricolpites minutus* has affinities with Platanaceae based upon a Cretaceous mesofossil investigation (Crane et al., 1986, Friis et al., 1988). On the other hand, the *Tricolpites labeonis* is also similar to *in situ*

pollen of the Early to Middle Albian flower *Aquia brookensis* from the “Bank near Brooke” locality, Virginia in pollen shape, size, and ornamentation (Crane et al., 1993). Crane et al. (1993) suggested that *Aquia brookensis* has affinities with Platanaceae based upon floral characters. Thus, the higher abundance of *Tricolpites labeonis* may be consistent with the megafossil record in which Platanaceae was the second most abundant species. Doyle and Hickey (1976) indicated that the tricolpate pollen in late Albian and Early Cenomanian may have a relationship to platanoid leaves based upon their co-occurrence. Friis and Pedersen (1996) suggested that the dispersed pollen genus *Tricolpites* may have a relationship with extant *Platanus* based upon in situ pollen morphology of three mid-Cretaceous platanoid flowers. The tricolpate and reticulate pollen of extant *Platanus* of Platanaceae (Erdtman, 1943) appears to be very similar to *Tricolpites cf. vulgaris*. The *Tricolpites cf. vulgaris* is the most abundant pollen type and its abundance might be explained by the abundance of leaves that co-occur with them.

Although magnoliids, which include eight genera and 14 species (Wang H., 2002), have the highest diversity among the megafossil flora in the megafossil record, the non-Lauraceae species were only four, which included two species of Chloranthaceae. In contrast, the leaf megafossils of Lauraceae (Wang H., 2002), with nine species that are the dominant types of angiosperms. This group is absent in the pollen record so it is probable that the palynoflora underrepresents this family. This is one bias that the pollen record may have because pollen of Lauraceae has very low sporopollenin content in the exine and they do not normally preserve well and survive the fossilization process (Traverse, 1988). One exception is a Turonian Lauraceae flower with *in situ* pollen from New Jersey described by Herendeen et al. (1994).

Doyleipollenites robbinsiae is one type of trichotomocolpate pollen recovered from both the Courtland Clay Pit and the Ochs Clay Pit. Also, *Doyleipollenites robbinsiae* is similar to *in situ* pollen on Early or Middle Albian fruiting units *Anacostia virginiensis* from Puddledock locality, Virginia (Friis et al., 1997) in pollen shape, aperture, and ornamentation. Friis et al. (1997) indicated that *Anacostia virginiensis* has affinities with magnoliids or monocotyledons.

Pedersen et al. (1991) described a new type of early Cenomanian fruit *Couperites mauldinensis* from the West Mauldin Mountain locality, Maryland, and the *in situ* pollen adhering to the sessile stigma were *Clavatipollenites*-type. Pedersen et al. (1991) suggested that the dispersed pollen assigned to *Clavatipollenites* may have relationships to several distinct magnoliid families.

Friis et al. (1999) studied the diversity of pollen associated with angiosperm reproductive structures in early Cretaceous floras from Portugal and pointed out that the majority of pollen types of early angiosperms are monosulcate, which may be recognized as *Clavatipollenites*, *Retimonocolpites* and *Liliacidites*, if they were dispersed. Friis et al. (1999) suggested that these species with monosulcate pollen may have magnoliid affinities.

Liliacidites sp.3 recovered from the Ochs Clay Pit is similar to *in situ* pollen of the Early or Middle Albian well-preserved flower *Virginianthus calycanthoides* from Puddledock locality, Virginia (Friis et al., 1994) in pollen shape, aperture, and ornamentation. *Virginianthus calycanthoides* is closely comparable to members of the family Calycanthaceae, which is a magnoliid of the order Laurales (Friis et al., 1994). The monosulcate pollen recovered from the Courtland Clay Pit as *Clavatipollenites*

tenellis, *Clavatipollenites* sp.2, *Liliacidites giganteus*, and *Liliacidites* cf. *reticulatus* may correlate with the non-Lauraceae magnoliid megafossil record.

The Trochodendrales and Buxales of the eudicots were absent in the leaf megafossil flora. But *Striatopollis paraneus* is similar to *in situ* pollen of an early Cenomanian inflorescence *Spanomera mauldinensis*, which was discovered at the Mauldin Mountain locality of Maryland (Friis et al., 1991), in pollen size, aperture, and unique ornamentation. Drinnan et al. (1991) also indicated that the *in situ* pollen of *Spanomera mauldinensis* were comparable to the dispersed pollen species *Striatopollis paraneus*. *Spanomera mauldinensis* provides the most complete evidence of mid-Cretaceous angiosperms related to extant Trochodendrales and Buxales (Friis et al., 1991). So the palynoflora can complement the megafossil flora, which may have a bias because of fossilization and preservation.

From the comparison between the megafossil record and the microfossil record at the Courtland Clay Pit, it is clear that both records are influenced by biases. A combination of mega and microfossil data will provide the most complete interpretation of the fossil floras. As an example, in addition to the magnoliids (which include Magnoliales and Laurales), Proteales, Saxifragales, the Trochodendrales and Buxales of the eudicots probably were also present in Courtland areas during middle Cenomanian based upon the microfossil records.

CHAPTER 9
EUSPORANGIATE FERNS FROM THE DAKOTA FORMATION, MINNESOTA,
USA (WITH DAVID DILCHER, HARALD SCHNEIDER AND DAVID JARZEN)

Abstract

Fossil records of the eusporangiate fern family Marattiaceae are common in Paleozoic and early Mesozoic sediments. However, the occurrence of this family during the Cretaceous and Tertiary is unknown. Within the Marattiaceae, extant species of *Marattia* are distributed worldwide, while *Danaea* occurs only in the New World, and *Angiopteris* and *Christensenia* show disjunct distributions throughout the Old World tropics except Africa. Two previously unknown marattioid ferns, *Goolangia minnesotensis* Hu, Dilcher, H. Schneid. et Jarzen gen. et sp. nov. and *Mesozoisynangia trilobus* Hu, Dilcher, H. Schneid. et Jarzen gen. et sp. nov., are described in this paper based on charcoalified isolated sporangia and synangia recovered from the Dakota Formation of the Courtland Clay Pit in south central Minnesota. These isolated sporangia and synangia have sessile, thick-walled sporangia and large spore output per sporangium which is consistent with features of extant eusporangiate ferns. The spore wall ultrastructure of *Goolangia minnesotensis* and *Mesozoisynangia trilobus* supports affinities with extant Marattiaceae. These fossils provide evidence for the existence of marattioid ferns during the mid-Cretaceous in North America and present the first unequivocal documentation of the Marattiaceae in post Jurassic times.

Adapted from Hu, S., Dilcher, D.L., Schneider, H., Jarzen, D.M., 2006. Eusporangiate ferns from the Dakota Formation, Minnesota, U.S.A. *Int J Plant Sci* 167: 579-589.

Introduction

Outcrops of the Dakota Formation in south central Minnesota often consist of clay sediments rich in plant fossils. The plant fossils from these mid-Cretaceous sediments have been studied for megafossils (Lesquereux, 1895; Wang H., 2002) and palynomorphs (Pierce, 1961; Hu, et al., 2004a, 2004b). Here we report sporangia similar to those of eusporangiate ferns, isolated from Dakota Formation sediments exposed in southern Minnesota. Previous to this study, fossils of eusporangiate ferns such as Marattiaceae and Ophioglossaceae have not been recovered from the Dakota Formation or other Cretaceous sediments worldwide (Tidwell and Ash, 1994; Collinson, 1996, 2001).

However fossil leptosporangiate ferns have been recovered from Dakota Formation in Kansas and Nebraska (Skog and Dilcher, 1992, 1994) and include species of Schizaeaceae, Gleicheniaceae, Matoniaceae, Dicksoniaceae and Marsileaceae. Additionally an assemblage of eight megaspore taxa, some of which have Marsileaceae affinities, were recovered from the Dakota Formation of Iowa (Hall, 1963, 1974).

Although the eusporangiate ferns have existed since the Carboniferous (Pryer et al., 2004), the Cretaceous fossil record lacks evidence for the occurrence of the marattioids and ophioglossids, traditionally assigned to the eusporangiate ferns. A good fossil record for the Marattiaceae exists from the Carboniferous to the Jurassic (Mamay, 1950; Stidd, 1974; Van Konijnenburg-Van Cittert 1975, 2002; Hill, 1987; Wan and Basinger, 1992; Liu et al., 2000; Wang et al., 2001; Wang Y., 2002), with a gap in the fossil record from the Jurassic to the Recent. The Ophioglossaceae are almost unknown as fossils with a single fossil record from the Paleocene of western Canada (Rothwell and Stockey, 1989).

This report presents evidence for the presence of eusporangiate fern sporangia, with affinities to the Marattiaceae, from the mid-Cretaceous of mid-continental North America

found preserved as charcoaled mesofossils with their associated spores. This study provides a new record of marattioid ferns to what is already known from other fern mesofossil studies of gleichenioid ferns (Gandolfo, et al, 1997) and heterosporous ferns (Lupia, et al., 2000).

Material and Methods

Samples were collected from dark, gray clays of the Dakota Formation of Cenomanian age (Setterholm, 1994) in Minnesota. Considering that Brenner et al. (2000) recognized Dakota Formation sediments in central Kansas and Nebraska as Late Albian in age and the transgressive seas of the Western Interior Seaway moved towards the northeast, the age of the Dakota Formation sediments in south central Minnesota must be not older than Late Albian and perhaps as young as lowermost Cenomanian. Organic rich gray, clay samples containing charcoaled mesofossils were collected from the Courtland Clay Pit, in south central Minnesota, about two miles from New Ulm (lat. 44°16'29" N, long. 94°23'13"W). Samples were immersed in a detergent (Alconox™) solution (ca. 2 teaspoons of detergent per liter of water) overnight or longer to thoroughly disaggregate the samples. The slurry was then sieved through 500µm and 125µm mesh sieves using flowing tap water. The air-dried residue containing many charcoaled specimens was sorted and specimens selected and identified using a WILD M5-84581 dissecting microscope at 6 to 50 X magnification. Specimens were immersed in 25% HCl overnight to remove carbonate materials, then washed three times in distilled water and immersed in 49% HF for 48-72 hours to remove silicates. Samples were neutralized through several washes in distilled water. Four complete or nearly complete isolated sporangia and synangia were selected for detailed study by light microscope (LM), transmission electron microscope (TEM) and scanning electron microscope (SEM).

For LM studies, spores were removed from the sporangia and treated with 5% KOH solution for about six hours, effectively disaggregating the spores. Samples were washed twice with distilled water and once with a 50% glycerin solution. The resulting residue was mounted on microscope slides using glycerin jelly and photographed using a ZEISS Axiophot™ imaging system. At least 29 spores from each sporangium were measured and observed for spore dimensions and morphology. Fragments of entire sporangia containing spores were removed and prepared for TEM using standard protocols (Hajat, 2000). Samples were infiltrated with 100% acetone for ten minutes. This was followed by an acetone and Spurr's epoxy resin solution series of 30%, 50%, 70%, and 100% with the samples remaining in each for one hour. The infiltrated specimens were transferred to molds and embedded in 100% Spurr's epoxy resin and placed in an oven at 60°C for 24 hours. Ultrathin sections were made using a Reichert Ultracut R™ ultra-microtome equipped with a diamond knife. Sections were transferred to butvar coated grids, and stained with 2% uranyl acetate for ten minutes and Reynolds lead citrate for five minutes. Sections were examined and photographed using a Hitachi H7000™ transmission electron microscope at an accelerate voltage of 75 kV. SEM samples were mounted on stubs using carbon adhesive tabs and graphite glue, and photographed using a FESEM Hitachi S4000™ at an accelerate voltage of 2-6 kV.

In order to estimate the spore number in each sporangium, we first calculated the actual sporangial area in which the spores were present. We then counted the spore layers and the spore number per layer in a cross section of sporangia. Next, we estimated the total numbers of cross sections per sporangia. A final estimate of total spore count

was reached by multiplying the number of hypothetical cross sections by the spore count of the section measured.

Results

Family: Marattiaceae

Genus: *GOOLANGIA* Hu, Dilcher, H. Schneid. et Jarzen gen. nov.

Type species: *Goolangia minnesotensis* Hu, Dilcher, H. Schneid. et Jarzen gen. et sp. nov.

Generic Diagnosis

Sporangium sessile with thick sporangial walls. Sporangium is elongate, asymmetrical, with a basal attachment scar for half of its length. The edge above the attachment scar is thin and the opposite edge consists of a ridge of cells elongated transversely to the sporangium. The orientation of surface cells adjacent to this ridge is perpendicular to the long axis of the sporangium. Sporangium is homosporous and with numerous (1,000 +) spores. Spores trilete, psilate to scabrate and randomly covered with globules. Laesurae are raised and frequently bifurcate before reaching the equator.

Etymology: “Gool” representing the name “Cooler” for Mr. Scott Cooler, owner of the Courtland Clay Pit, and “angia” from the Greek, capsule or container, referring to the sporangia.

Species: *Goolangia minnesotensis* Hu, Dilcher, H. Schneid. et Jarzen sp. nov.

Species Diagnosis

General morphology

Sporangium is elongate, elliptical, slightly asymmetrical, and measures 1.2 x 3.5 mm (Plate 29, Fig. 1). An attachment scar is evident (Plate 29, Fig. 2), along about half the length of one edge of the sporangium. The edge above the attachment scar is very thin (17 μ m). The opposite edge consists of a ridge (ca 90 μ m thick) of cells elongated transversely to the sporangium (Plate 29, Figs. 2, 3). The orientation of surface cells adjacent to this ridge is perpendicular to the long axis of the sporangium (Plate 29, Fig.

3). These cells are 10 x 27-51 μm . Sporangium cross-section is 142 μm thick (Plate 29, Fig. 6), consisting of an upper multicellular layer (29 μm thick) and a lower multicellular layer (38 μm thick) surrounding a chamber filled with spores (Plate 29, Fig. 6).

Homosporous spores number about 4,500.

Spore morphology

Spores are circular to subcircular with a trilete mark (Plate 29, Figs. 4, 5). No distinction between exospore and perispore is visible, and the wall is between 1 to 2 μm thick. Size range is 47-77 μm (average 60 μm , 29 spores measured). Laesurae are slightly raised, extending to the equator and frequently bifurcate about 2/3 of the length before reaching the equator (Plate 29, Fig. 5, arrow). Ornamentation is psilate to finely scabrate and randomly covered with globules (Plate 29, Figs. 4, 5).

Etymology: “minnesotensis” named for Minnesota where the fossil was discovered.

Type material: holotype: 19007-036708-M1. Specimen deposited in the Paleobotany/Palynology Collection, Florida Museum of Natural History, Gainesville, Florida, USA.

Type locality: Courtland Clay Pit, New Ulm, Minnesota, USA.

Formation: Dakota Formation.

Age: Latest Albian to earliest Cenomanian

Description

The evident attachment scar is important because it suggests that the elongate sporangium was part of a synangium. We view this sporangium as one of a cluster of sporangia (Plate 30, Figs. 1, 2) rather than consisting of a number of individual sporangia fused together. We emphasize this because along the elongate axis of the sporangium, spores appear to form a superficially continuous mass that is separated into 13 to 15 groups by cracks on the surface (Plate 29, Fig. 7).

The spores (Plate 29, Figs. 4, 5) ranged in size from 47 to 77 μm with a mode of 56 μm . The spores are unremarkable in their ornamentation and therefore an isolated spore

would not be recognized as belonging to the Marattiaceae. Spore ultrastructure as observed using TEM shows the important characters that demonstrate their similarity with extant species of the Marattiaceae.

The spore wall consists of a perispore (P) (120-130 nm) and an exospore (E) (3-6.7 μm) (Plate 29, Figs. 8, 9). The thin and homogenous perispore forms a nearly continuous layer surrounding the exospore (Plate 29, Fig. 9). Spherical granules are attached to the surface of the perispore (Plate 29, Fig. 9, arrows). The exospore is thicker in the proximal face than in the distal face (Plate 29, Fig. 8). The exospore is differentiated into a homogenous outer exospore layer (*Ee* in Plate 29, Fig. 11), a thicker and less dark middle exospore layer (*Em* in Plate 29, Figs. 10, 11) with cavities, and a thin and dark inner exospore layer (*Ei* in Plate 29, Fig. 11, upper arrow). The outer exospore layer is homogenous and up to 3.2 μm thick. The middle exospore layer is 2-6 μm thick with a maximum thickness at the flank of the aperture (Plate 29, Fig. 11). The cavities of the middle exospore layer have a diameter of 7-21 nm (Plate 29, Fig. 10, arrow). The transition between the inner and middle layer is clearly visible whereas the transition between middle and outer layer is less obvious. The inner exospore layer is thickest (200 nm) at the base of the aperture and its thickness gradually decreases (to 30-33 nm) toward the apical part of the proximal fold and the distal face (Plate 29, Fig. 8). A subapertural mass is present below the apertural slit (Plate 29, Fig. 11, lower arrow).

Systematic Remarks

The morphology of *Goolangia minnesotensis* resembles extant eusporangiate fern sporangia in the following characters. *G. minnesotensis* is sessile, has thick sporangial walls (ca 34 μm thick), and has a large number of homosporous spores (ca 4,500).

Ophioglossaceae and Marattiaceae are the only eusporangiate fern families. These two

families can be distinguished by ultrastructures of the spore walls. The ultrastructure of the spore walls of both families is distinctive in having three layers. The layers in Ophioglossaceae show numerous lamellae in the middle layer while these lamellae are only weakly developed in Marattiaceae (Tryon and Lugardon, 1991). The ultrastructure of the fossil spores, found in *G. minnesotensis*, exhibits three layers (Plate 29, Fig. 11) showing small cavities in the middle exospore layer which lacks any lamellae. The middle exospore layer can be most clearly observed in the apical part of the aperture. The fossil spore wall ultrastructure is similar to the Marattiaceae rather than the Ophioglossaceae (Tryon and Lugardon, 1991).

Goolangia minnesotensis represents a single sporangium dispersed from a sporangial cluster laterally fused basally for half of its length (Plate 30, Figs. 1, 2). The spores are present throughout the entire individual sporangium which lacks any internal septa or chambers. A scar clearly demarcates the extent of the fusion of the sporangia with others to form a synangium (Plate 30, Fig. 1). The attachment scar terminates at about one-half of the sporangial length. The rest of the inner margin of the sporangium is thin (ca 17 μm) in sectional view. This contrasts with the thickened ridge (ca. 90 μm) that extends along the outer margin of the sporangium and may have functioned to open the sporangium along the inner thin area. *G. minnesotensis* may be close to *Angiopteris* judging from the morphology of the sporangium and spore wall ultrastructure. However *G. minnesotensis* sporangia are fused for about half of their length, while *Angiopteris* sporangia are fused basally.

The size of *Goolangia minnesotensis* seems to be larger (3.5 mm long) than extant *Angiopteris* sporangia (0.3-0.6 mm long) (Hill, 1987). The middle Jurassic fossil

sporangia of *Angiopteris blackii*, from Yorkshire, England, range in size from 0.6-1.1 mm long (Hill, 1987). Some Paleozoic fossil marattialeans had relatively large sporangia; *Eoangiopteris goodii* Millay may be up to 2 mm long (Millay, 1978), *Sclocopteris major* Mamay is 2.1-2.9 mm long (Mamay, 1950), and *Millaya tularosana* Mapes and Schabillion is 1.7-2.0 mm long (Mapes and Schabillion, 1979). The sporangium size (3.5 mm long) of *G. minnesotensis*, while large, may not be inconsistent with earlier described fossil sporangia of Marattiaceae.

Angiopteris blackii, *Eoangiopteris andrewsii* and *E. goodii* have basal attached sporangia (Hill, 1987; Millay, 1978; Mamay, 1950), while *Sclocopteris major* and *Millaya tularosana* have laterally attached sporangia (Millay, 1979; Mapes and Schabillion, 1979). *Goolangia minnesotensis* is most similar to the basally fused sporangia of *A. blackii* (Hill, 1987) of middle Jurassic age, and *E. andrewsii* (Mamay, 1950) and *E. goodii* (Millay, 1978) of Pennsylvanian age. These synangia consist of individual sporangia clustered and fused at their base as seen in *A. blackii* with 4-16 sporangia per sorus, *E. andrewsii* with 5-8 sporangia per sorus and *E. goodii* with 10-19 sporangia per sorus (Hill, 1987; Mamay, 1950; Millay, 1978). The basic differences between *Goolangia* and *Eoangiopteris* are obvious and they are as follows: 1) the sporangia of *Goolangia* were laterally fused basally for half of their length and those of *Eoangiopteris* were attached laterally at base and free from each other distally (Mamay, 1950; Millay, 1978); 2) the dehiscence of *Goolangia* occurs along upper half of the sporangium and that of *Eoangiopteris* extends entire length of the sporangium (Mamay, 1950); 3) the spore output of *Goolangia* is relatively high (1,000 +) and that of *Eoangiopteris* is low (a maximum of approximately one hundred) (Mamay, 1950); 4) the

ornamentation of the spores of *Goolangia* is psilate to scabrate and that of the spores of *Eoangiopteris* is verrucate (Millay, 1978).

Compared with spores of extant Marattiaceae, including *Angiopteris*, the in situ spores of *Goolangia minnesotensis* are unique in several aspects. First, the ornamentation of the fossil spores is psilate to scabrate which is not comparable with the conspicuously ornamented spores of extant Marattiaceae ferns (Tryon and Lugardon, 1991). Second, the spore number per sporangium in *Angiopteris* is about 1,500 (Bower, 1923) and may range as high as 2,000-2,500 (Chang, 1975). Fossil *Angiopteris blackii* have a spore number of 3,000 per sporangium (Hill, 1987). The estimated spore content of 4500 for *G. minnesotensis* is larger than extant species or those from earlier fossil records. Third, considering the published record of spore sizes ranging from 20-40 μm (Camus, 1990) for extant species of Marattiaceae, the spore size of 47-77 μm for *G. minnesotensis*, although relatively large, is closely compared with the spore sizes of Paleozoic marattialean species, e.g. *Scolecopteris major*, 45-55 μm ; *S. iowensis*, 65-80 μm ; *Eoangiopteris andrewsii*, 45-60 μm (Mamay, 1950); *E. goodii*, 57-83 μm (Millay, 1978); and *Millaya tularosana*, 90-113 μm (Mapes and Schabilion, 1979). Millay (1978) considered that large spores might constitute a primitive character in Marattiaceae.

Although Lycopodiaceae and Psilotaceae have sessile and homosporous sporangia, *Goolangia minnesotensis* clearly differs from them in the nature of its spore ultrastructure. Spore wall ultrastructure of Lycopodiaceae is unique in having compact lamellae that are elaborated in centripetal sequence, and that of the Psilotaceae in its slightly undulate surface of outer exospore layer (Tryon and Tryon, 1982; Tryon and Lugardon, 1991). Moreover the elongate-ellipsoidal shape and monolete aperture in the

spores of the Psilotaceae clearly set them apart from the spores of *G. minnesotensis* (Tryon and Lugardon, 1991).

Family: Marattiaceae

Genus: MESOZOISYNANGIA Hu, Dilcher, H. Schneid. et Jarzen gen. nov.

Type species: *Mesozoisynangia trilobus* Hu, Dilcher, H. Schneid. et Jarzen gen. et sp. nov.

Generic Diagnosis

Synangium sessile, consisting of three basally fused trilobed sporangia. Each thick-walled sporangium has a central protruding lobe and two lateral lobes. Cells on the tip of the central lobe are elongated parallel to the lobe surface with thickened cell walls. Sporangium is homosporous and with numerous (800 +) spores. Spores trilete, psilate to scabrate, with few globules on the spore surface. Laesurae are raised.

Etymology: “Mesozoi” meaning Mesozoic, “synangia” indicating the nature of the sporangia typical of eusporangiate ferns.

Species: *Mesozoisynangia trilobus* Hu, Dilcher, H. Schneid. et Jarzen sp. nov.

Species Diagnosis

General morphology

The individual sporangia occur as fused synangium consisting of three sporangia (Plate 31, Figs. 1, 2, 7, 8), or as isolated 3-lobed sporangium (Plate 31, Figs. 5, 6). Individual sporangia are trilobed (Plate 31, Figs. 5, 6), ranging in size from 0.6 X 0.6 mm to 0.9 X 1.2 mm. The sporangium consists of an upper multicellular layer (36 µm thick) and a lower multicellular layer (39 µm thick) surrounding a chamber filled with spores (Plate 32, Fig. 1). The sporangium in cross-section was 116 µm thick (Plate 32, Fig. 1). Each individual sporangium may contain about 3,800 spores, whereas the smallest of the sporangia (Plate 31, Fig. 8) may contain about 900 spores. Spores are homosporous.

Spore morphology

Spores are subtriangular to circular with a trilete mark (Plate 32, Figs. 2, 3). The spore wall is between 0.5 to 1.5 μm thick. Spores range from 27 to 44 μm (average 33 μm , 63 spores measured). The laesurae are raised and extend to the equator (Plate 32, Figs. 2-5). Ornamentation is psilate to finely scabrate with few globules on the spore surface (Plate 32, Figs. 2-5).

Etymology: “trilobus” meaning each fossil sporangium has three lobes.

Type material: holotype: 19007-036708-M2. Paratypes: 19007-036708-M3, 19007-036708-M4. Specimens deposited at the Paleobotany/Palynology Laboratory, Florida Museum of Natural History, Gainesville, Florida, USA.

Type locality: Courtland Clay Pit, New Ulm, Minnesota, USA.

Formation: Dakota Formation.

Age: Latest Albian to earliest Cenomanian

Description

The individual sporangia were attached basal-centrally (Plate 31, Fig. 6, arrow denotes the attachment scar), each sporangium having a central protruding lobe and two lateral lobes (Plate 31, Fig. 5, arrows). Each synangium consists of three sporangia (Plate 31, Figs. 2, 8, arrows). Cells on the tip of the central lobe of the middle sporangium (Plate 31, Fig. 2) are elongated parallel to the lobe surface with thickened cell walls (Plate 31, Fig. 3). There are no spores in the tip of this central lobe (Plate 31, Fig. 4, arrow), perhaps suggesting that it is a sterile lobe.

Average size of spores is 33 μm while the mode is 32 μm . The smooth ornamentation of the spores makes it very difficult to link dispersed spores to the Marattiaceae. Spore ultrastructure (TEM) is important in establishing relationship with the Marattiaceae.

Granules are often found in masses between spores (Plate 32, Fig. 9), or are attached to the surface of the spore and occasionally form granule masses. The spore

wall consists of an exospore (1-1.9 μm) (*E* in Plate 32, Fig. 6). A perispore is not visible. The exospore is slightly thicker at the proximal face than at the distal face (Plate 32, Fig. 6), and is differentiated into a homogenous outer exospore layer (*Ee* in Plate 32, Fig. 7), a middle exospore layer (*Em* in Plate 32, Fig. 8) with cavities (Plate 32, Fig. 8, arrow), and a thin and dark inner exospore layer (*Ei* in Plate 32, Fig. 7, arrow). The transition between the inner and middle layer is clearly visible, whereas the transition between the middle and outer layer is often undetectable. The outer exospore layer is homogenous and up to 1.6 μm . The middle exospore layer is 252 nm thick with a maximum thickness at the flank of the aperture. The cavities of the middle exospore layer have a diameter of 7-28 nm (Plate 32, Fig. 8). The inner exospore layer is thickest (56 nm) at the base of the aperture, and its thickness gradually decreases (to 28 nm) toward the apical part of the proximal fold and the distal face (Plate 32, Fig. 7).

Systematic Remarks

The observed features of basal sporangia attachment, a thick sporangia wall (ca 31 μm in average), a large spore output (ca 900-3,800) and homospority suggest that these specimens have eusporangiate fern affinities. The spore ultrastructure of *Mesozoisynangia trilobus* is relatively simple compared with that of *Goolangia minnesotensis*. Although inner, middle and outer exospore layers may be differentiated, the middle exospore layer, with cavities, is thin and less developed. It differs from Ophioglossaceae spore ultrastructure because the middle exospore layer lacks the lamellae typical of that family. The spores of *M. trilobus* are comparable to extant Marattiaceae because in the middle exospore layer lamellae are absent and cavities are rare.

The basally fused synangia are similar to those of *Angiopteris*. Compared with spore output per sporangium of 1,500-2,500 in extant *Angiopteris* (Bower, 1923; Chang, 1975) and the fossil *Angiopteris blackii* producing about 3,000 spores per sporangium (Hill, 1987), the spore output of *Mesozoisynangia trilobus* of 900-3,800 spores per sporangium is comparable to *Angiopteris*. The spore size of *M. trilobus* (27-44 μm) is also comparable to that of extant *Angiopteris* (20-37 μm) as is the spore wall ultrastructure. The absence of a perispore in *M. trilobus* spores may indicate that the spores were immature (Wang et al., 2001).

Although a comparison of the fossil specimens with extant *Angiopteris* is strong, there are significant differences. The three-lobed sporangium differs from that of extant *Angiopteris* which is typically a squat obovoid shape (Hill, 1987). Additionally, spore ornamentation is not comparable with extant *Angiopteris* spores which display tuberculate to rugate ornamentation. There are important fossil records of Marattiaceae in North America from the Late Carboniferous to Permian (Mamay, 1950; Stidd, 1974; Millay, 1979). *Acaulangium* Millay, *Cyathotrachus* (Watson) Mamay, *Scoleopteris* Zenker and *Eoangiopteris* Mamay are the best-known genera of petrified marattialean synangia in North America (Millay, 1979). Among them, the sporangia of *Eoangiopteris* are free from each other and may have given rise to the extant basally fused synangia of *Angiopteris* (Mamay, 1950). Characteristics of sporangia shape and low spore number in each sporangium (maximum ca. 100) (Mamay, 1950) exclude the possibility that *Mesozoisynangia trilobus* share affinities with *Eoangiopteris*. The ancestors of *M. trilobus* are unknown.

In summary, *Mesozoisynangia trilobus* is similar to *Angiopteris* in having basally fused synangia, spore output per sporangium, spore size, and spore wall ultrastructure. However, the morphology of the individual sporangia and spore ornamentation differ.

Discussion

The finding of this fossil eusporangiate fern material indicates that the elements of Marattiaceae were present in North America during the mid-Cretaceous. Spores of *Goolangia minnesotensis* are comparable with the dispersed spore *Dictyophyllidites impensus* (Hedlund) Singh, differing only in spore wall thickness, being twice as thick in *D. impensus*. Judging from the distribution of *D. impensus* which has been recovered in sediments from Arizona, Oklahoma, Utah, Wyoming to Alberta and even in the deep sea core near the Bahamas (Singh, 1983), *G. minnesotensis* may have had a wide distribution in North America. To our knowledge, this is the first record of Marattiaceae in Cretaceous deposits worldwide. The poor fossil record of maratioid ferns in the Dakota Formation may be partly explained by the susceptibility of their fronds to decay (Hill, 1987). On the other hand, charcoalfied plant remains, produced by wildfires (Scott, 2000) are almost pure carbon and are chemically highly inactive and may remain three-dimensional in the fossil material (Eklund et al., 2004).

The sedimentary environment at the Courtland Clay Pit during mid-Cretaceous may have been a large lake (Hajek et al., 2002) with low water energy. The charcoalfied isolated fern sporangia and synangia under these conditions would be well preserved. Considering that modern elements of Marattiaceae are ecologically specialized in the shaded floor of wet, tropical and subtropical forests, especially along streams, gullies and ravines (Tryon and Tryon, 1982; Camus, 1990), the fossil sporangia would have been easily transported to sedimentary basins as their habitats were generally close to the river

systems. This also implies that the paleoclimate in Minnesota during the mid-Cretaceous probably was lacking freezing weather (subtropical). However, the angiosperm fossil leaf record shows a mean annual temperature (MAT) of 21°C (Dilcher et al., 2005), typical of a warm temperate climate. Probably frosts were infrequent or absent, and moisture abundant. These forests may have provided extensive habitats for the evolution and diversity of ferns, which as understory plants, probably dominated the ecosystem (Coe, et al., 1987; Skog and Dilcher, 1994). The existence of two different types of *Angiopteris*-like ferns during mid-Cretaceous contributes to our understanding of the fate of these ferns during the late Mesozoic and their present day diversity. Evidence suggests that a diversification of pteridophytes occurred in the Cretaceous after or during the rise of the angiosperms (Schneider et al., 2004).

The diversity of ferns during the deposition of the mid-Cretaceous Dakota Formation sediments can be best understood when we consider other fern spore and megafossil data from the Dakota Formation. The relative abundance of fern spores varies from 45% to 47% in sediments analyzed from Kansas and Nebraska (Farley and Dilcher, 1986). There are 22 species reported as spores (Farley and Dilcher, 1986) and 12 species reported as megafossils at the Rose Creek locality in Nebraska (Skog and Dilcher, 1994). These taxa are form species and do not correspond to natural species. Their affinities usually are unknown or speculative. In addition, fern spore morphology among related taxa is often similar making specific identification difficult or impossible (Tryon and Tryon, 1982). Analyzing the fern diversity based only upon miospores will create a bias similar to that already observed for megafossils. The megafossil record reflects local environment while pollen and spore records reflect regional vegetation (Dilcher and

Farley, 1988; Potter, 1976). Wang (2004) noted that mesofossils recovered from the Dakota Formation reflected a regional bias as do pollen and spore records published by Farley and Dilcher (1986). Friis et al. (1999) suggested that mesofossils might reflect local vegetation because they are deposited close to their parent plants. The dilemma of regional vs. local origin of the eusporangiate fern sporangia is evident and for now remains an open question.

Mesofossils consist of charcoaled plant remains and are mid-sized fossils between larger megafossils and smaller microfossils. When plant tissues are charcoaled, delicate structures, such as anthers containing pollen (Crane and Herendeen, 1996) and sporangia containing spores, are often well preserved. Therefore these mesofossils provide additional characters that allow comparisons to morphological features unique to extant plants. This information complements the megafossil record providing information not otherwise available. In this study, new information includes the nature of the sporangia and the spores contained within them. Dispersed spores may be related to a taxon with known affinities, making it possible to compare some mid-Cretaceous dispersed spores with eusporangiate ferns.

The data presented here represent only two taxa. However the total diversity of eusporangiate vs. leptosporangiate ferns present during the mid-Cretaceous probably can not be determined from only dispersed spores and mesofossils. The broad distribution of mid-Cretaceous ferns can be seen from both megafossil and microfossil records of the Dakota Formation. There were 12 -14 fern megafossil species in the western coastal plain of the Western Interior Seaway (Rushforth, 1971) and 10 of the same species are present in the eastern coastal plain of the Western Interior Seaway while two species are

unique (Skog and Dilcher, 1994). The spore taxa found in mid-Cretaceous localities of the Dakota Formation in Arizona (Agasie, 1969; Romans, 1975), Utah (May and Traverse, 1973), Oklahoma (Hedlund, 1966), Kansas and Nebraska (Farley and Dilcher, 1986), and Minnesota (Pierce, 1961) are all similar (Farley and Dilcher, 1986).

Although angiosperms may have become more diverse during the mid-Cretaceous, the pteridophytes still dominated the ecosystem (Skog and Dilcher, 1994). *Goolangia minnesotensis* and *Mesozoisynangia trilobus* are the first eusporangiate ferns recorded in the Dakota flora of North America. This discovery indicates that pteridophytes had a higher diversity during the Cretaceous than previously thought. Although it is clear that the leptosporangiate ferns diversified during the Cretaceous along with the diversification of angiosperms (Schneider et al., 2004), this study suggests that the eusporangiate ferns may also have been an element in this same ecosystem.

CHAPTER 10 CONCLUSIONS

Based upon the palynological and palybotanical investigation of the Dakota Formation, early Late Cretaceous sediments at the Courtland Clay Pit, Highway 4 Clay Pit, and Ochs Clay Pit in south central Minnesota, the following conclusions are reached.

There are 218 types of palynomorphs recognized. Among them, 41 types of angiosperm pollen were recovered, five of which are described as new species. The new species are *Dryadopollis minnesotensis* Hu, sp. nov., *Dryadopollis minutus* Hu, sp. nov., *Liliacidites sinuatus* Hu, sp. nov., *Phimopollenites striolata* Hu, sp. nov., and *Tricolpites labeonis* Hu, sp. nov.. At the same time 42 types of gymnosperm pollen, and 78 spores of ferns and fern allies were recovered. Spores of ferns and fern allies were the most diverse among the terrestrial palynomorphs. Moreover, two types of megaspores, ten types of algal spores and colonies, seven types of fungal spores and fruiting body, 18 types of dinoflagellate cysts, and 20 types of acritarchs were recovered. The discovery of typical marine dinoflagellate cysts, such as *Oligosphaeridium reniforme*(Tasch) Davey, 1969, *Coronifera oceanica* Cookson and Eisenack, 1958, *Cyclonephelium* cf. *vannophorm* Davey, 1969, and *Subtilisphaera deformans* (Davey and Verdier) Stover and Evitt, 1978, in the sediments above the lignite at Ochs Clay Pit supports the interpretation of estuarine environments by Sloan (1964).

Based upon the common occurrence of *Liliacidites reticulatus*, *Tricolpites* cf. *vulgaris*, *Phimopollenites striolata* and *Fraxinoipollenites constrictus* in sample 036710 at the Courtland Clay Pit, in sample 046517 at the Highway 4 Clay Pit, and in sample

046522 at the Ochs Clay Pit, I propose that the sediments from which these samples were collected represent time equivalent deposits (Figure 5-12). Thus it is possible to make some stratigraphic comparisons between these three clay pits. By comparison with the results of Singh (1983), Nichols (1994), Ravn and Witzke (1995), Witzke et al. (1996), and Brenner et al. (2000), based upon the occurrence of megaspore *Balmeisporites glenelgensis*, fern spores *Dictyophyllidites impensus* and *Cicatricosisporites crassiterminatus*, and angiosperm psilate tricolporate pollen type *Nyssapollenites* sp. and the obligate tetrad *Artiopollis indivisus* in the research areas, the age of the Cretaceous coeval sediments exposed at the Courtland Clay Pit, Highway 4 Clay Pit and Ochs Clay Pit is probably middle Cenomanian.

Based upon the analysis of angiosperm pollen characteristics from the Ochs Clay Pit, Courtland Clay Pit, and Highway 4 Clay Pit, the pollen types that appear to be insect-pollinated accounted for 77% of all pollen types, and the pollen types that appear to be wind-pollinated accounted for 23% of all pollen types. Wind-pollinated plants probably were not dominant around coastal lakes, swamps, and the inland meandering river areas during the middle Cenomanian.

It is probable that 15 angiosperm pollen types recovered from the lignite represent plants that may have inhabited coastal swamps and adjacent areas during the middle Cenomanian. Based upon the occurrence, relative abundance, and pollen clumps, the angiosperms releasing *Liliacidites sinuatus* and *Artiopollis indivisus* may have grown in the swamps. On the other hand, the angiosperms releasing *Fraxinoipollenites constrictus*, *Liliacidites reticulatus*, *Phimopollenites striolata*, and *Tricolpites* cf. *vulgaris* may not have grown in coastal swamps.

The species diversity of ferns and fern allies (16 types) was slightly higher than that of angiosperms (15 types) in coastal swamp and adjacent areas during the Cenomanian. Based upon relative abundance analysis it appears that the dominant ferns and fern allies in coastal swamps may have been the ferns or fern allies that produced *Gleichiidites senonicus* (31%) and ? *Gleichiidites* sp. (42%). Moreover, *Deltoidospora hallii*, ? *Auritulinasporites* sp., *Laevigatosporites ovatus* may have been important elements in the coastal swamps and adjacent areas.

Based upon relative abundance, the plants releasing bisaccate pollen probably did not inhabit the coastal areas. But other non-bisaccate pollen such as ? *Eucommiidites* sp., *Araucariacites australis*, *Bacumonoporites baculatus*, *Inaperturopollenites* sp., *Monosulcites*. sp.2, *Sabalpollenites scabrous*, *Taxodiaceapollenites hiatus* may have grown in coastal swamps or adjacent areas. Among them, the plant releasing ?*Eucommiidites* may have been restricted to coastal swamps. Also, the plants releasing pollen *Inaperturopollenites* sp., *Sabalpollenites scabrous*, and *Taxodiaceapollenites hiatus* may have been dominant among the gymnosperm plants in coastal swamps and adjacent areas.

The palynological data recovered from samples representing coastal swamps suggest that although angiosperms became important in species diversity the ferns and fern allies still play an important role in the ecosystem. This conclusion supports that proposed by Farley and Dilcher (1986) and Coe et al (1987). Based on the comparison with palynological assemblages recovered from coal or lignite from northwestern Arizona, northwestern Iowa and northeastern Nebraska, and central Kansas (Agasie, 1969; Farley, 1982; Farley and Dilcher, 1986; Ravn and Witzke, 1995), it is possible that

the characteristic vegetation elements of the coastal swamps during Cenomanian were diverse angiosperms, abundant ferns and fern allies, and a relative low abundance of gymnosperms.

A comparison between the megafossil record and the microfossil record at the Courtland Clay Pit indicates that both records are influenced by biases. The best method is to combine the results from both the megafossil record and the microfossil record in order to reach a final interpretation of the nature of the fossil floras. At Courtland Clay Pit, in addition to magnoliids (which include Magnoliales and Laurales), Proteales, Saxifragales which were recovered from leaf records, the Trochodendrales and Buxales of the eudicots were all present during middle Cenomanian based upon the microfossil records. Also the *in situ* pollen records of mesofossil investigations were crucial for an accurate interpretation of the dispersed pollen records.

Two new marattioid ferns, *Goolangia minnesotensis* Hu, Dilcher, H. Schneid. et Jarzen gen. et sp. nov. and *Mesozoisynangia trilobus* Hu, Dilcher, H. Schneid. et Jarzen gen. et sp. nov., were discovered based on charcoalified isolated sporangia and synangia recovered from the Dakota Formation of the Courtland Clay Pit. These fossils provide evidence for the existence of marattioid ferns during the Cenomanian in North America and present the first unequivocal documentation of the Marattiaceae in post Jurassic times. The *in situ* spores of *Goolangia minnesotensis* are comparable with the dispersed spore *Dictyophyllidites impensus* (Hedlund) Singh. According to the distribution of *D. impensus* which has been recovered in sediments from Arizona, Oklahoma, Utah, Wyoming to Alberta and even in the deep sea core near the Bahamas (Singh, 1983), *G.*

minnesotensis appears to have had a wide distribution in North America (Singh, 1983) during middle Cenomanian.

APPENDIX A
PROCESSING PROCEDURES USED BY GLOBAL GEOLAB LIMITED, CACADA

Acid Digestion/Cleaning

1. 5-15 grams of sample is placed in a 250 polypropylene beaker. The specific weight for each sample is measured and recorded on the processing record. Then two lycopodium spore tablets (batch # 124961) are added to each sample.
2. A 10% solution of HCL is added, watching for an overly violent reaction, which is dampened with an atomized spray of distilled water from a spray bottle. This minimizes the dilution of the acid.
3. Allow time for carbonates to dissolve, generally overnight.
4. Decant the spent HCL. Add distilled water, allow settling and decanting again. The sample is diluted and decanted three times to remove any remaining calcium ions, which can produce a precipitate when HF is added.
5. 70% HF is added, watching for any violent reaction, which is dampened with distilled water as above. The sample in HF is oscillated for up to four hours until digestion completed.
6. Pour the digested sample into a 50ml. Polypropylene test tube and centrifuge for five minutes at 2000RPM. Carefully decant the top $\frac{3}{4}$ or the spent HF.
7. Add distilled water while vortexing and centrifuge for two minutes. (Repeat until neutral)
8. This washing/centrifuging is repeated until the fine caustic material has been removed. (Three or four times)
9. To allow for a better heavy liquid separation, add a few drops of concentrated HCL vortex while adding water and centrifuge for four minutes.

Heavy Liquid Separation

1. Add Approximately 25ml of ZnBr₂ Sp. Gravity - 2.0; vortex thoroughly.
2. Place each test tube in an ultrasonic bath for approximately ten seconds.

3. Allow the samples to sit for ten minutes before centrifuging for fifteen minutes at 2000 RPM. I feel that the ten-minute wait allows for better separation.
4. Pour off the “float” into another 50ml tube, wash and centrifuge for two minutes at 2000 RPM, repeat three times
5. Transfer the remaining residue to a 20ml glass tube. Examine a small smear of the residue to determine the amount of oxidation required.

Oxidation

1. Place approximately 3ml of Schultz solution on the residue, vortex and place the tube in a hot bath for a time determined in step 14. (Note- time of oxidation for these samples was approximately 30 seconds.)
2. Remove the spent Schultz solution by washing and centrifuging until neutral. Check small smear of residue to see if the oxidation is sufficient.
3. Add a 10% solution of NH_4OH (and place in hot water bath) for two minutes. Centrifuge and wash three times as in step 17.
4. Examine the residue to determine if the desired level of oxidation has been achieved. If more is required repeat steps 16-18

Mounting of Slides

1. The sieved fractions are pipetted off and mixed in one drop of polyvinyl alcohol with a glass-stirring rod.
2. When the polyvinyl alcohol/residue has dried, one drop of clear casting resin added and the cover slip is turned and sealed. Permanent curing occurs in approximately one hour.

APPENDIX B
PALYNOMORPH RAW DATA SHEET

Table 1. The spreadsheet of palynomorphs from Courtland Clay Pit.

<i>Fraxinoipollenites</i>																
<i>constrictus</i>								20	P							
<i>Liliacidites giganteus</i>								P								
<i>Liliacidites</i> cf.																
<i>reticulatus</i>								P								
<i>Nyssapollenites</i> sp.								P	P	3						
<i>Phimopollenites striolata</i>									P							
<i>Retimonocolpites</i>																
<i>dividuus</i>								P								
<i>Rousea</i> cf. <i>delicipollis</i>								P	26	P						
<i>Satishia</i> sp.								P								
? <i>Spinizonocolpites</i> sp.								P								
<i>Stellatopollis largissimus</i>								P								
<i>Stellatopollis</i> sp.									P							
<i>Striatopollis paraneus</i>									6							
<i>Tricolpites</i> cf. <i>vulgaris</i>								44	P	P	P	P	52	P	49	P
<i>Tricolpites labeonis</i>								27	P	P		P	15	P	6	P
<i>Tricolpites nemejci</i>								1				P	P			
Tricolpate sp.4								13	P		P	P		P		
Tricolpate sp.7								P		P						
Tricolpate sp.11													P			
Total angiosperm pollen								122				115		133		
Gymnosperm pollen																
<i>Alisporites rotundus</i>								3	P			P	1		1	
<i>Araucariacites australis</i>								1	P				P			
<i>Bacumonoporites</i>																
<i>baculatus</i>											P		P		P	
<i>Cedripites cretaceus</i>												P		P		
<i>C.</i> sp.								2	P		P	P	4		3	
<i>Classopollis torosus</i>								3		P		P	1			
<i>Cycadopites</i> sp.								1				P	2	P		
<i>Equisetosporites</i> sp.1								P								

Table 1--continued.

Taxa	036690	036694	036702	036704	036707	036708	036709	036710	18297
Gymnosperm pollen									
<i>Alisporites rotundus</i>	3	P			P	1		1	
<i>Araucariacites australis</i>	1	P				P			
<i>Bacumonoporites baculatus</i>				P			P	P	
<i>Cedripites cretaceus</i>					P		P		
<i>C. sp.</i>	2	P		P	P	4		3	
<i>Classopollis torosus</i>	3		P		P	1			
<i>Cycadopites sp.</i>	1				P	2	P		
<i>Equisetosporites sp.1</i>	P								
<i>E. sp.2</i>						P		5	
<i>E. sp.3</i>						6			
<i>Eucommiidites sp. 1</i>							P		
<i>Exesipollenites sp.</i>						P			
<i>Inaperturopollenites sp.</i>	80	P	P	P	P	34	P	49	
<i>Monosulcites sp.1</i>	1					P			
<i>M. sp.2</i>		P						1	
<i>M. sp.3</i>									
<i>M. sp.4</i>		P							
<i>Pityosporites constrictus</i>	3	P		P	P	6	P	P	
<i>Pristinupollenites sulcatus</i>	2	P		P	P	P	P	4	
<i>P. inchoatus</i>	1					P	P		
<i>P. microsaccus</i>	P					2		3	
<i>P. pannosus</i>	1	P			P	P		9	
<i>P. crassus</i>						P			
<i>P. sp.</i>			P						
<i>P. sp.2</i>								1	
<i>Punctabivesiculites parvus</i>	1						P		
cf. <i>Punctamultivesiculites inchoatus</i>	1								
<i>Rugubivesiculites rugosus</i>	2				P	1	P	5	
<i>R. cf. multiplex</i>				P	P	2	P		
<i>R. cf. reductus</i>	1					1		1	
<i>R. convolutus</i>		P	P	P			P		
? <i>Rugubivesiculites sp.</i>						P			
<i>Sabalpollenites scabrurus</i>	3			P		8	P	25	
<i>Taxodiaceapollenites hiatus</i>	38	P	P	P	P	23	P	18	
Total gymnosperm pollen	144					91		125	

Table 1--continued

Taxa	036690	036694	036702	036704	036707	036708	036709	036710	18297
<i>Lycopodiacidites</i> sp.1						P			
<i>Lycopodiacidites</i> sp.2	1						P		
<i>Lycopodiumsporites</i> sp.								P	
<i>Microfoveolatosporis pseudoreticulatus</i>								P	
<i>Neoraistrickia</i> sp.								P	
<i>Plicatella fucosa</i>	P					P		2	
<i>P. witzkei</i>	P					P		P	
<i>P.</i> sp.1						P			
<i>P.</i> sp.2	1								
<i>Retitriletes</i> sp.1						P			
<i>R.</i> sp.2						P			
<i>Stereisporites</i> sp.1	P					1			
<i>Sestrosporites</i> sp.1								P	
<i>Taurocusporites segmentatus</i>	P					1			
<i>Trilobosporites purvernulentus</i>	P							P	
<i>Triporoletes reticulatus</i>	P					P		P	
<i>Triporoletes involucratus</i>	P								
<i>Verrucosisporites</i> sp. spore type 1			P					P	
Total spore	23					25		39	
Total terrestrial palynomorphs	289					231		297	
Algal and fungal spores									
Fungal spore sp.1	6	P	P	P	P	5	P		
Fungal spore sp.4		P							
Fungal spore sp.7						4			
Fungal fruiting body (Microthyriaceae)	P								
<i>Laevigatasporites</i> sp.	P	P				4			
<i>Oedogonium cretaceum</i>		P							
<i>Palambages</i> sp.	P					P			
<i>Pediastrum</i> sp.	P					P			
<i>Ovoidites</i> sp.	1					P		3	
<i>Schizosporis reticulatus</i>								P	
<i>Tetraporina</i> sp.	P								
Total algal and fungal spores	7					13		3	

Table 1--continued

Taxa	036690	036694	036702	036704	036707	036708	036709	036710	18297
Dinoflagellate cysts and acritach									
? <i>Canningia</i> sp.	P								
Dino A	4			P	P	32	P	P	
Dino B	1					P			
Dino C					P	4	P		
Dino D	P					2			
Dino F						P			
Dino H	P								
cf. <i>Geiselodinium</i> sp.						P			
<i>Nyktericysta</i> cf. <i>pentagona</i>	P					1			
cf. <i>Odontochitina</i> sp.						P			
cf. <i>Pterodinium cingulatum</i> subsp. <i>cingulatum</i>						P			
Acritach type A	P								
Acritach type B	P								
? Acritach type 1	1								
? Acritach type 2	1								
? Acritach type 3	P					4			
? Acritach type 4	P								
? Acritach type 5	P								
<i>Micrhystridium singulare</i>	P								
<i>Micrhystridium</i> sp.1						23			
<i>M.</i> sp.2						P			
<i>M.</i> sp.3	P				P	7	P	2	
<i>M.</i> sp.4	P		P				P		
<i>M.</i> sp.5				P					
<i>Pterospermella australiensis</i>						P			
<i>Veryhachium</i> cf. <i>reductum</i>	1								
<i>Veryhachium</i> sp.1						1			
<i>Veryhachium</i> sp.2	P								
<i>Veryhachium</i> sp.3	P								
Total dinoflagellate cysts and acritach	8					74		2	
Total palynomorphs	304					318		302	

Table 2. The spreadsheet of palynomorphs from Highway 4 Clay Pit.

Taxa	046517	036716	036717
Angiosperm pollen			
<i>Liliacidites cf. inaequalis</i>	2	P	1
<i>Liliacidites reticulatus</i>	2	P	P
<i>Liliacidites sp.5</i>		P	1
<i>Phimopollenites striolata</i>	188	25	6
<i>Rousea cf. delicipollis</i>	P		
<i>Tricolpites cf. vulgaris</i>	45	6	12
<i>Fraxinopollenites constrictus</i>	14		
Total angiosperm pollen	251	31	20
Gymnosperm pollen			
<i>Araucariacites australis</i>	1	5	7
<i>Bacumonoporites baculatus</i>	1	8	16
<i>Cedripites cretaceus</i>		5	4
<i>C. sp.</i>	2	17	17
<i>Classopollis torosus</i>	1		
<i>Entylissa sp.</i>		6	P
<i>Inaperturopollenites sp.</i>	11	16	6
<i>M. sp.2</i>	2	6	10
<i>Parvisacites radiatus</i>		31	31
? <i>Pityosporites constrictus</i>	P	12	2
<i>Podocarpidites minisculus</i>	P	1	1
<i>P. sp.</i>		8	9
<i>Pristinupollenites sulcatus</i>	5	5	2
<i>P. inchoatus</i>		8	4
<i>P. microsaccus</i>		3	3
<i>P. pannosus</i>	3	8	9
<i>P. crassus</i>			3
<i>Punctabivesiculites parvus</i>	P	12	12
<i>Rugubivesiculites multisaccus</i>		9	2
<i>Rugubivesiculites rugosus</i>	11	26	20
<i>R. convolutus</i>	1	15	19
<i>Sabalpollenites scabrus</i>	2	20	29
<i>Taxodiaceapollenites hiatus</i>	3	1	2
Total gymnosperm pollen	43	222	208

Table 2—continued.

Taxa	046517	036716	036717
Spore			
? <i>Auritulasporites</i> sp.	1	13	12
<i>Camarozonosporites</i> sp.1			1
? <i>Cerotosporites</i> sp.		P	P
<i>Cicatricosisporites coconinoensis</i>		P	P
<i>C.</i> sp.2		P	
<i>C.</i> sp.3			P
<i>Deltoidospora hallii</i>		7	12
<i>Deltoidospora</i> sp.		2	
? <i>Dictyophyllidites impensus</i>	P	P	P
<i>Gleichiidites senonicus</i>		5	38
? <i>Gleichiidites</i> sp.	6	4	
? <i>Laevigatosporites irroratus</i>			1
<i>Laevigatosporites ovatus</i>	P	3	
<i>P. witzkei</i>		1	P
<i>P. fucosa</i>			P
<i>Punctatriletes punctus</i>		3	9
? <i>Retitriletes</i> sp.		P	
? <i>Stoverisporites</i> sp.		P	P
<i>Triporoletes reticulatus</i>	P		P
Total spore	7	38	73
Total terrestrial palynomorphs	301	291	301
Megaspore			
Megaspore type 1			P
Algal and fungal spores			
Fungal spore sp.1		2	1
Fungal spore sp.2			P
Fungal spore sp.3		1	
Fungal spore sp.4		7	
Fungal spore sp.5	2	1	
Fungal spore sp.6		1	
<i>Laevigatasporites</i> sp.		1	P
<i>Oedogonium cretaceum</i>			2
<i>Palambages</i> sp.		3	
? <i>Ovoidites</i> sp.1			2
Total algal and fungal spores	2	16	5
Total palynomorphs	303	307	306

Table 3. The spreadsheet of palynomorphs from Ochs Clay Pit.

Taxa	046522	046526	046533	046535	046536	046540	046545
Angiosperm pollen							
<i>Artiopollis indivisus</i>	6	9	8	40	50	32	113
<i>Clavatipollenites tenellis</i>		1					
<i>Clavatipollenites</i> sp.2				1			1
? <i>Clavatipollenites</i> sp.3					6	1	1
<i>Cupuliferoideaepollenites</i> sp.	31	11	P	4	5	17	7
<i>Doyleipollenites robbinsiae</i>			P		2	P	2
<i>Foveotricolpites</i> sp.	3						
<i>Foveotricolporites rhombohedralis</i>	P	4	P				
<i>Fraxinoipollenites constrictus</i>	7						
<i>Liliacidites</i> sp.2			P				
<i>Liliacidites</i> sp.3			P	10	10	2	5
<i>Liliacidites</i> sp.4				4	P		2
<i>Liliacidites sinuatus</i>				8	P		
<i>Liliacidites</i> cf. <i>reticulatus</i>	P						
<i>Nyssapollenites</i> sp.			12	2		6	
<i>Phimopollenites striolata</i>	11	6					
<i>Psilatricolporites subtilis</i>	2						
<i>Retimonocolpites dividuus</i>	6						
<i>Tricolporate</i> sp.2		P		P	P		
<i>Tricolpites labeonis</i>		7	164	5	6	6	16
<i>Tricolpites nemejci</i>	6	2		2	3	10	1
<i>Tricolpites</i> cf. <i>vulgaris</i>	59	29	11				1
<i>Tricolpate</i> sp.4	20	10	1	1			
<i>Tricolpate</i> sp.7		4					
<i>Tricolpate</i> sp.8		2				P	
<i>Tricolpate</i> sp.10				2	2	P	6
<i>Tricolpate</i> sp.11				2		2	
<i>Tricolpate</i> sp.12						9	12
<i>Tricolpate</i> sp.14						6	2
Total angiosperm pollen	151	85	196	81	84	91	169

Table 3—continued.

Taxa	046522	046526	046533	046535	046536	046540	046545
Gymnosperm pollen							
<i>Alisporites rotundus</i>		1	P	5	1	P	P
<i>Araucariacites australis</i>	1	3	1	2	3	1	
<i>Bacumonoporites baculatus</i>	2	P	P	P	1		1
<i>Cedripites cretaceus</i>	3	1	P	2	1	1	1
<i>C. sp.</i>	7	5	P	6	2	P	P
<i>Cycadopites sp.</i>	10	10	10				
<i>Equisetosporites sp.1</i>		3	1				
<i>Eucommiidites sp. 1</i>	2						
? <i>Eucommiidites sp.</i>					1		
<i>Inaperturopollenites sp.</i>	24	80	60	25	42	64	33
<i>Monosulcites sp.1</i>		3					
<i>M. sp.2</i>		5	P	2	1		3
<i>M. sp.3</i>		P					
<i>M. sp.4</i>						4	1
<i>Pityosporites constrictus</i>		2	1	3	2	1	
? <i>Pityosporites constrictus</i>	3	P		3	1		
<i>Pristinupollenites sulcatus</i>	1	1	P	3	1		
<i>P. inchoatus</i>		1				P	
<i>P. microsaccus</i>		3					
<i>P. pannosus</i>	4	1	P	4	P		P
<i>Parvisacites radiatus</i>	1	P	1	P	4	1	P
<i>Podocarpidites minisculus</i>		2		2			
<i>P. canadensis</i>		P					
<i>P. sp.</i>	2						
<i>Punctabivesiculites parvus</i>		1	1	4	P		
<i>Punctamultivesiculites cf. inchoatus</i>		1	P				
<i>Rugubivesiculites rugosus</i>	6	3	P	3		P	1
<i>R. cf. multiplex</i>				3	1		P
<i>R. cf. reductus</i>					4	3	1
<i>R. convolutus</i>	4	7	1	6	1		P
<i>Sabalpollenites scabrus</i>	11	6	2	15	9	1	1
<i>Taxodiaceapollenites hiatus</i>	7	16	14	3	1	25	4
Total gymnosperm pollen	88	155	92	91	76	101	46

Table 3—continued.

Taxa	046522	046526	046533	046535	046536	046540	046545
Spore							
<i>Appendicisporites auritus</i>		P					
<i>A. cf. matesovae</i>		P					
<i>A. problematicus</i>			P	P		P	
? <i>Auritulasporites</i> sp.	6	3	2	9	2	2	3
<i>Camarozonosporites</i> sp.1		5	P	2		5	
<i>C. sp.3</i>		P		P		1	
<i>Cicatricosisporites</i> cf. <i>crassiterminatus</i>		P					
<i>Cicatricosisporites hughesi</i>		2					
<i>C. crassiterminatus</i>			P				
<i>C. sp.4</i>		P				P	
<i>Concavissimisporites</i> sp.		P					
? <i>Concavissimisporites</i> sp.			P				
<i>Converrucosisporites</i> sp.			P	1			
<i>Costatoperforosporites</i> sp.	1	P					
<i>Crybelosporites</i> sp.			P				
<i>Cyathidites australis</i>		P	1			P	2
<i>Deltoidospora halii</i>	13	13	10	28	14	20	14
<i>Deltoidospora</i> sp.	1						
<i>Dictyophyllidites impensus</i>	1	1		P		P	
<i>Gleichiidites senonicus</i>	14	12	6	30	31	12	10
? <i>Gleichiidites</i> sp.	6	4		53	34	3	8
<i>Ischyosporites</i> sp.		1	P	1	P		
? <i>Januasporites</i> sp.		P					
? <i>Klukisporites</i> sp.		P					
<i>Laevigatosporites ovatus</i>	15	6	1	1	6	1	
<i>Lycopodiacidites</i> sp.2						1	
<i>Lycopodiumsporites marginatus</i>		P		P			
<i>Microfoveolatosporis pseudoreticulatus</i>					P	P	
cf. <i>Phaeoceros</i> form A	P						
<i>Plicatella fucosa</i>			P				
<i>Punctatriletes punctus</i>		1		P			
<i>Stereisporites</i> sp.1		1				23	
<i>Sestrosporites</i> sp.2				P	2	1	
<i>Trilobosporites purvernulentus</i>				1	1		
<i>Triporoletes reticulatus</i>		1					
<i>Undulatisporites</i> sp.		P					
<i>Verrucosisporites</i> sp.							P
Total spore	51	47	18	117	88	67	34
Total terrestrial palynomorphs	290	287	306	289	248	259	249

Table 3—continued.

Taxa	046522	046526	046533	046535	046536	046540	046545
Algal and fungal spores							
Fungal spore sp.1		2	1			P	
Fungal spore sp.5	1						
<i>Oedogonium cretaceum</i>	4	1		8	26	6	4
<i>Ovoidites grandis</i>		P	P				
<i>Ovoidites</i> sp.		2	3		26	13	6
? <i>Ovoidites</i> sp.2		P		1			
<i>Palambages</i> sp.		4				P	
<i>Schizosporis reticulatus</i>			P				P
<i>Tetraporina</i> sp.							1
Total algal and fungal spores	5	9	4	9	52	19	11
Megaspore							
<i>Balmeisporites glenelgensis</i>					1		
Total megaspore	0	0	0	0	1	0	0
Dinoflagellate cysts and acritach							
<i>Coronifera</i> cf. <i>oceanica</i>						P	
<i>Cyclonephelium</i> cf. <i>vannophorm</i>						1	P
? <i>Cyclonephelium</i> sp.						2	2
Dino A		3	P			4	
Dino B							3
Dino C		P				10	31
Dino D						1	1
Dino H		2				P	
Dino I							P
cf. <i>Geiselodinium</i> sp.							6
<i>Nykericysta</i> cf. <i>pentagona</i>						P	2
<i>Oligosphaeridium reniforme</i>						2	
<i>Oligosphaeridium</i> sp.						2	1
<i>Subtilisphaera deformans</i>							1
? <i>Trithyrodinium</i> sp.		P	P			P	
Acritach type C						P	P
<i>Micrhystridium</i> sp.3						1	1
<i>M.</i> sp 5						3	
<i>Veryhachium reductum</i>		1					P
Total dinoflagellate cysts and acritach		6				26	46
Total palynomorphs	295	302	310	298	301	304	306

APPENDIX C
PLATE EXPLANATION

Plate 1

1. Courtland Clay Pit. Showing collection site.
2. Lower section at Courtland Clay Pit.

Plate 2

1. Upper section at Courtland Clay Pit.
2. Close up of upper section at Courtland Clay Pit.

Plate 3

1. Overall view of the Ochs Clay Pit.
2. Close up of the section at Ochs Clay Pit.

Plate 4

1. Lignite layer evident at Ochs Clay Pit.
2. Close up of Ochs Clay Pit upper sediments representing transitional environments.

Plate 5

1. Overall view of the Highway 4 Clay Pit.
2. Close up of southwest (SW) section of Highway 4 Clay Pit.

Plate 6 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Clavatipollenites tenellis* Phillips & Felix 1972, 046526-PY03A, N40, high focus.
2. Same as 1, mid-focus.
3. Same as 1, low focus.
4. *Clavatipollenites* sp.2, 046535-PY02A, U40/4, high focus.
5. Same as 4, mid-focus.
6. Same as 4, low focus.
7. ? *Clavatipollenites* sp.3, 046536-PY05B, L23/1, high focus.
8. Same as 7, mid-focus.
9. Same as 7, low focus.
10. *Liliacidites sinuatus* Hu, sp. nov., 046535-PY02A, S33/3, mid-focus.
11. *Liliacidites sinuatus* Hu, sp. nov., 046535-PY02A, Y39/1, high focus, holotype.
12. Same as 11, mid-focus.
13. Same as 11, low focus.
14. *Liliacidites giganteus* Singh 1983, 036708 + 10 μ , O41/4, mid-focus.
15. *Liliacidites* cf. *reticulatus* (Brenner) Singh 1971, 036716-A5 + 10 μ , M16, mid-focus, showing entire pollen clumps.
16. *Liliacidites* cf. *reticulatus* (Brenner) Singh 1971, 046522-PY01A, O33/4, high focus.

17. Same as 16, mid-focus.
18. Same as 16, low focus.
19. Same as 15, high focus, showing part of pollen clumps closely.

Plate 7 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. Same as 19 in plate 6, mid-focus.
2. Same as 19 in plate 6, low-focus.
3. *Liliacidites* cf. *inaequalis* Singh 1971, 046517-A1 +10 μ , S26, high focus.
4. Same as 3, mid-focus.
5. *Liliacidites* sp.2, 046533-PY03A, Q22/1, high focus.
6. Same as 5, mid-focus.
7. Same as 5, low focus.
8. *Liliacidites* sp.3, 046535-PY02A, Y30/2, high focus.
9. Same as 8, mid-focus.
10. Same as 8, low focus.
11. *Liliacidites* sp.4, 046535-PY02A, G34, high focus.
12. Same as 11, mid-focus.
13. Same as 11, low focus.

Plate 8 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Liliacidites* sp.5, 036716-PY01A, U35/3, high focus.
2. Same as 1, mid-focus.
3. Same as 1, low focus.
4. *Retimonocolpites dividuus* Pierce 1961, 046522-PY01A, H42/1, mid-focus.
5. ? *Spinizonocolpites* sp., 036690 + 10 μ , P41/4, high focus.
6. Same as 5, mid-focus.
7. *Stellatopollis largissimus* Singh 1983, 036690 + 10 μ , R43/3, mid-focus.
8. *Stellatopollis* sp., 036710 + 10 μ , K34/1, mid-focus.
9. *Doyleipollenites robbinsiae* Ravn & Witzke, 1995, 046533-PY03A, M38/3, high focus.
10. Same as 9, mid-focus.
11. Same as 9, low focus.
12. *Artiopollis indivisus* Agasie, 1969, 046522-PY01A, Q28, high focus.

Plate 9 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. Same as 12 in plate 8, mid-focus.
2. Same as 12 in plate 8, low focus.
3. *Artiopollis indivisus* Agasie, 1969, SEM, 046533 stub3, scale bar = 5 μ m.
4. Same as 3, scale bar = 2 μ m.
5. *Artiopollis indivisus* Agasie, 1969, 046535-PY02A, S32, mid-focus. Showing pollen clumps.
6. Same as 5, high focus, showing part of pollen clumps closely.
7. Same as 6, mid-focus.

Plate 10 (All scale bar is equal to 10µm unless otherwise indicated)

1. *Artiopollis indivisus* Agasie, 1969, 046535-PY03A, L23/2, high focus. Showing pollen clumps.
2. Same as 1, mid-focus.
3. Same as 1, low focus.
4. *Cupuliferoideaepollenites* sp., 046522-PY01A, Q18/4, mid-focus. Showing pollen clumps.
5. *Cupuliferoideaepollenites* sp., 046522-PY01A, x45, mid-focus.
6. *Cupuliferoideaepollenites* sp., SEM, 036708 stub12. Showing pollen clumps.
7. Same as 6, close-up of one pollen grain.
8. *Foveotricolpites* sp., 046522-PY01A, S41, high focus.
9. Same as 8, mid-focus.
10. Same as 8, low focus.
11. *Fraxinoipollenites constrictus* (Pierce) Chlonova, 1976, 046517-A1, R24/3, mid-focus.
12. *Fraxinoipollenites constrictus* (Pierce) Chlonova, 1976, 046517-A1, R13/3, high focus.
13. Same as 12, mid-focus.
14. Same as 12, low focus.
15. *Fraxinoipollenites constrictus* (Pierce) Chlonova, 1976, SEM, 046522 stub2.
16. *Rousea* cf. *delicipollis* Srivastava, 1975, 046517-A1, H15/4, high focus.
17. Same as 16, mid-focus.
18. Same as 16, low focus.
19. *Satishia* sp., 036690 +10 µ, N39/1, high focus.
20. Same as 19, mid-focus.

Plate 11 (All scale bar is equal to 10µm unless otherwise indicated)

1. *Striatopollis paraneus* (Norris) Singh, 1971, 036710-PY01B, O33, high focus.
2. Same to 1, mid-focus.
3. Same to 1, low focus.
4. *Striatopollis paraneus* (Norris) Singh, 1971, 036710-PY01B, H32/3, high focus.
5. Same to 4, mid-focus.
6. Same to 4, low focus.
7. *Tricolpites labeonis* Hu, sp. nov., 046526-PY03A, Y37, high focus.
8. Same to 7, mid-focus.
9. Same to 7, low focus.
10. *Tricolpites labeonis* Hu, sp. nov., SEM, 046533 stub3. Scale bar = 2 µm.
11. *Tricolpites labeonis* Hu, sp. nov., SEM, 046533 stub3. Scale bar = 2 µm.
12. *Tricolpites labeonis* Hu, sp. nov., SEM, 046533 stub3. Scale bar = 2 µm.
13. *Tricolpites labeonis* Hu, sp. nov., 046533-PY03A, R35/1, high focus. Showing pollen clumps.
14. Same as 13, mid-focus.
15. Same as 13, low focus.

Plate 12 (All scale bar is equal to 10µm unless otherwise indicated)

1. *Tricolpites nemejci* Pacltova 1971, 046535-PY02A, B41/4, high focus.

2. Same as 1, mid-focus.
3. Same as 1, low focus.
4. *Tricolpites* cf. *vulgaris* (Pierce) Srivastava, 1969, 046522-PY01A, C37/3, high focus.
5. Same as 4, mid-focus.
6. Same as 4, low focus.
7. *Tricolpites* cf. *vulgaris* (Pierce) Srivastava, 1969, 036717-PY01A, S21, mid-focus. Showing pollen clumps.
8. *Tricolpate* sp.4, 046522-PY01A, M45/1, high focus.
9. Same as 8, mid-focus.
10. Same as 8, low focus.
11. *Tricolpate* sp.7, 046526-PY03A, Y42/1, high focus.
12. Same as 11, mid-focus.
13. Same as 11, low focus.
14. *Tricolpate* sp.8, 046526-PY03A, Y23/2, high focus.
15. Same as 14, mid-focus.
16. Same as 14, low focus.
17. *Tricolpate* sp.10, 046535-PY02A, R32/4, high focus.
18. Same as 17, mid-focus.
19. Same as 17, low focus.
20. *Tricolpate* sp.11, 046535-PY02A, x48, high focus.
21. Same as 20, mid-focus.
22. Same as 20, low focus.

Plate 13 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Tricolpate* sp.12, 046540-PY03A, J19, high focus.
2. Same as 1, mid-focus.
3. Same as 1, low focus.
4. *Tricolpate* sp.14, 046540-Py03A, S29, high focus.
5. Same as 4, mid-focus.
6. Same as 4, low focus.
7. *Dryadopollis minnesotensis* Hu, sp. nov., 036694-PY01A, S31/1, high focus.
8. Same as 7, mid-focus.
9. Same as 7, low focus.
10. *Dryadopollis minnesotensis* Hu, sp. nov., 036708 + 10 μ , N36, mid-focus. Showing pollen clumps.
11. *Dryadopollis minnesotensis* Hu, sp. nov., 036708 + 10 μ , M35/1, mid-focus. Showing pollen clumps.
12. *Dryadopollis minnesotensis* Hu, sp. nov., 036708 + 10 μ , N34/3, mid-focus. Showing pollen clumps.
13. *Dryadopollis minnesotensis* Hu, sp. nov., SEM, 036708, Stub 12. Showing pollen clumps. Scale bar = 6 μ m.
14. Same as 13, close-up of the pore. Scale bar = 1 μ m.

Plate 14 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Dryadopollis minnesotensis* Hu, sp. nov., SEM, 036708, Stub 11. Showing pollen clumps.

2. *Dryadopollis minutus* Hu, sp. nov., 036704-PY01A, L41, holotype, high focus.
3. Same as 2, mid-focus.
4. Same as 2, low focus.
5. *Foveotricolporites rhombohedralis* Pierce, 1961, 046526-PY03A, P44/4, high focus.
6. Same as 5, mid-focus.
7. Same as 5, low focus.
8. *Foveotricolporites rhombohedralis* Pierce, 1961, 046526-PY03A, U26/3, high focus.
9. Same as 8, mid-focus.
10. Same as 8, low focus.
11. cf. *Foveotricolporites* sp., 036708 +10 μ , R35/1, high focus.
12. Same as 11, mid-focus.
13. cf. *Foveotricolporites* sp., 036708 +10 μ , E42, mid-focus.
14. *Phimopollenites striolata* Hu, sp. nov., 046517-A1, + 10 μ , N29/3, high focus.
15. Same as 14, mid-focus.
16. Same as 14, low focus.
17. *Phimopollenites striolata* Hu, sp. nov., 046517-A1, + 10 μ , R22/1, high focus.
18. Same as 17, mid-focus.
19. *Phimopollenites striolata* Hu, sp. nov., 046517-A1, + 10 μ , F14, high focus.
Showing pollen clumps.
20. Same as 19, mid-focus.
21. Same as 19, low focus.

Plate 15 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Phimopollenites striolata* Hu, sp. nov., SEM, 046517 stub 1, polar view. Scale bar = 2 μ m.
2. Same as 1, close-up of pollen surface. Scale bar = 1 μ .
3. *Phimopollenites striolata* Hu, sp. nov., SEM, 046517 stub 1, equatorial view. Scale bar = 2 μ m.
4. *Nyssapollenites* sp., 046533-PY03A, W30/3, high focus.
5. Same as 4, mid-focus.
6. Same as 4, low focus.
7. *Nyssapollenites* sp., 046533-PY03A, x42, high focus.
8. Same as 7, mid-focus,
9. Same as 7, low focus.
10. *Nyssapollenites* sp., SEM, 046533 stub3. Scale bar = 2 μ m.
11. Same as 10, close-up of pollen surface. Scale bar = 1 μ m.
12. Same as 10, close-up of pore. Scale bar = 1 μ m.

Plate 16 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. Tricolporate sp.2, 046526-PY03A, x43/3, high focus.
2. Same as 1, mid-focus.
3. Same as 1, low focus.
4. *Psilatricolporites subtilis* (Groot, Penny and Groot) Singh 1983, 046522-PY01A, N29/3, mid-focus. Showing pollen clumps.
5. *Alisporites rotundus* Rouse, 1959, 046526-PY03A, U28/4, mid-focus.
6. *Cedripites cretaceous* Pocock 1962, 036716-A5, + 10 μ , H32, mid-focus.

7. *Cedripites* sp., 036716-A5, + 10 μ , P25, mid-focus.
8. *Parvisaccites radiatus* Couper 1958, 036716-A5, + 10 μ , P15/1, mid-focus.
9. *Pityosporites constrictus* Singh 1964, 036708 + 10 μ , G41/3, mid-focus.
10. ? *Pityosporites constrictus*, 036716-A5, + 10 μ , V12/4, mid-focus.
11. *Podocarpidites canadensis* Pocock, 1962, 046526-PY03A, U28/4, mid-focus.
12. *Podocarpidites minisculus* Singh 1964, 036717-PY02A, T41, mid-focus.
13. *Podocarpidites* sp., 036716-A5, + 10 μ , L12/2, mid-focus.

Plate 17 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Pristinuspollenites crassus* (Pierce) Tschudy, 1973, 036717-PY01A, Q20/2, mid-focus.
2. *Pristinuspollenites inchoatus* (Pierce) Tschudy 1973, 036717-PY01A, R26/1, mid-focus.
3. *Pristinuspollenites microsaccus* (Couper) Tschudy 1973, 036708 +10 μ , F39/2, mid-focus.
4. *Pristinuspollenites pannosus* (Pierce) Tschudy 1973, 036708 +10 μ , E34, mid-focus.
5. *Pristinuspollenites sulcatus* (Pierce) Tschudy 1973, 036708 +10 μ , x39/1, mid-focus.
6. ? *Pristinuspollenites* sp., 036702-PY01A, L34, mid-focus.
7. *Pristinuspollenites* sp. 2, 036710 +10 μ , W42, mid-focus.
8. *Punctabivesiculites parvus* Pierce, 1961, 036716-A5, +10 μ , V31/4, mid-focus.
9. *Rugubivesiculites convolutus* Pierce 1961, 036717-PY01A, S27/4, mid-focus.
10. *Rugubivesiculites* cf. *multiplax* Pierce 1961, 046535-PY02A, W26/3, mid-focus.
11. *Rugubivesiculites multisaccus* Singh, 1983, 036717-PY01A, Q29/3, mid-focus.
12. *Rugubivesiculites* cf. *reductus* Pierce 1961, 046536-PY05B, S24/4, mid-focus.
13. *Rugubivesiculites rugosus* Pierce 1961, 036708 +10 μ , F29/1, mid-focus.
14. ? *Rugubivesiculites* sp., 036708 +10 μ , E31/2, mid-focus.
15. *Araucariacites australis* Cookson 1947, 036708 +10 μ , F40/3, mid-focus.
16. *Inaperturopollenites* sp., 036690 +10 μ , R40/1, mid-focus.
17. *Taxodiaceapollenites hiatus* (Potonie) Kremp 1949, 036708 +10 μ , G28/2, mid-focus.
18. *Eucommiidites* sp.1, 046522-PY01A, H20/2, mid-focus.
19. *Eucommiidites* sp. 2, 046536-PY05B, O49/1, mid-focus.
20. *Equisetosporites* sp.1, 046526-PY03A, T40/3, mid-focus.

Plate 18 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Equisetosporites* sp.2, 036708 +10 μ , W38/4, mid-focus.
2. *Equisetosporites* sp.3, 036708 +10 μ , O32, mid-focus.
3. *Equisetosporites* sp.3, SEM, 036708 stub 12. Scale bar = 6 μ m.
4. *Cycadopites* sp., 046522-PY01A, R25/1, mid-focus.
5. Same as 4, low focus.
6. *Entylissa* sp., 036717-PY01A, M22, mid-focus.
7. *Monosulcites* sp. 1, 036708 +10 μ , M31, mid-focus.
8. *Monosulcites* sp. 2, 036717-PY01A, x23, mid-focus.
9. *Monosulcites* sp. 3, 046526-PY03A, Q35/1, mid-focus.
10. *Monosulcites* sp. 4, 046540-PY03A, M40/2, high focus.
11. Same as 10, mid-focus.
12. *Sabalpollenites scabrous* (Brenner) Wingate, 1980, 036708 +10 μ , F27/2, mid-focus.

13. *Bacumonoporites baculatus* Pierce, 1961, 036717-PY01A, S24/3, mid-focus.
14. *Classopollis torosus* (Reissinger) Couper 1958, 036708 +10 μ , M41, mid-focus.
15. *Exesipollenites* sp., 036708 +10 μ , x38/2, mid-focus.
16. *Punctamultivesiculites* cf. *inchoatus* Pierce, 1961, 046526-PY03A, Y37, mid-focus.
17. *Biretisporites* sp.1, 036710 +10 μ , R31/1, mid-focus.
18. *Biretisporites* sp.2, 036690 +10 μ , Y31/2, mid-focus.
19. *Cyathidites australis* Couper 1953, 036708 +10 μ , T30/1, mid-focus.
20. *Cyathidites minor* Couper 1953, 036708 +10 μ , D29, mid-focus.

Plate 19 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Cyathidites punctatus* (Delcourt and Sprumont 1955) Delcourt, Dettmann, and Hughes, 1963, 036710 +10 μ , O39, mid-focus.
2. *Deltoidospora hallii* Miner 1935, 036717-PY01A, R41/3, mid-focus.
3. *Deltoidospora* sp., 036716-A5 +10 μ , U38/1, mid-focus.
4. *Undulatisporites* sp., 046526-PY03A, x48, mid-focus.
5. *Dictyophyllidites impensus* (Hedlund) Singh, 1983, 036717-PY01A, M24, mid-focus.
6. *Dictyophyllidites* sp.1, 036710 +10 μ , T32/1, mid-focus.
7. *Stereisporites* sp., 036708 +10 μ , C40/3, mid-focus.
8. ? *Auritulinasporites* sp., 036717-PY01A, R25/4, mid-focus.
9. *Baculatisporites comaumensis* (Cookson) Potonie 1956, 036690 +10 μ , V35, mid-focus.
10. ? *Concavissimisporites* sp., 036690 +10 μ , V41/4, mid-focus.
11. *Baculatisporites* sp., 036710 +10 μ , V35, mid-focus.
12. *Converrucosisporites* sp., 046533-PY03A, N23, high focus.
13. Same as 12, mid-focus.
14. *Neoraistrickia* sp., 036710 +10 μ , L28/4, mid-focus.
15. ? *Ceratosporites* sp., 036708 +10 μ , H44/2, mid-focus.
16. *Impardecispora* sp.1, 036690 +10 μ , V43/2, mid-focus.
17. *Verrucosisporites* sp., 036710 +10 μ , U37, mid-focus.
18. ? *Granulatisporites* sp., 036708 +10 μ , E39/4, mid-focus.
19. *Punctatriletes punctus* Pierce, 1961, 036717-PY01A, L25/1, mid-focus.
20. cf. *Phaeoceros* form A Jarzen, 1979, 046522-PY01A, H44/1, high focus.
21. Same as 20, mid-focus.
22. *Lycopodiacidites* sp.1, 036708 +10 μ , O36, high focus.
23. Same as 22, mid-focus.
24. *Lycopodiacidites* sp.2, 046540-PY03A, T34/3, high focus.
25. Same as 24, mid-focus.
26. *Foveotriletes* sp., 036710 +10 μ , V29/1, mid-focus.
27. ? *Foveotriletes* sp., 036708 +10 μ , J36, high focus.
28. Same as 27, mid-focus.

Plate 20 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Foveosporites* sp., 036690 +10 μ , T47/4, mid-focus.
2. *Lycopodiumsporites marginatus* Singh, 1964, 046526-PY03A, Q42/1, high focus.
3. Same as 2, mid-focus.
4. *Lycopodiumsporites* sp. 1, 036710 +10 μ , N33/4, mid-focus.

5. *Klukisporites* sp.1, 036690 +10 μ , V33/4, mid-focus.
6. *Klukisporites* sp.2, 036690 +10 μ , P39, mid-focus.
7. ? *Klukisporites* sp., 046526-PY03A, O20/4, high focus.
8. Same as 7, low-focus.
9. *Taurocusporites segmentatus* Stover 1962, 036708 +10 μ , L41/4, mid-focus.
10. ? *Januasporites* sp., 046526-PY03A, M40/4, mid-focus.
11. *Cicatricosisporites coconinoensis* Agasie, 1969, 036717-PY01A, S31/1, mid-focus.
12. *Cicatricosisporites crassiterminatus* Hedlund, 1966, 046533-PY03A, P25/3, high focus.
13. Same as 12, mid-focus.
14. *Cicatricosisporites* cf. *crassiterminatus* Hedlund, 1966, 046526-PY03A, Q27, high focus.
15. Same as 14, low focus.
16. *Cicatricosisporites hallei* Delcourt and Sprumont 1955, 036690 +10 μ , Y42/1, mid-focus.
17. *Cicatricosisporites hughesi* Dettmann 1963, 046526-PY03A, N40/2, high focus.
18. Same as 17, mid-focus.
19. *Cicatricosisporites* sp.1, 036710 +10 μ , W37, mid-focus.
20. *Cicatricosisporites* sp.2, 036716-A5 +10 μ , J25/3, mid-focus.
21. *Cicatricosisporites* sp.4, 046526-PY03A, J24/2, high focus.
22. Same as 21, mid-focus.

Plate 21 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Costatoperforosporites* sp., 046522-PY01A, P29/4, mid-focus.
2. ? *Ischyosporites* sp., 046526-PY03A, E33/4, high focus.
3. Same as 2, low focus.
4. *Retitriletes* sp.1, 036708 +10 μ , R31/1, mid-focus.
5. *Retitriletes* sp.2, 036708 +10 μ , Q28/4, high focus.
6. Same as 5, mid-focus.
7. ? *Retitriletes* sp., 036716-A5 +10 μ , M28, high focus.
8. Same as 7, mid-focus.
9. ? *Stoverisporites* sp., 036717-PY01A, R36/2, mid-focus.
10. *Gleicheiidites senonicus* Ross emend. Skarby 1964, 036710 +10 μ , S36/1, mid-focus.
11. ? *Gleicheiidites* sp., 036716-PY01A, U18/1, mid-focus.
12. *Sestrosporites* sp. 1, 036710 +10 μ , P33, mid-focus.
13. *Sestrosporites* sp. 2, 046535-PY02A, G34, high focus.
14. Same as 13, mid-focus.
15. *Camarozonosporites* sp.1, 036708 +10 μ , H29/4, mid-focus.
16. *Camarozonosporites* sp.3, 046526-PY03A, V45/4, mid-focus.
17. Same as 16, low focus.
18. *Crybelosporites* sp., 046533-PY03A, W32/3, high focus.
19. Same as 18, mid-focus.
20. *Laevigatosporites ovatus* Wilson and Webster 1946, 036710 +10 μ , K44/3, mid-focus.
21. *Laevigatosporites* cf. *irroratus* Hedlund 1966, 036717-PY01A, N22/3, mid-focus.
22. *Laevigatosporites* sp.2, 036690 +10 μ , N38/4, mid-focus.

23. *Microfoveolatosporis pseudoreticulatus* (Hedlund) Singh, 1963, 036710 +10 μ , G35/3, mid-focus.
24. *Aequitriradites spinulosus* (Cookson and Dettmann) Cookson and Dettmann 1961, 036708 +10 μ , H38/4, mid-focus.
25. *Triporoletes involucratus* (Chlonova) Playford, 1971, 036690 +10 μ , D28/4, mid-focus.
26. *Triporoletes reticulatus* (Pocock) Playford 1971, 036710 +10 μ , T46/1, high focus.
27. Same as 26, mid-focus.

Plate 22 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Triporoletes* sp.1, 036708 +10 μ , Q38, mid-focus.
2. *Triporoletes* sp.2, 036708 +10 μ , O35/3, high focus.
3. Same as 2, mid-focus.
4. *Triporoletes* sp.3, 036708 +10 μ , F37/1, mid-focus.
5. *Chomotriletes* sp., 036690 +10 μ , M42/1, mid-focus.
6. Spore type 1, 036710 +10 μ , O35, mid-focus.
7. Same as 6, V32/3, mid-focus.
8. *Appendicisporites auritus* Agasie 1969, 046526-PY03A, R42, mid-focus.
9. *Appendicisporites matesovae* (Bolkhovitina) Norris 1967, 036690 +10 μ , E41, mid-focus.
10. *Appendicisporites* cf. *matesovae* (Bolkhovitina) Norris 1967, 046526-PY03A, C25, mid-focus.
11. *Appendicisporites potomacensis* Brenner 1963, 036708 +10 μ , D30/1, high focus.
12. Same as 11, mid-focus.
13. *Appendicisporites problematicus* (Burger) Singh, 1971, 046535-PY02A, K37, high focus.
14. Same as 13, mid-focus.
15. *Plicatella fucosa* (Vavrdova) Davies 1985, 036708 +10 μ , F41, mid-focus.
16. *Plicatella witzkei* Ravn 1995, 036708 +10 μ , Q29/1, mid-focus.
17. *Plicatella* sp.1, 036708 +10 μ , O35/1, mid-focus.
18. *Plicatella* sp.2, 036690 +10 μ , L39/4, high focus.
19. Same as 18, low focus.
20. *Trilobosporites purverulentus* (Verbitskaya) Dettmann, 1963, 046536-PY05B, K20/2, mid-focus.

Plate 23 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Laevigatasporites* sp., 036708 +10 μ , V35, mid-focus.
2. *Oedogonium cretaceum* Zippi, 1998, 036717-PY01A, P31, mid-focus.
3. *Ovoidites grandis* (Pocock) Zippi, 1998, 046526-PY03A, T49/2, mid-focus.
4. *Ovoidites* sp., 036710 +10 μ , Q36/1, mid-focus.
5. ? *Ovoidites* sp. 1, 036717-PY01A, S24/4, mid-focus.
6. ? *Ovoidites* sp. 2, 046526-PY03A, C21/2, mid-focus.
7. *Palambages* sp., 046526-PY03A, O24, mid-focus.
8. *Pediastrum* sp., 036708 +10 μ , F34, mid-focus.
9. *Schizosporis reticulatus* Cookson and Dettmann, 1959, 036710 +10 μ , U40, mid-focus.
10. Same as 9, low focus.

11. *Tetraporina* sp., 036690 +10 μ , W45, mid-focus.
12. Fungal spore type 1, 036717-PY01A, H29/4, mid-focus.
13. Fungal spore type 2, 036717-PY02A, R32/2, mid-focus.
14. Fungal spore type 3, 036716-PY01A, T30/3, mid-focus.
15. Fungal spore type 4, 036716-PY01A, T31, mid-focus.
16. Fungal spore type 5, 036716-PY01A, R34/4, mid-focus.
17. Fungal spore type 6, 036716-PY01A, R36/1, mid-focus.
18. Fungal fruiting body of the family Microthyriaceae, 036690 +10 μ , K34/3, mid-focus.

Plate 24 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. Megaspore type 1, 036717-PY01A, F28/1, mid-focus.
2. *Balmeisporites glenelgensis* Cookson and Dettmann, 046536-PY05B, S36/2, mid-focus.
3. Same as 2, low focus.

Plate 25 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Oligosphaeridium reniforme* (Tasch) Davey, 1969, 046540-PY03A, x23/2, high focus.
2. Same as 1, mid-focus.
3. ? *Oligosphaeridium* sp., 046540-PY03A, U37, high focus.
4. Same as 3, mid-focus.
5. ? *Oligosphaeridium* sp., 046540-PY02A, P48/2, high focus.
6. Same as 5, mid-focus.
7. *Nyktericysta* cf. *pentagona* (Singh, 1983) Bint, 1986, 036708 +10 μ , L30/2, high focus.
8. Same as 7, mid-focus.

Plate 26 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. *Nyktericysta* cf. *pentagona* (Singh, 1983) Bint, 1986, 036690 +10 μ , P35/4, mid-focus.
2. ? *Canningia* sp., 036690 +10 μ , D43/3, mid-focus.
3. *Coronifera oceanica* Cookson and Eisenack, 1958, 046540-PY03A, O39/2, high focus.
4. Same as 3, mid-focus.
5. Same as 3, low focus.
6. *Cyclonephelium* cf. *vannophorm* Davay, 1969, 046540-PY03A, Q36/4, high focus.
7. Same as 6, mid-focus.
8. ? *Cyclonephelium* sp., 046540-PY03A, T20/1, high focus.
9. Same as 8, mid-focus.
10. cf. *Odontochitina* sp., 036708 +10 μ , B34, mid-focus.
11. cf. *Pterodinium cingulatum* subsp. *cingulatum*, 036708 +10 μ , K39/2, mid-focus.
12. *Subtilisphaera deformans* (Davey and Verdier) Stover and Evitt, 1978, 046545-PY02A, W23, mid-focus.

Plate 27 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. cf. *Geiselodinium* sp., 036708 +10 μ , Q32/2, mid-focus.
2. ? *Trithyrodinium* sp., 046526-PY03A, M20/4, high focus.
3. Same as 2, low focus.
4. Dino cyst type A, 036708 +10 μ , G35/2, mid-focus.
5. Dino cyst type B, 036690 +10 μ , K32/1, mid-focus.

6. Dino cyst type C, 036708 +10 μ , O37/2, mid-focus.
7. Dino cyst type D, 036708 +10 μ , O35, mid-focus.
8. Dino cyst type H, 036690 +10 μ , C28, mid-focus.
9. Dino cyst type I, 046545-PY02A, J22, mid-focus.
10. *Micrhystridium singulare* Firtion, 1952, 036690 +10 μ , T32, mid-focus.
11. *Micrhystridium* sp.1, 036708 +10 μ , N43, mid-focus.
12. *Micrhystridium* sp.2, 036708 +10 μ , O44, mid-focus.
13. *Micrhystridium* sp.3, 036690 +10 μ , U32, mid-focus.
14. *Micrhystridium* sp.4, 036690 +10 μ , R39, mid-focus.
15. *Micrhystridium* sp.5, 046540-PY03A, U28/4, high focus.
16. Same as 15, mid-focus.
17. *Pterospermella australiensis* (Deflandre & Cookson) S.K. Srivastava, 1984, 036708 +10 μ , Q35/4, mid-focus.
18. *Veryhachium* cf. *reductum* Deunff, 036690 +10 μ , R47, mid-focus.
19. *Veryhachium* sp.1, 036708 +10 μ , K41/1, mid-focus.
20. *Veryhachium* sp.2, 036690 +10 μ , P35/2, mid-focus.
21. *Veryhachium* sp.3, 036690 +10 μ , x39/4, mid-focus.
22. Acritarch type A, 036690 +10 μ , F33/2, mid-focus.
23. Acritarch type B, 036690 +10 μ , O42/3, mid-focus.

Plate 28 (All scale bar is equal to 10 μ m unless otherwise indicated)

1. Acritarch type C, 046540-PY03A, H30, high focus.
2. Same as 1, mid-focus.
3. ? Acritarch type 1, 036690 +10 μ , W27, mid-focus.
4. ? Acritarch type 2, 036690 +10 μ , U35, mid-focus.
5. ? Acritarch type 3, 036690 +10 μ , W34/3, mid-focus.
6. ? Acritarch type 4, 036690 +10 μ , W36/3, mid-focus.
7. ? Acritarch type 5, 036708 +10 μ , S44/2, mid-focus.

Plate 29

Dissecting microscope, light microscopy (LM), SEM and TEM images of sporangium and *in situ* spores of *Goolangia minnesotensis* Hu, Dilcher, H. Schneid. et Jarzen (Holotype 19007-036708-M1).

1. Overview of sporangium. Scale bar = 1 mm.
2. Close up of attachment scar (arrows). Scale bar = 1 mm.
3. Close up of thickened edge, showing the orientation of surface cells adjacent to this ridge as perpendicular to the long axis of the structure. Scale bar = 80 μ m.
4. Detail view of a spore, showing spores randomly covered with globules. Scale bar = 10 μ m.
5. Detail view of a spore, showing scabrate ornamentation and bifurcating trilete mark (arrow). Scale bar = 10 μ m.
6. Close up of cross section of sporangium, detailing the upper and lower multicellular layer. Scale bar = 60 μ m.
7. Surface view of sporangium, with superficially continuous spore mass. Scale bar = 100 μ m.

8. Spore TEM section, showing exospore (E) is thicker at the proximal face than in the distal face. Scale bar = 5 μm .
9. Spore TEM section, showing thin perispore (P) and the granules (arrows). Scale bar = 1 μm .
10. Close up of proximal fold, showing middle exospore layer (Em) with cavities (arrow). Scale bar = 0.5 μm .
11. Close up of aperture area, showing inner exospore layer (Ei) (arrow), middle exospore layer (Em) and outer exospore layer (Ee). Scale bar = 2.5 μm .

Plate 30

Suggested reconstruction of *Goolangia minnesotensis* Hu, Dilcher, H. Schneid. et Jarzen.

1. Synangium with seven sporangia. Scale bar = 1 mm.
2. Individual sporangium, splitting open from upper half of left thin edge (te, arrow) for spore release; attachment scar (as, arrow) on lower half of left edge. Scale bar = 1 mm.

Plate 31

Dissecting microscope and SEM images of sporangia/synangia of *Mesozoisynangia trilobus* Hu, Dilcher, H. Schneid. et Jarzen.

1. One side of synangium (Holotype 19007-036708-M2). Scale bar = 1 mm.
2. Obverse side of synangium (Holotype 19007-036708-M2), showing three sporangia (arrows) attached with each other basally. Scale bar = 1 mm.
3. Close up of the central lobe (Holotype 19007-036708-M2), showing cells at the tip of the lobe as elongated and parallel to the lobe surface. Scale bar = 36 μm .
4. Close up of cross section of the central lobe (Holotype 19007-036708-M2), there are no spores in the tip of the lobe (arrow denotes the end of spores). Scale bar = 100 μm .
5. One side of sporangium (Paratype 19007-036708-M3). Note that the three lobes of this isolated sporangium are indicated by arrows. Scale bar = 1 mm.
6. Obverse side of the sporangium (Paratype 19007-036708-M3), arrow denotes attachment scar. Scale bar = 1mm.
7. One side of part of synangium (Paratype 19007-036708-M4). Scale bar = 100 μm .
8. Another side of synangium (Paratype 19007-036708-M4), showing three sporangia (arrows) attached with each other basally. Scale bar = 1 mm.

Plate 32

LM, SEM and TEM images of sporangium and *in situ* spores of *Mesozoisynangia trilobus* Hu, Dilcher, H. Schneid. et Jarzen.

1. Cross section of sporangium (Holotype 19007-036708-M2). Scale bar = 100 μm .
2. Detail view of spore (Holotype 19007-036708-M2). Scale bar = 10 μm .
3. Detail view of spore (Paratype 19007-036708-M3). Scale bar = 10 μm .
4. Close up of spores (Holotype 19007-036708-M2). Scale bar = 20 μm .
5. Close up of spores (Paratype 19007-036708-M3). Scale bar = 20 μm .
6. Spore TEM section (Holotype 19007-036708-M2), showing exospore (E). Scale bar = 2 μm .
7. Apertural area of spore (Holotype 19007-036708-M2), showing inner exospore layer (Ei) and outer exospore layer (Ee). Scale bar = 1 μm .

8. Close up of spore aperture area (Holotype 19007-036708-M2), showing cavities (arrow) in middle exospore layer (Em). Scale bar = 400 nm.
9. Granules between spores (Paratype 19007-036708-M3). Scale bar = 2 μm .

APPENDIX D
PLATES



Plate 1



Plate 2



Plate 3

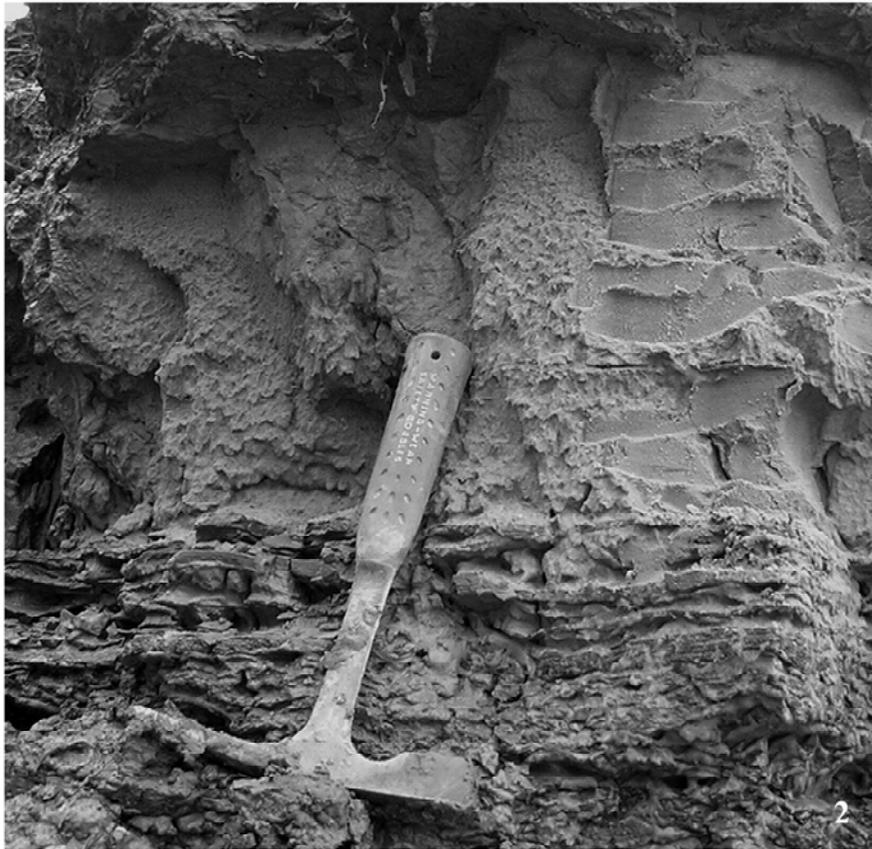


Plate 4



Plate 5

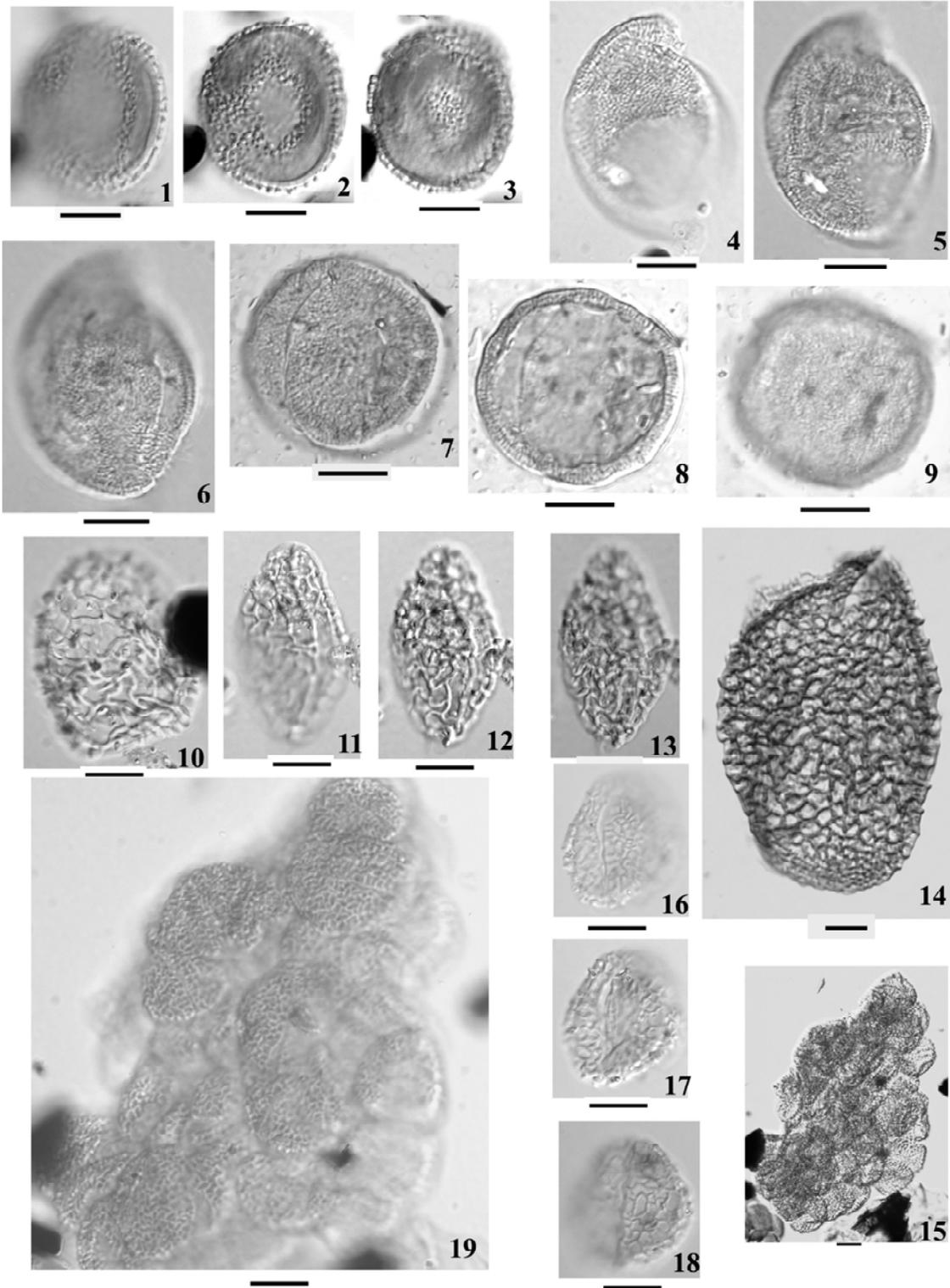


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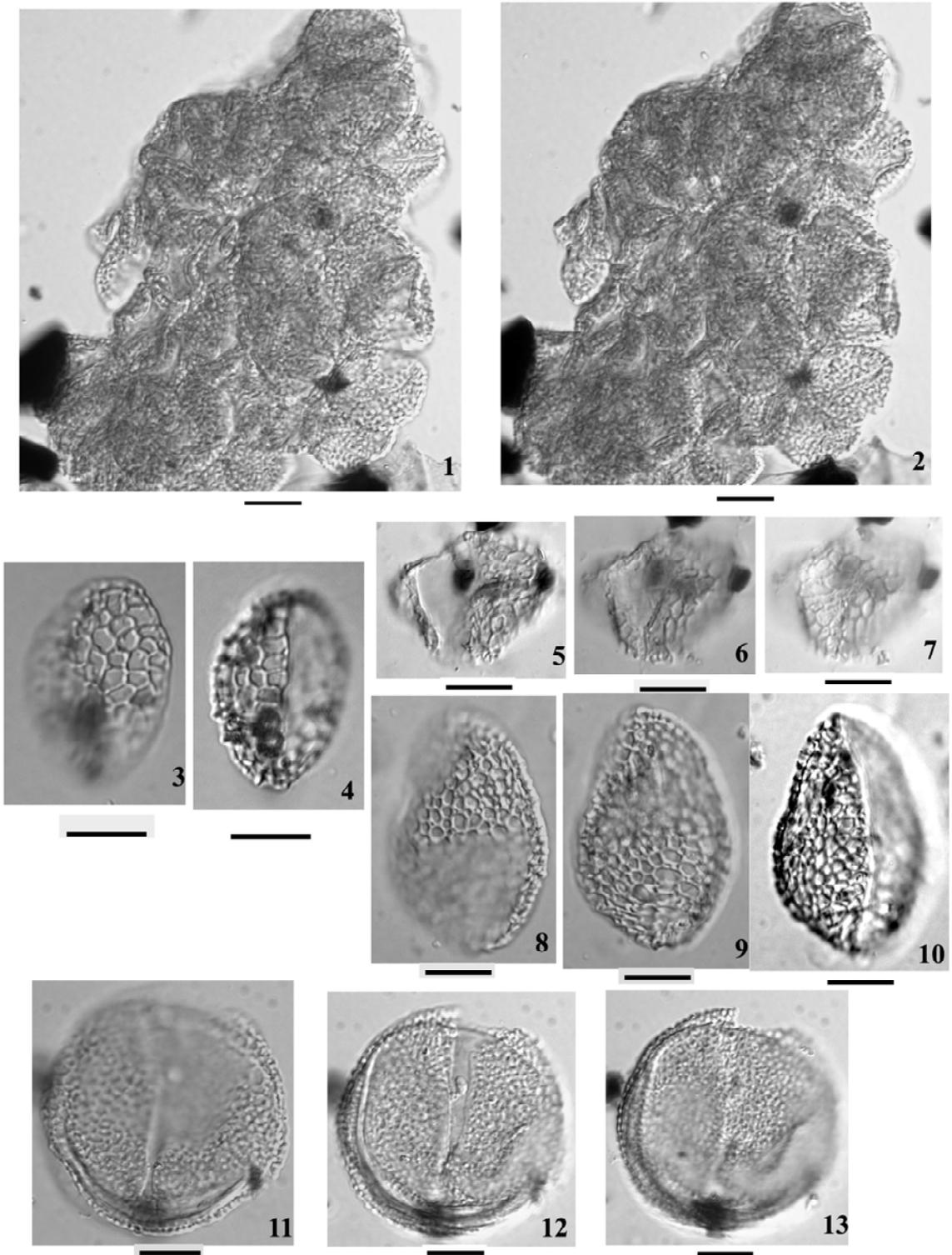


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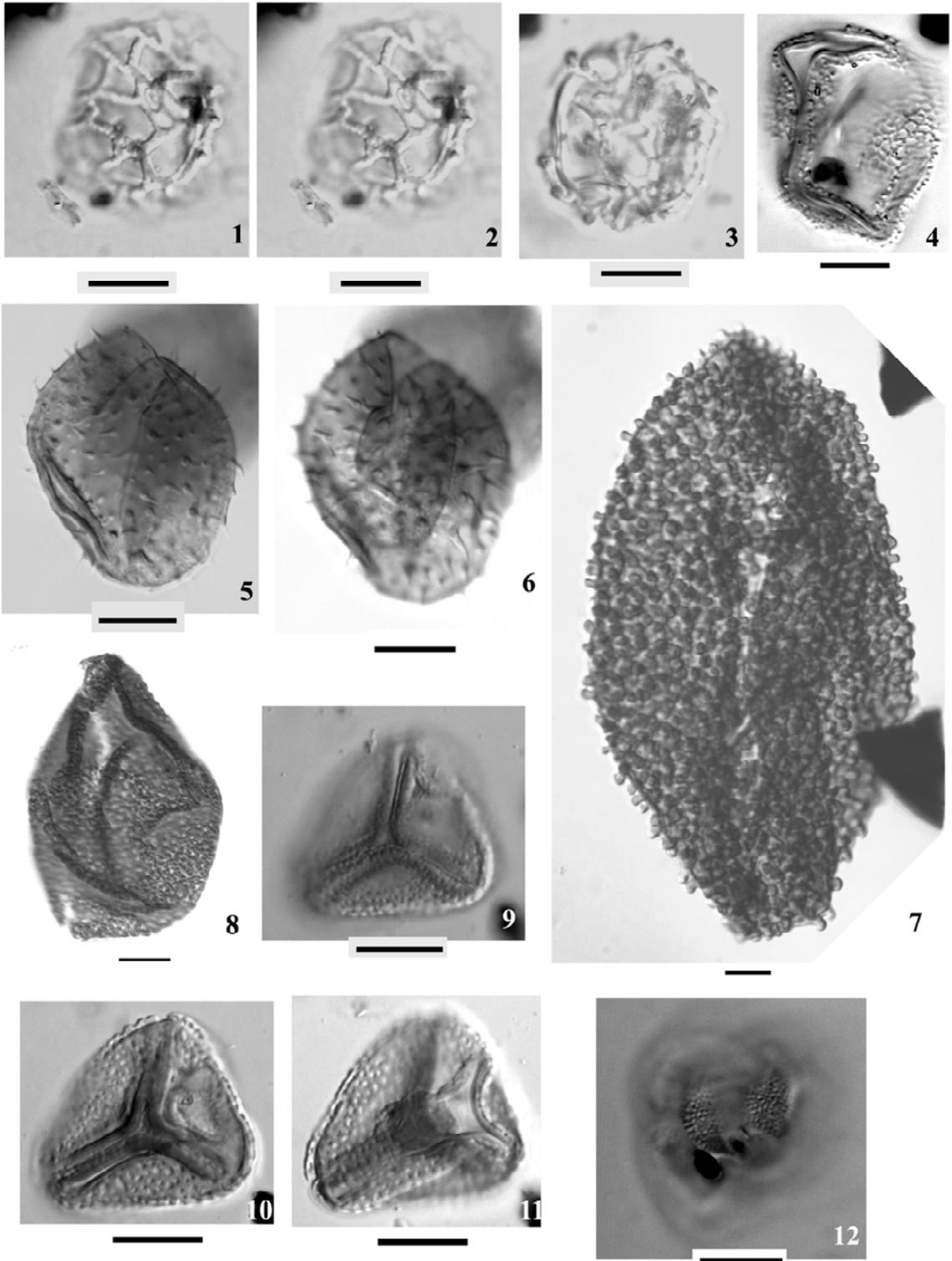


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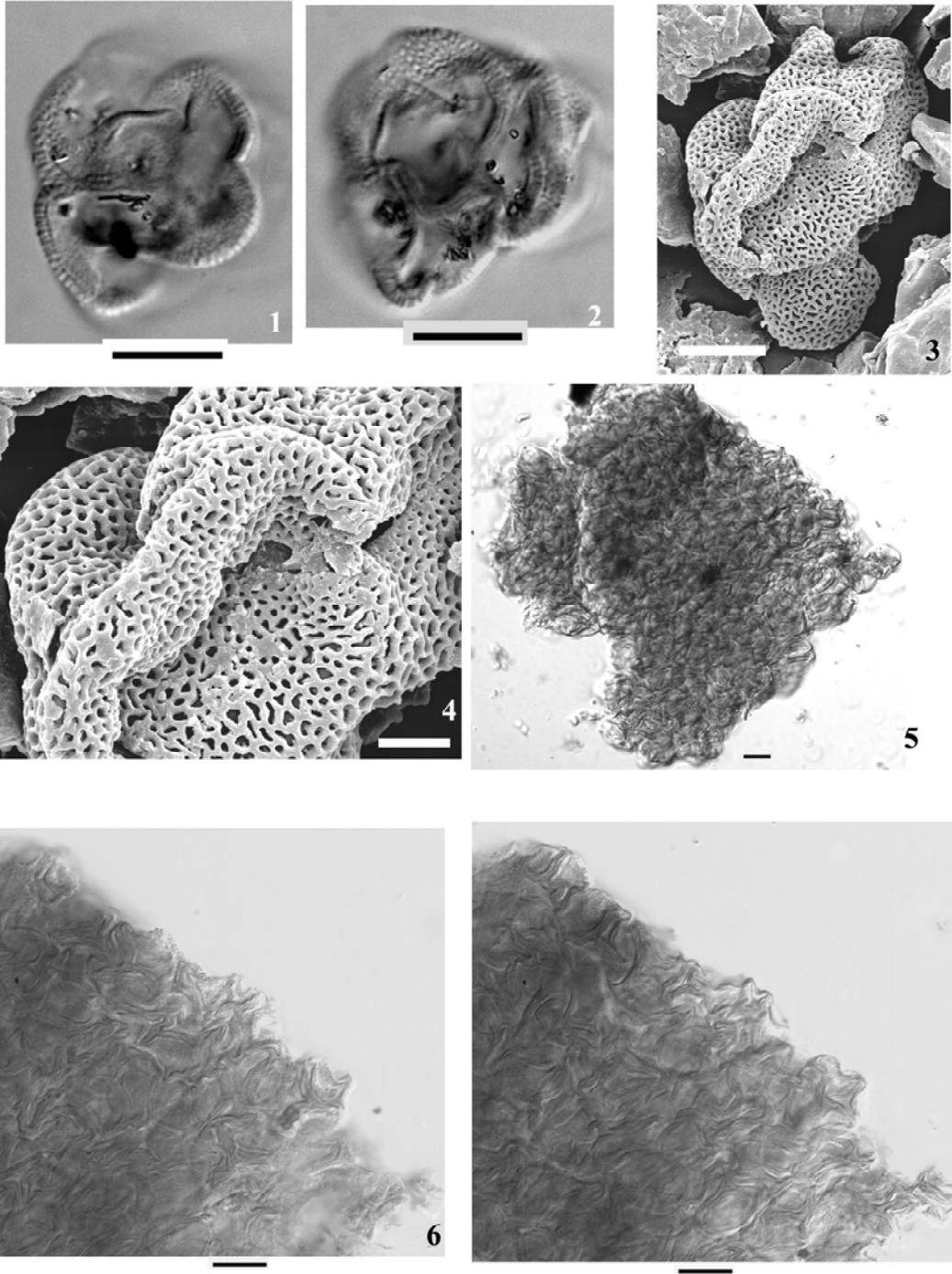


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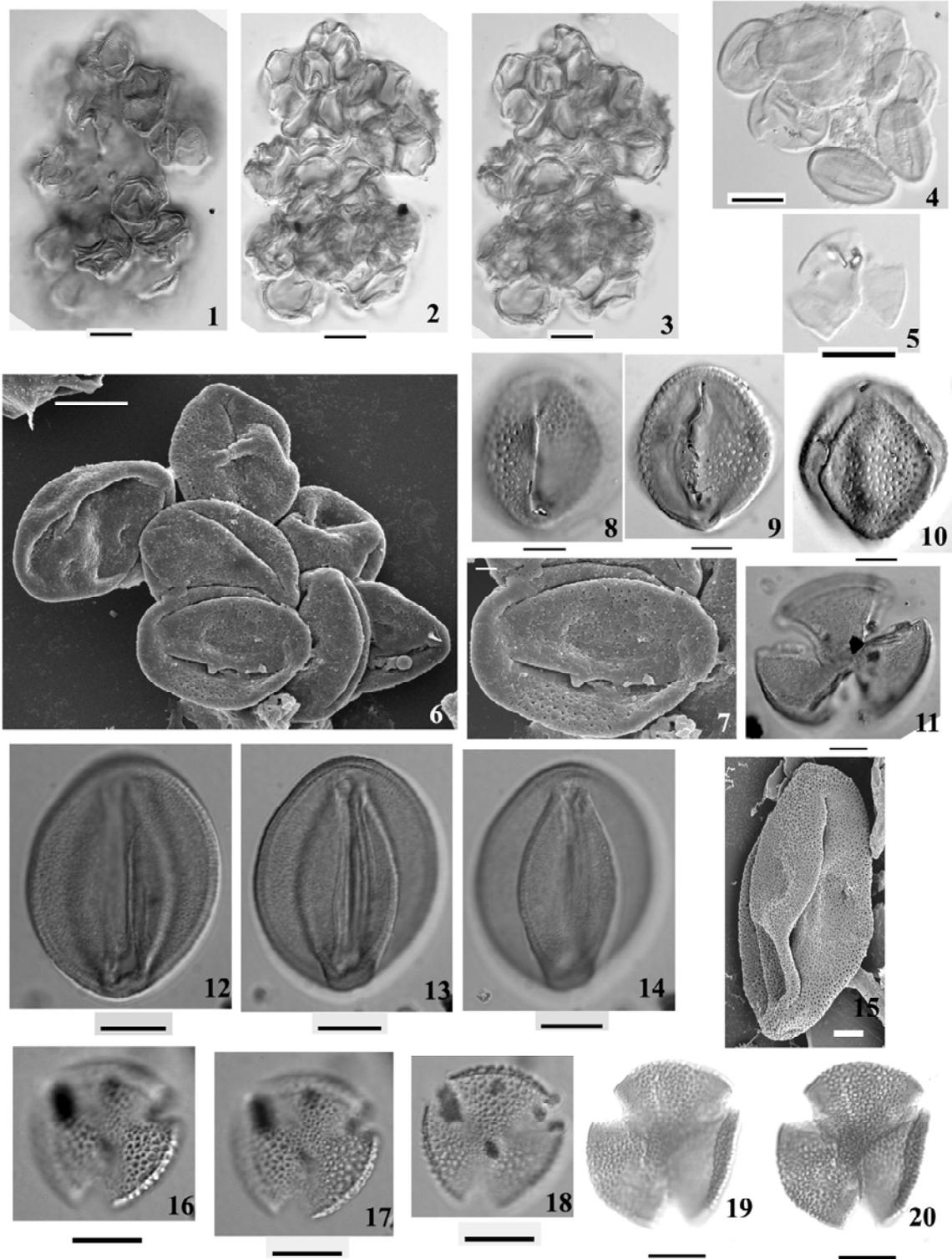


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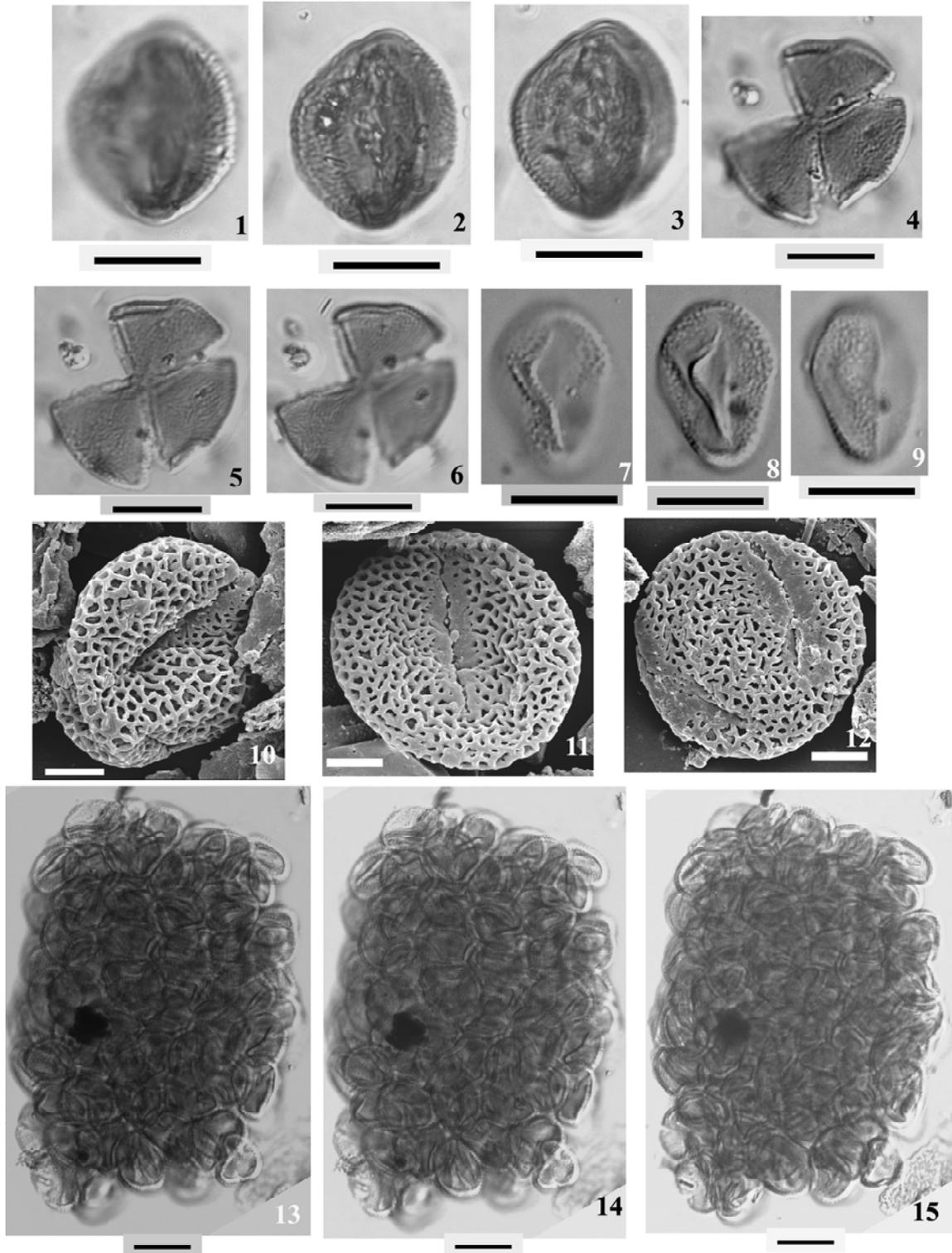


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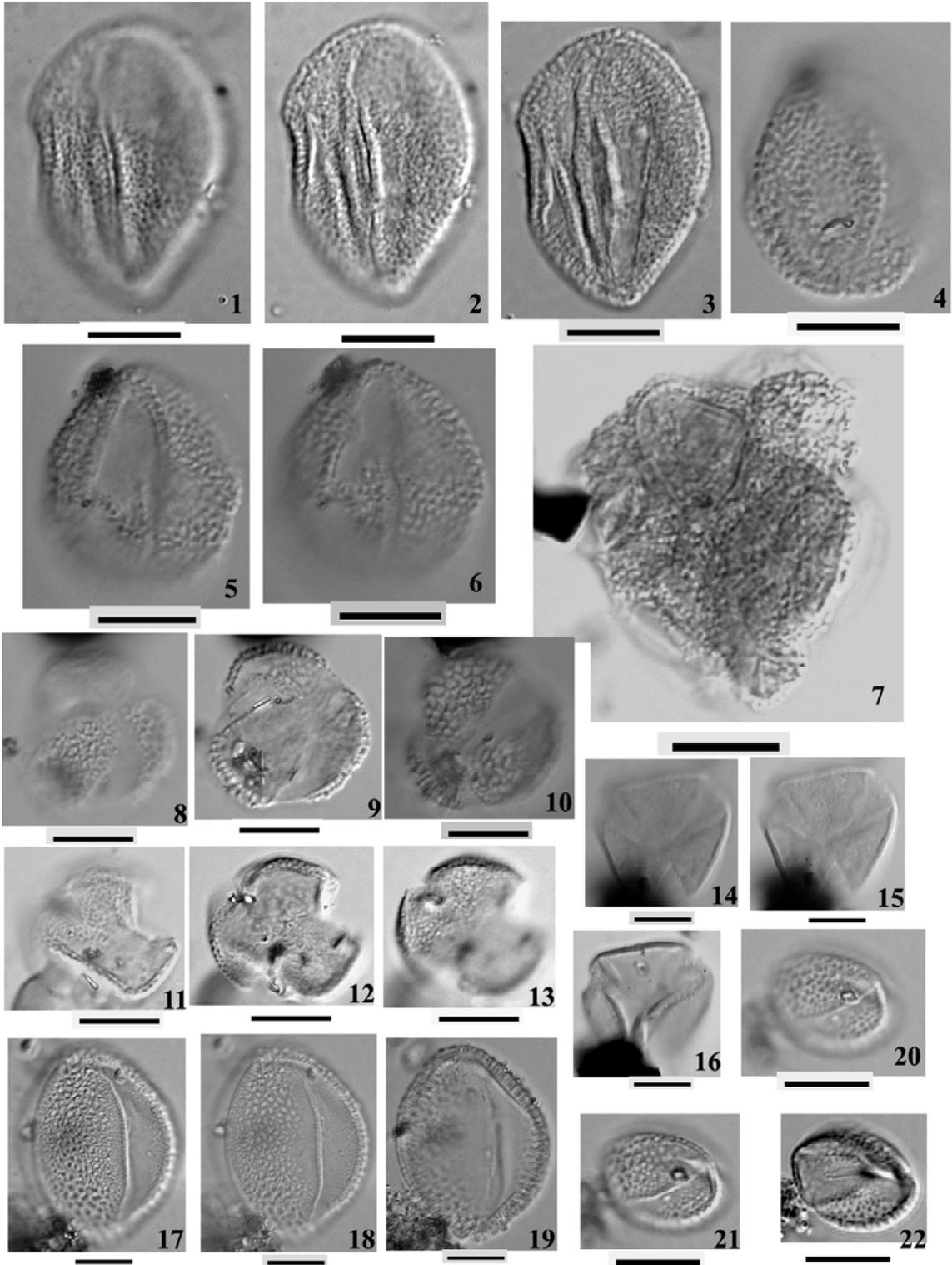


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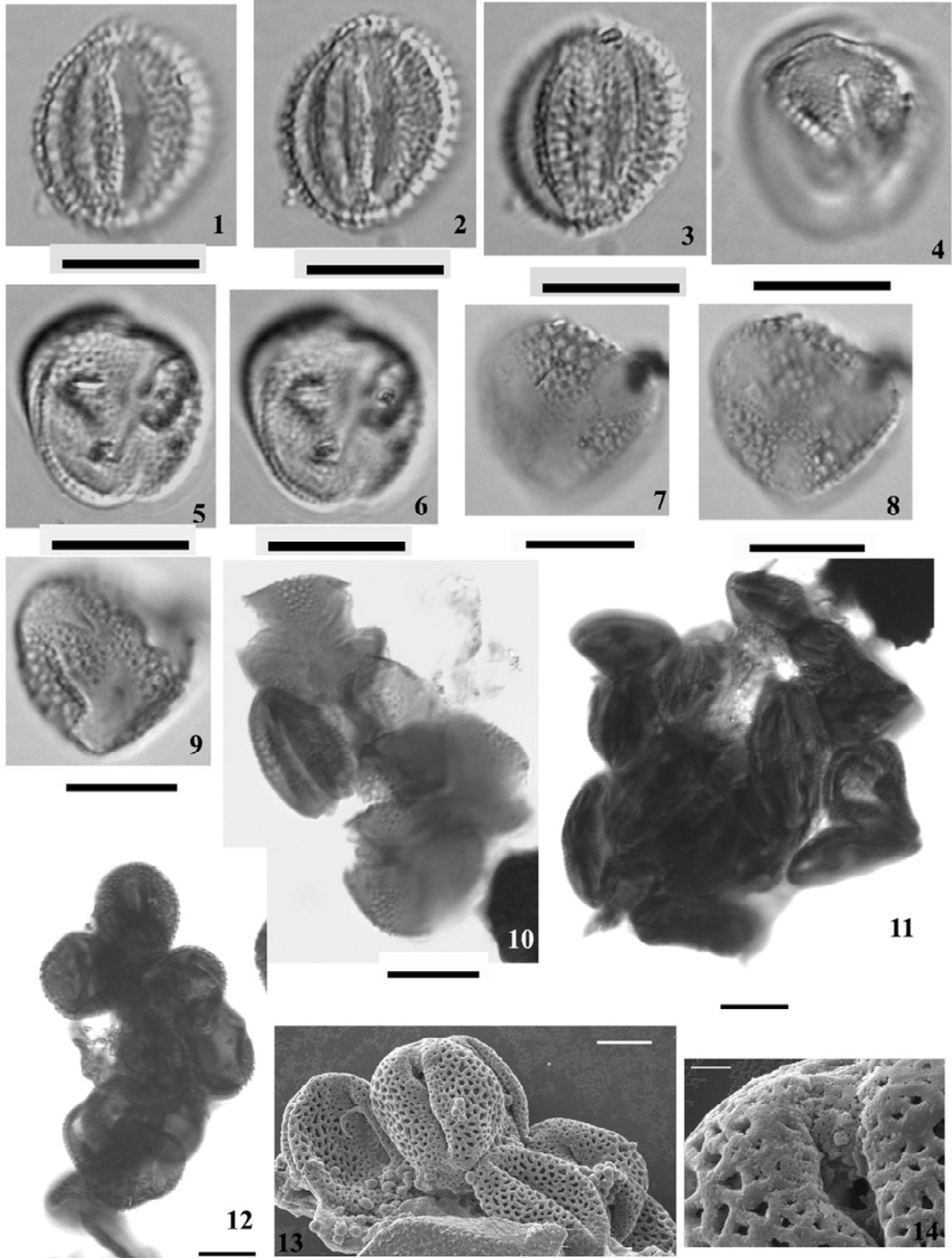


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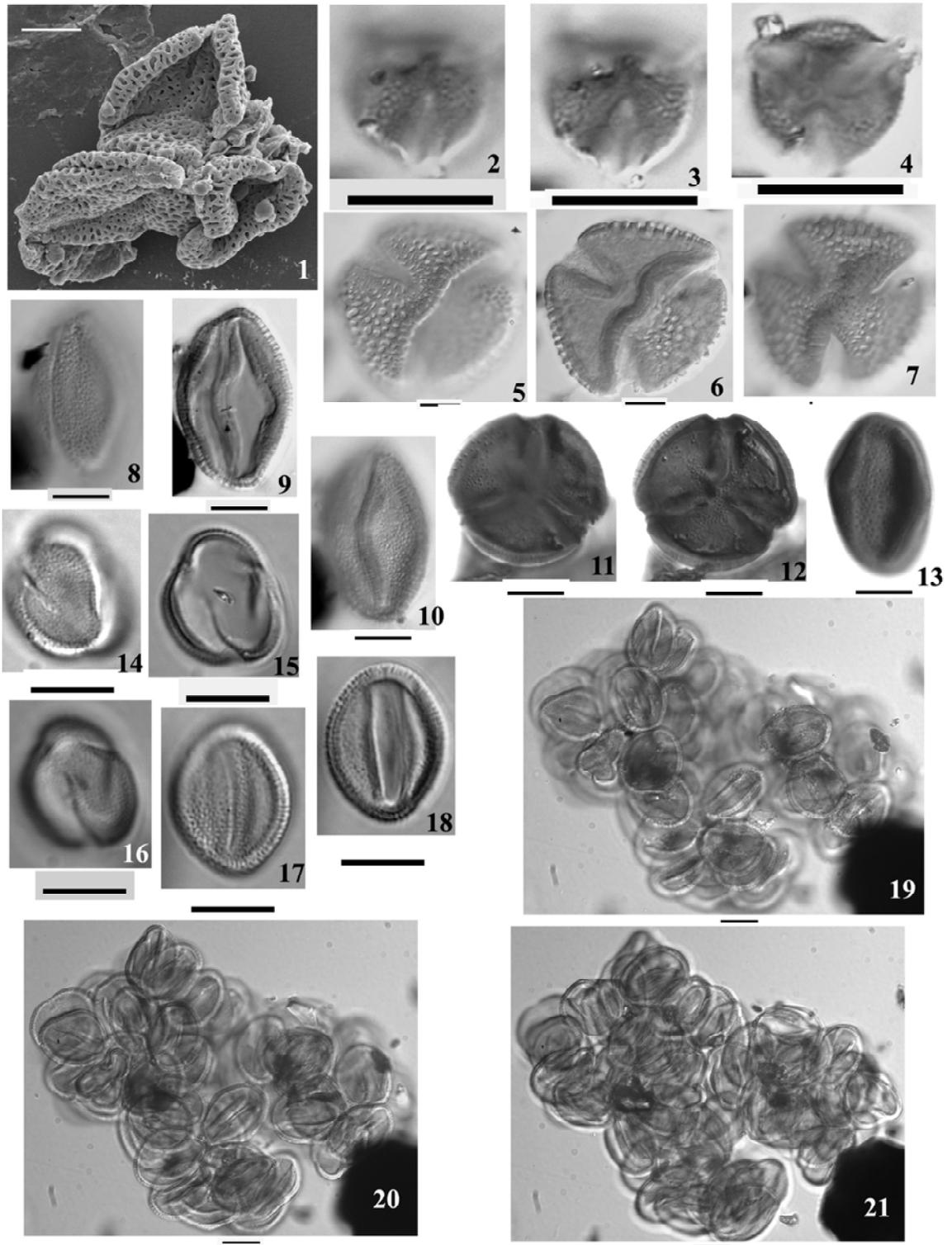


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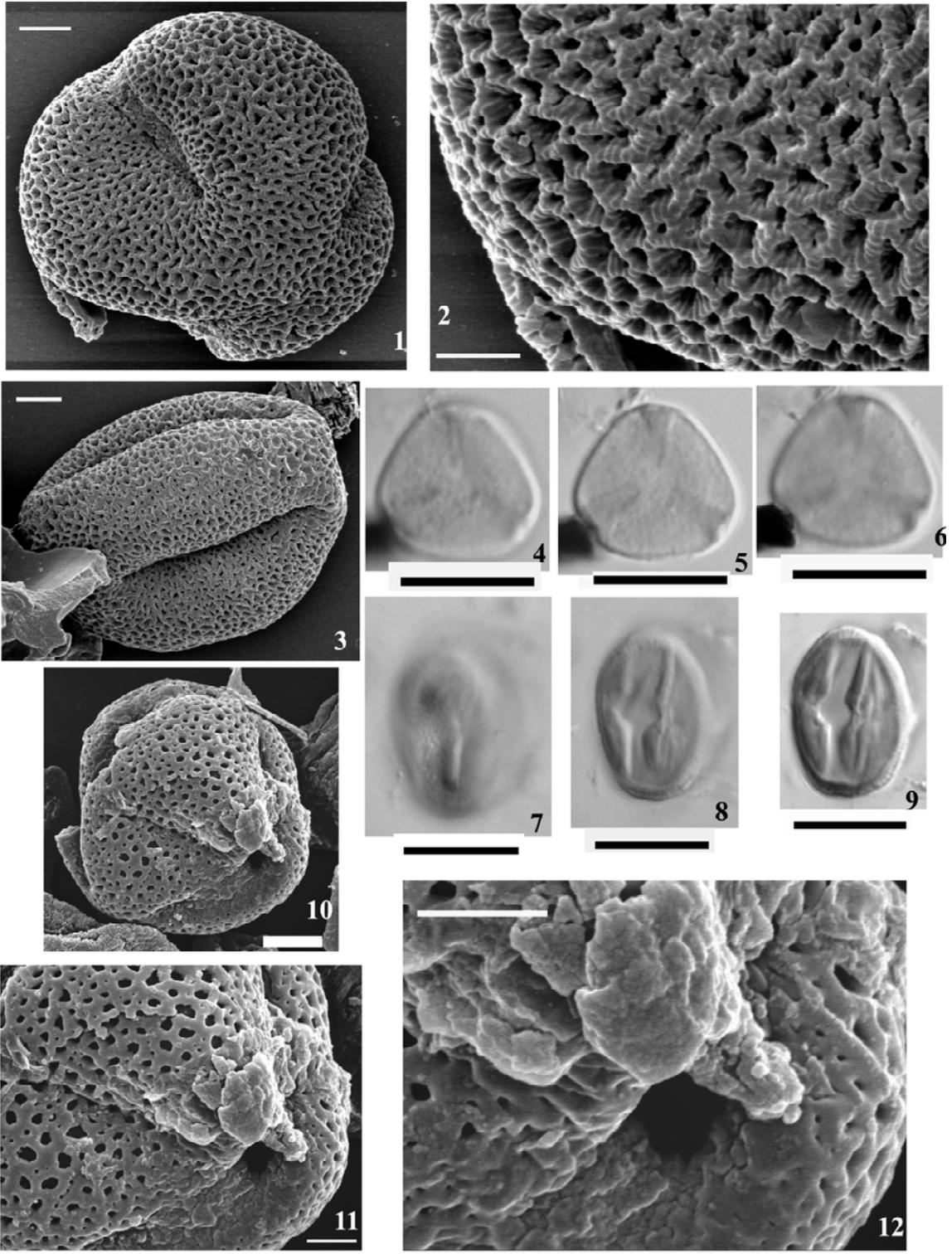


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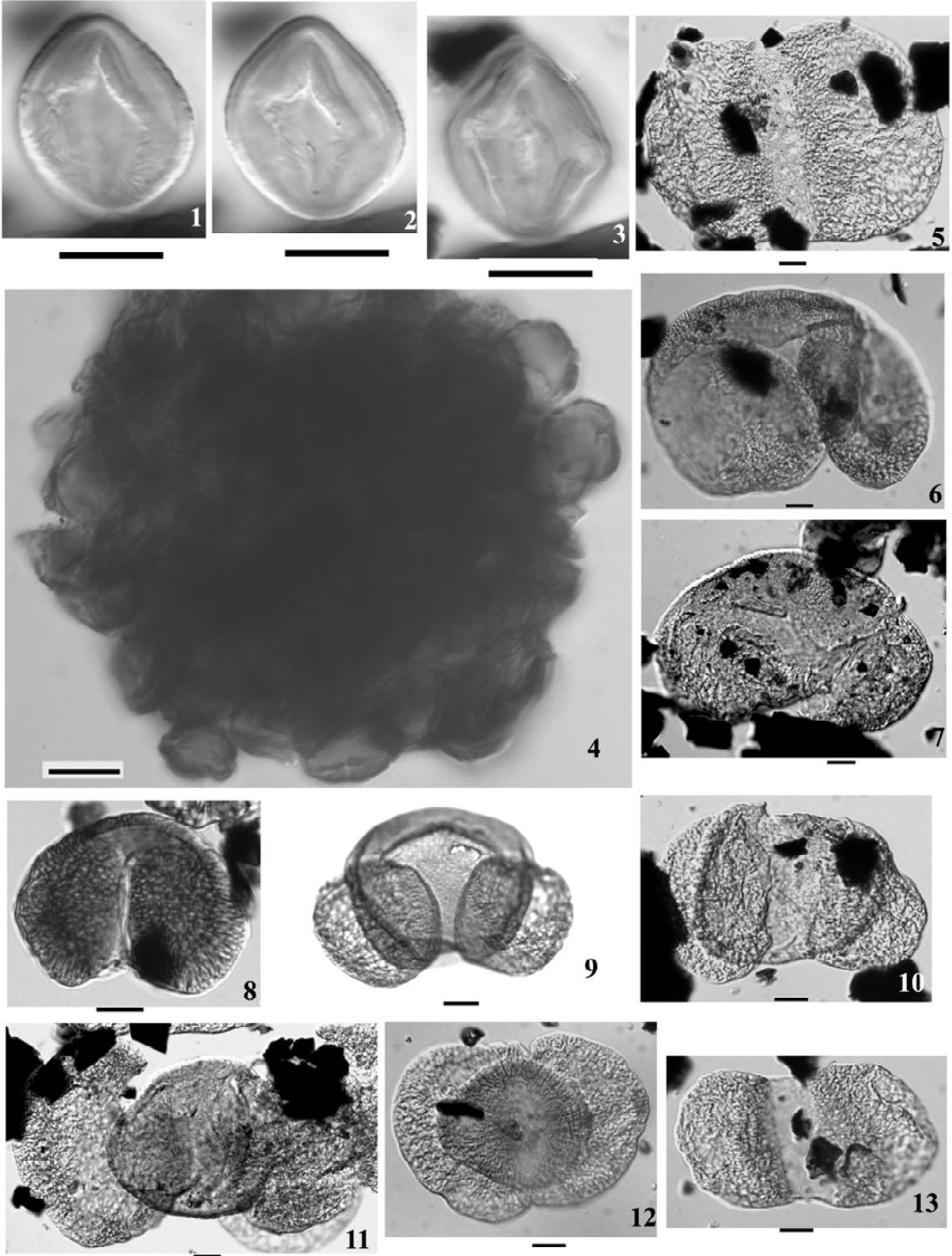


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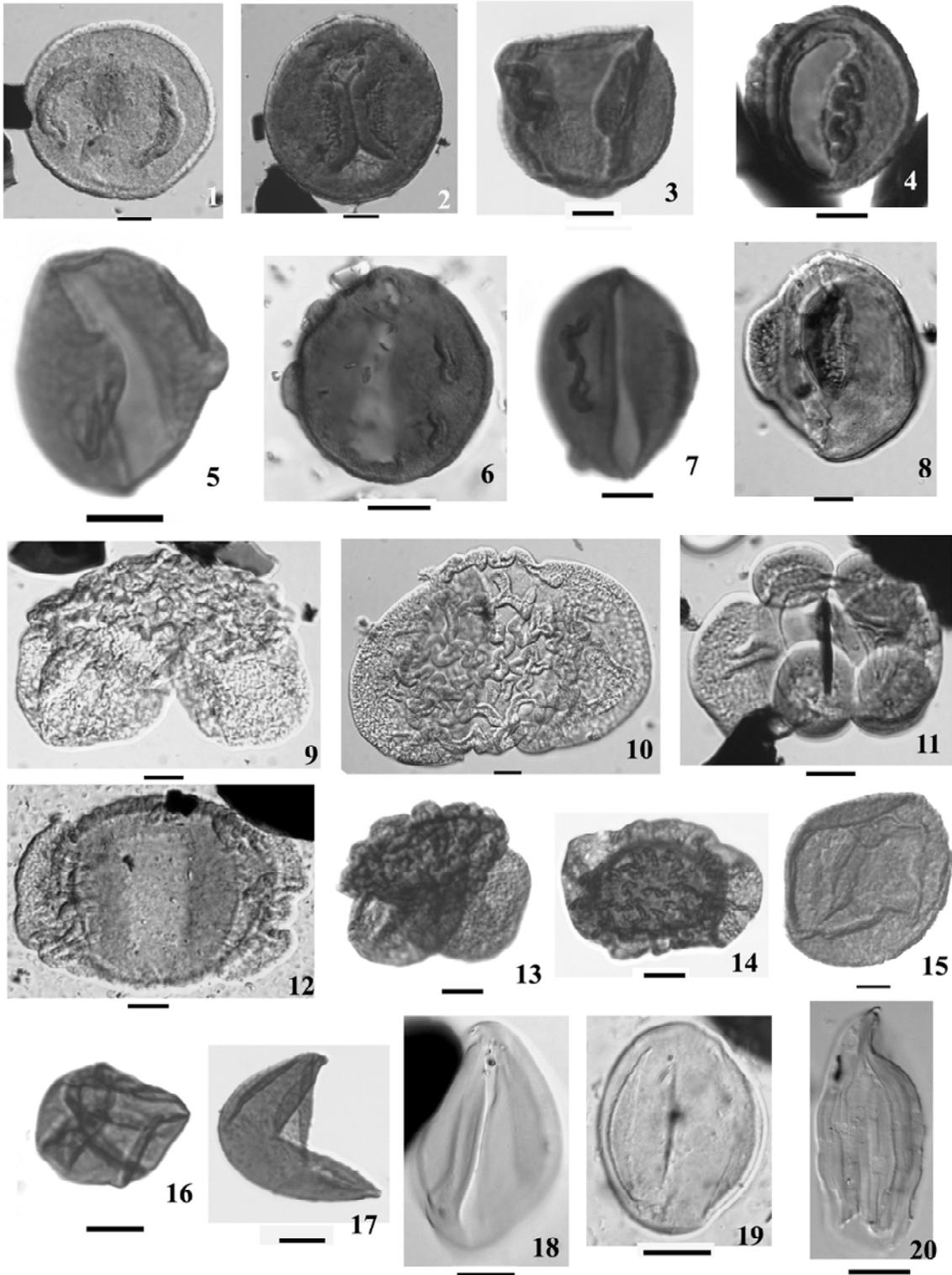


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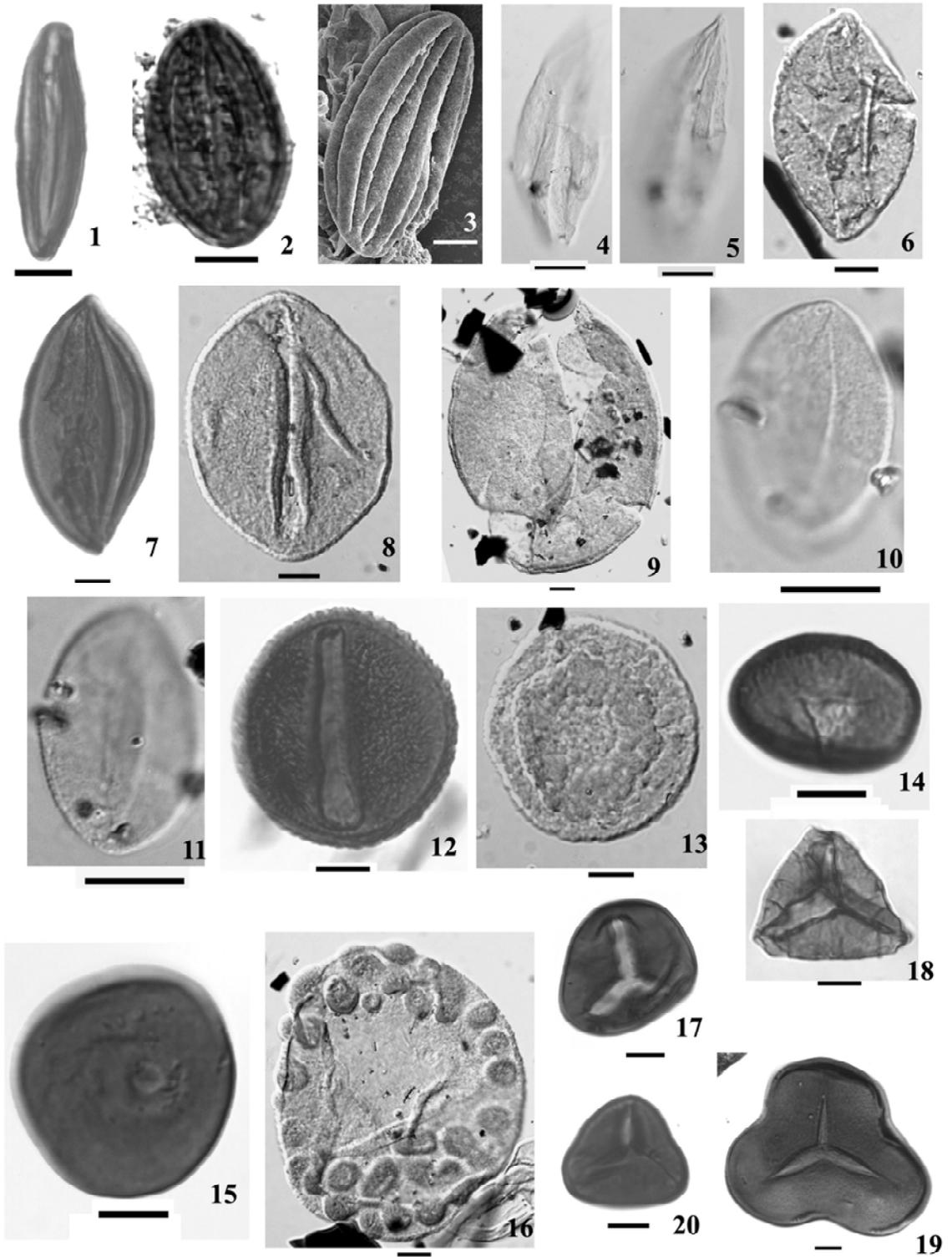


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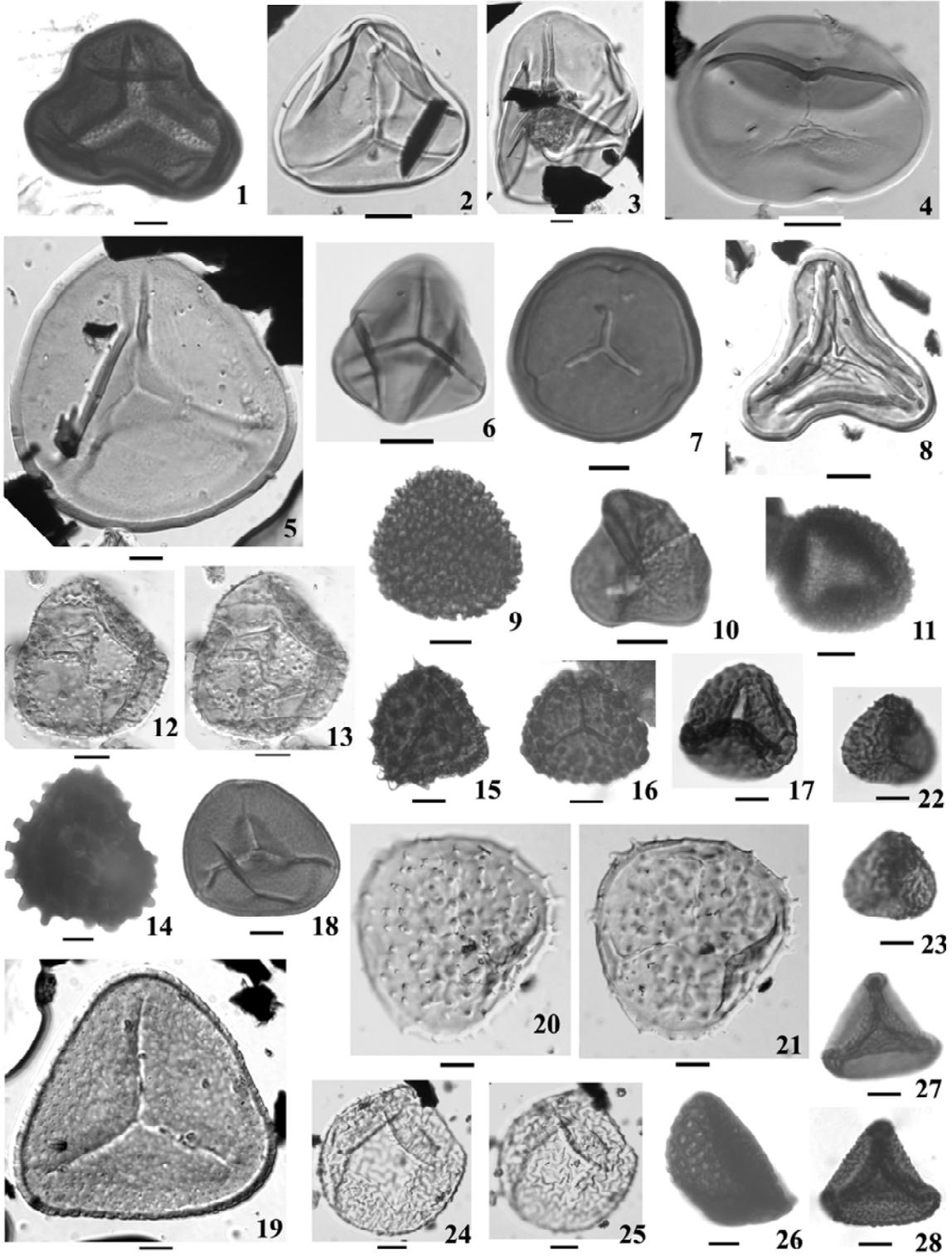


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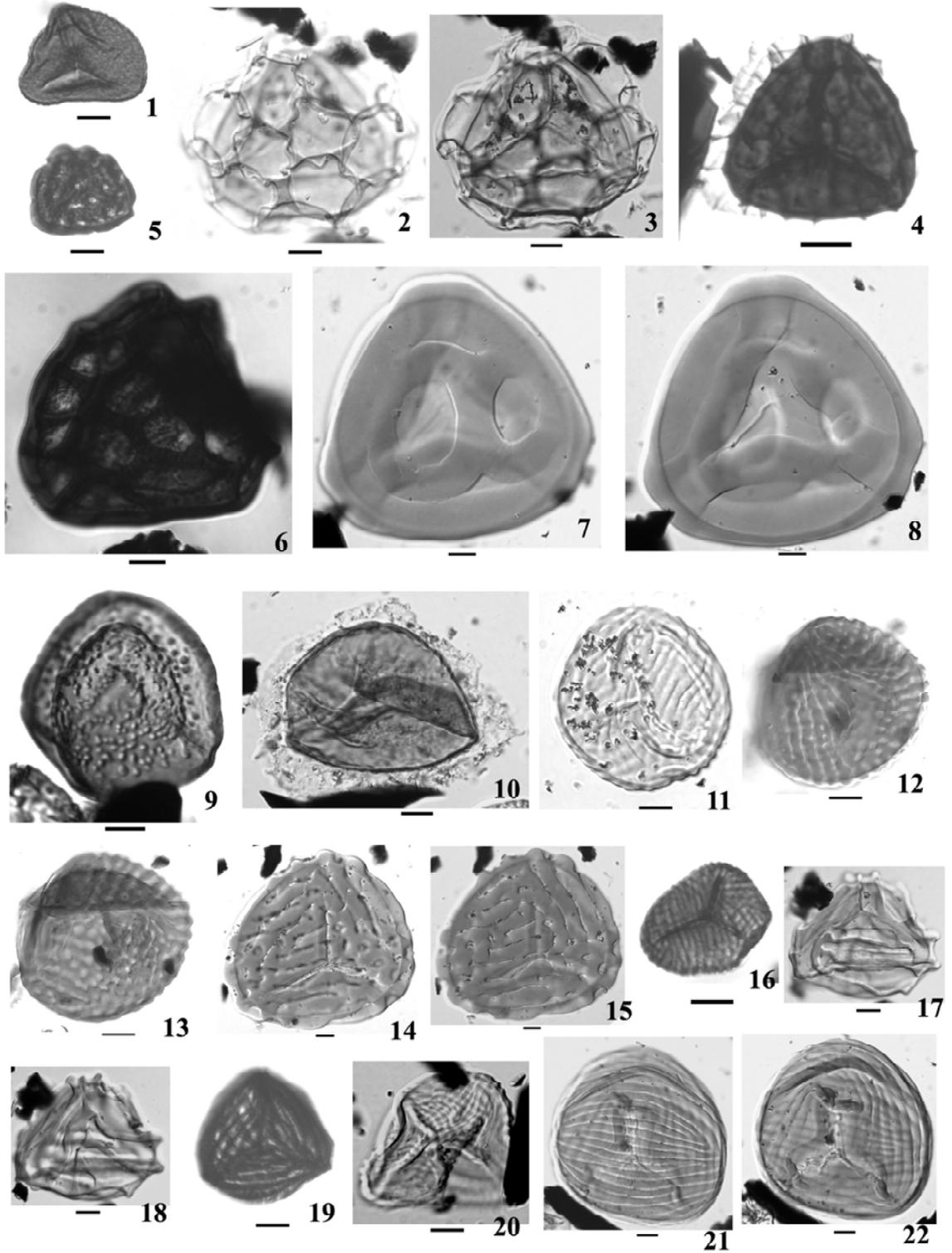


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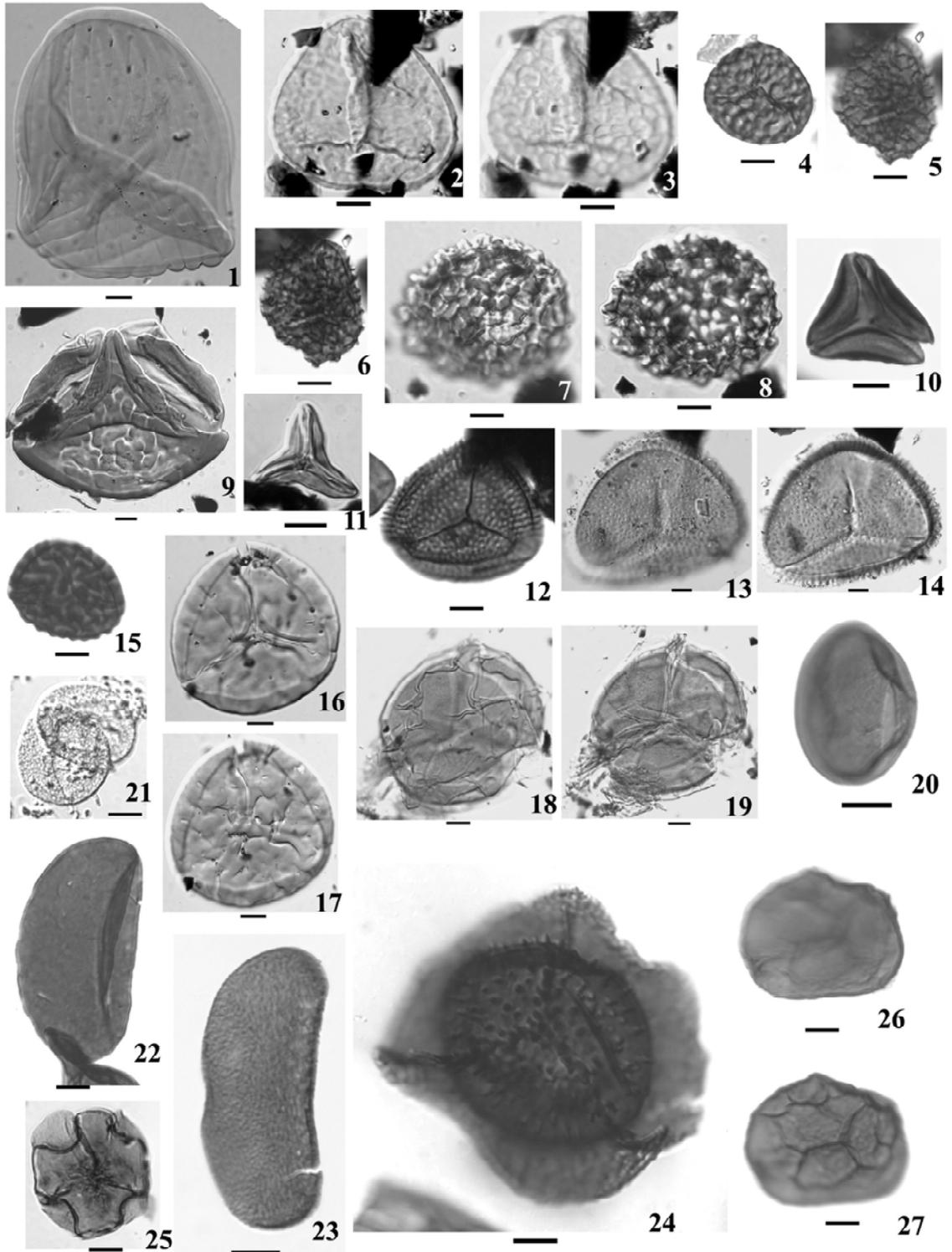


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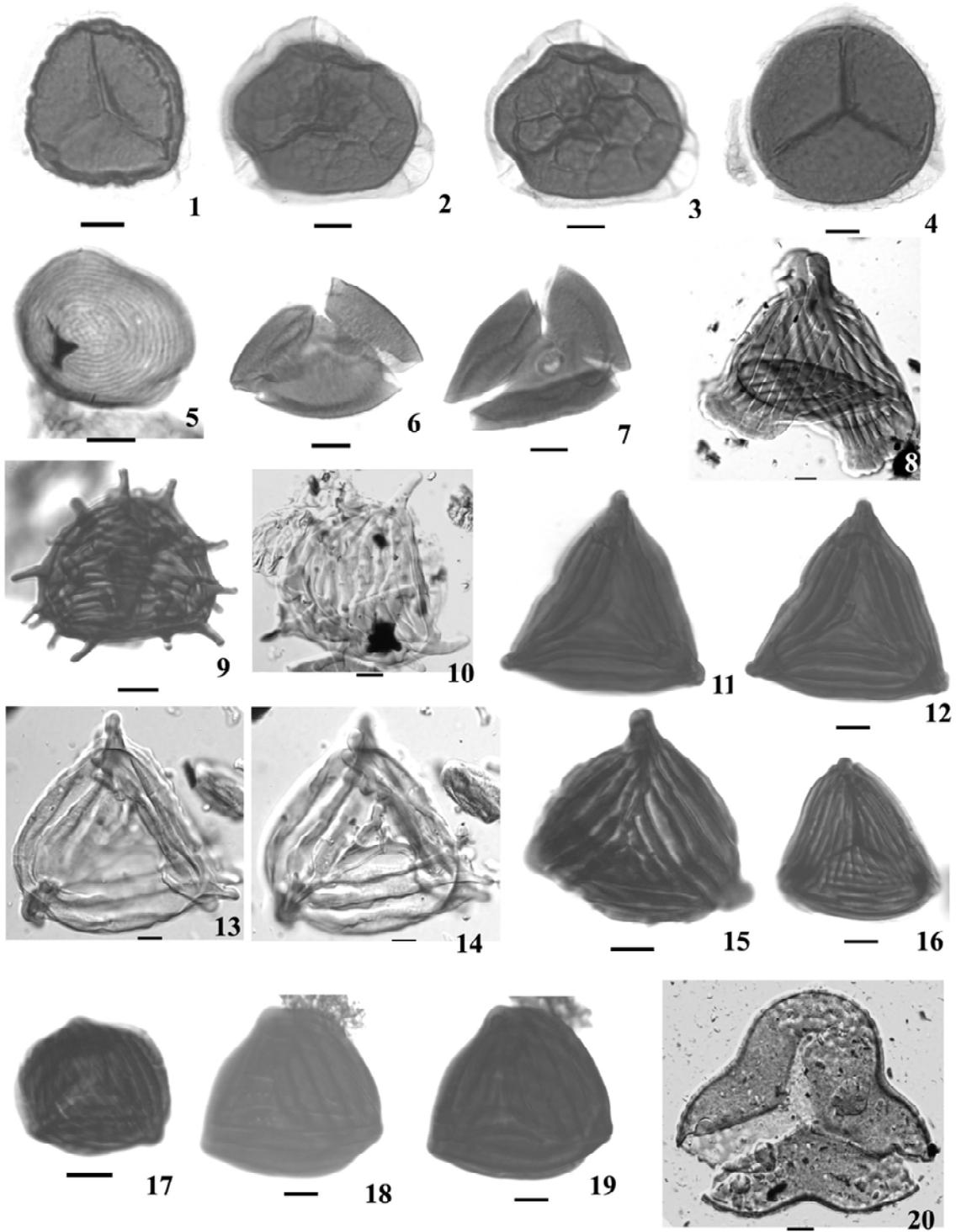


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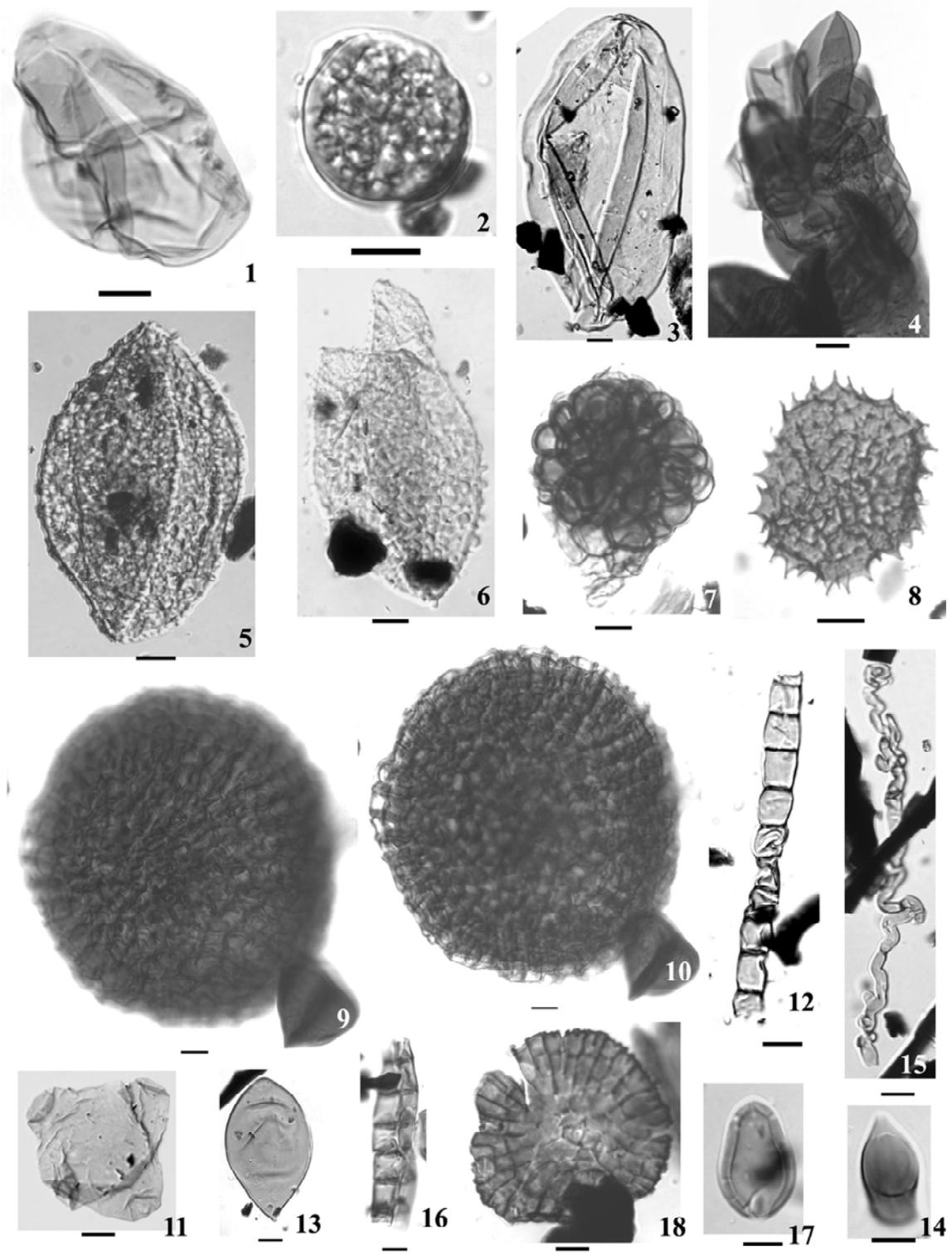


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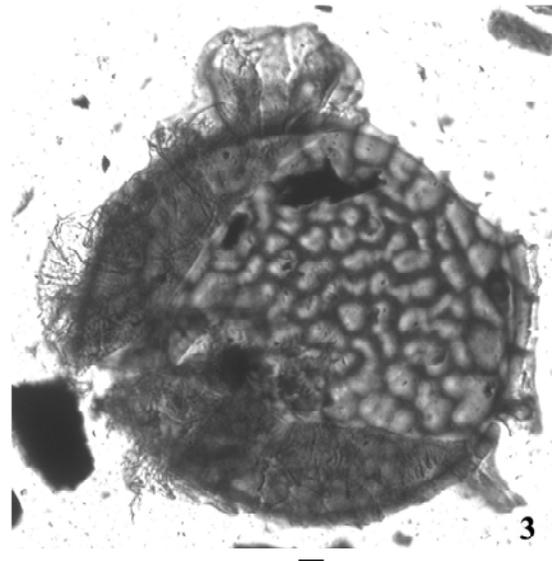
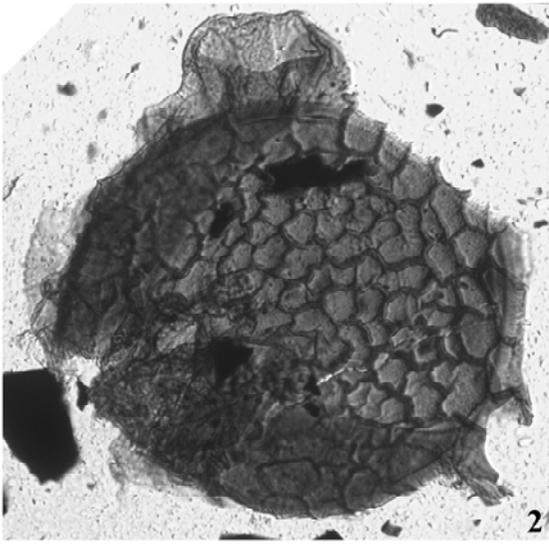
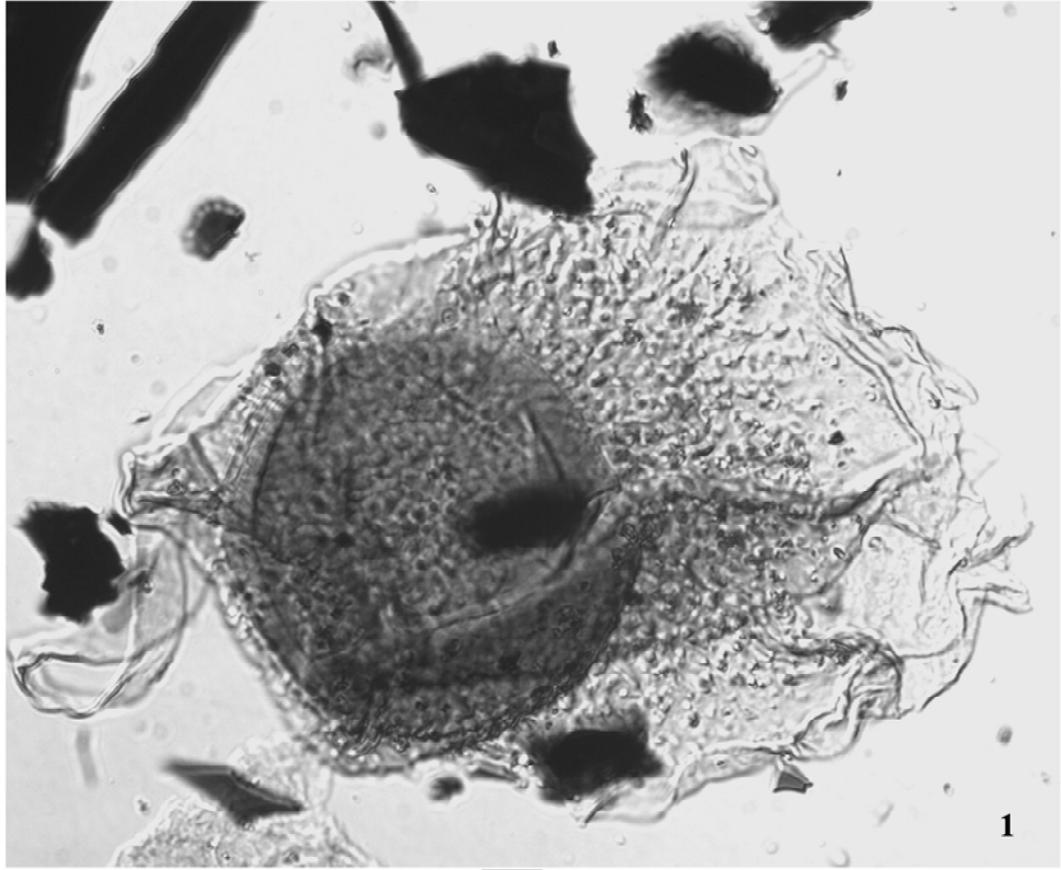


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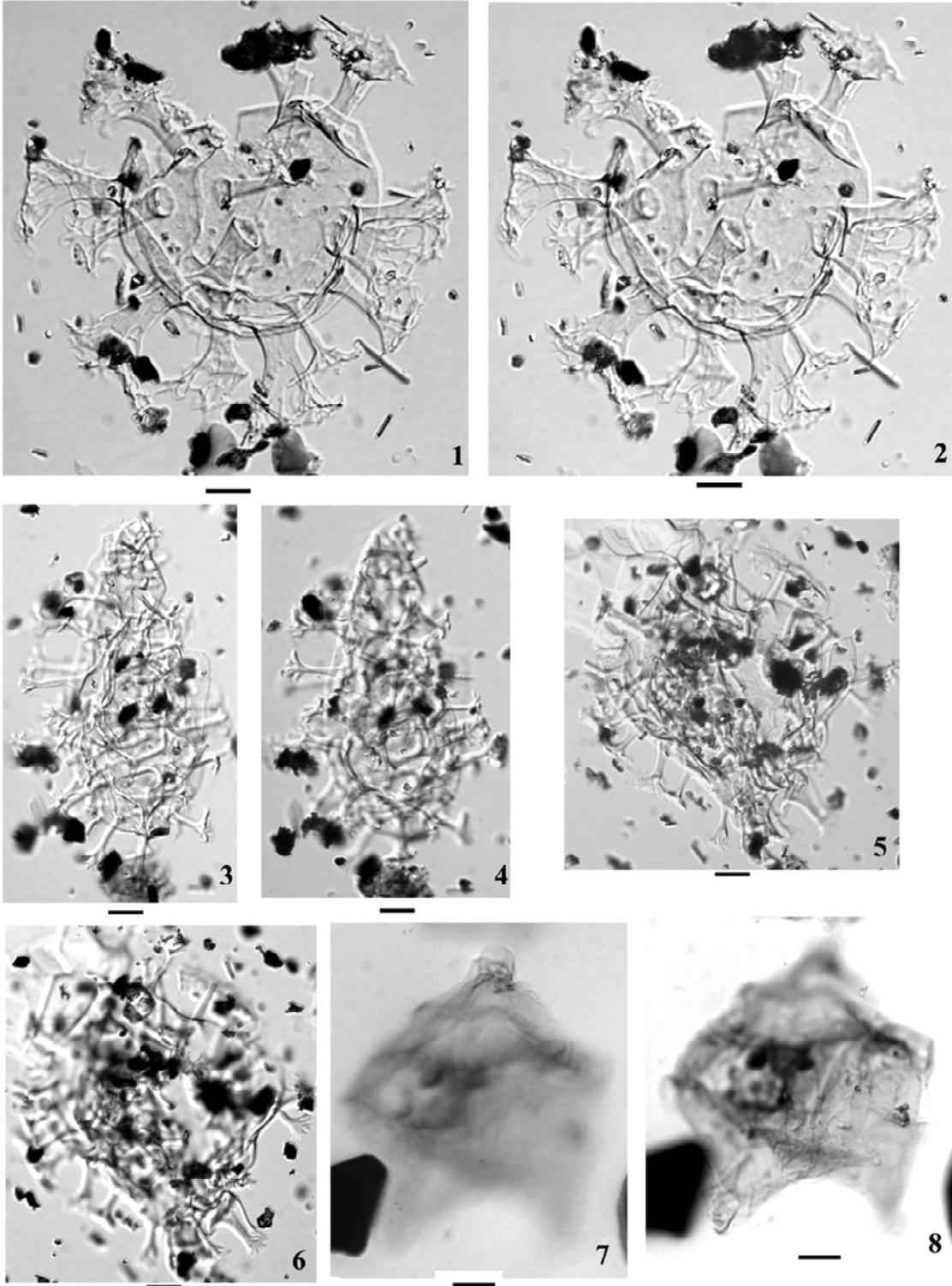


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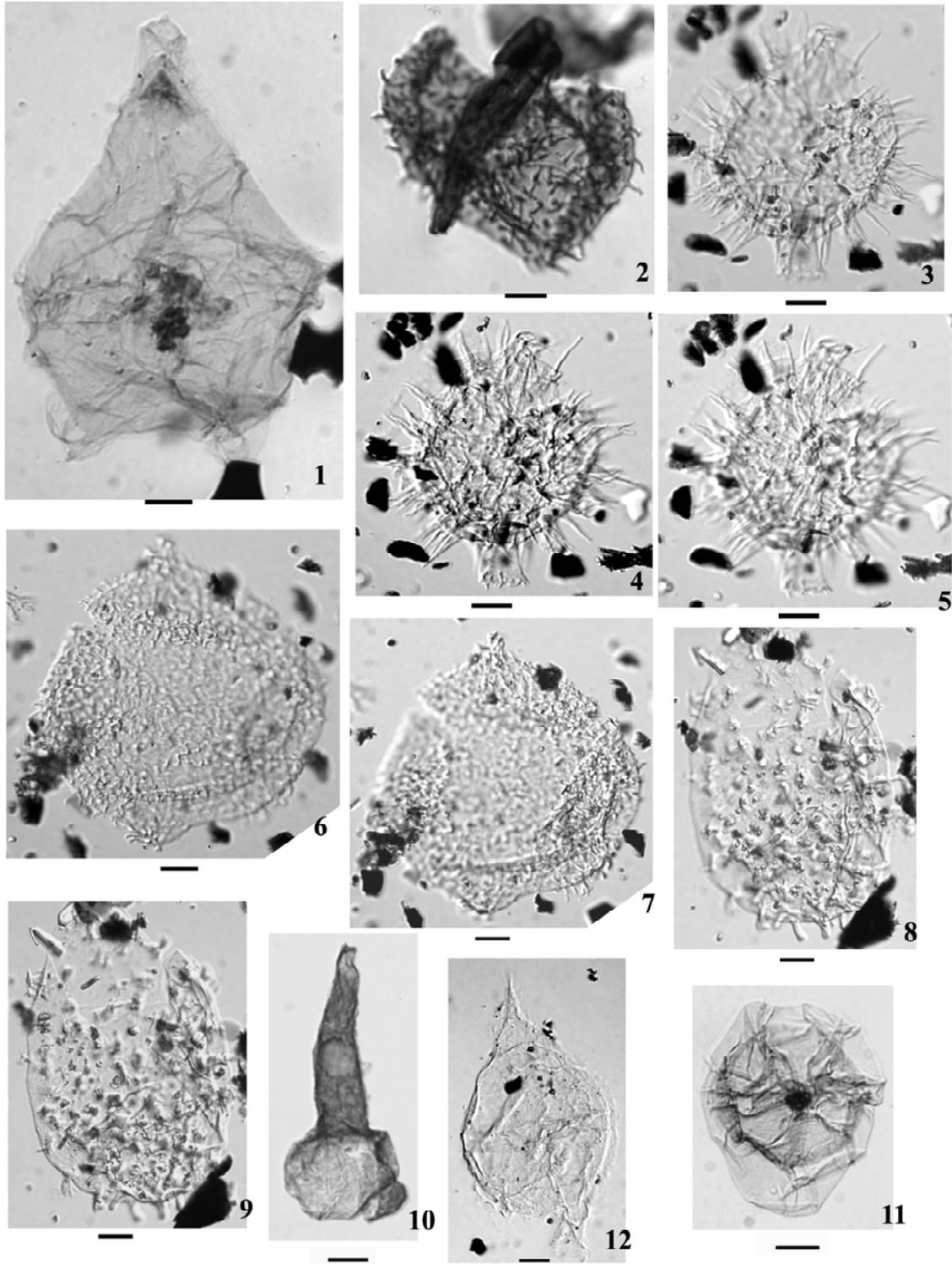


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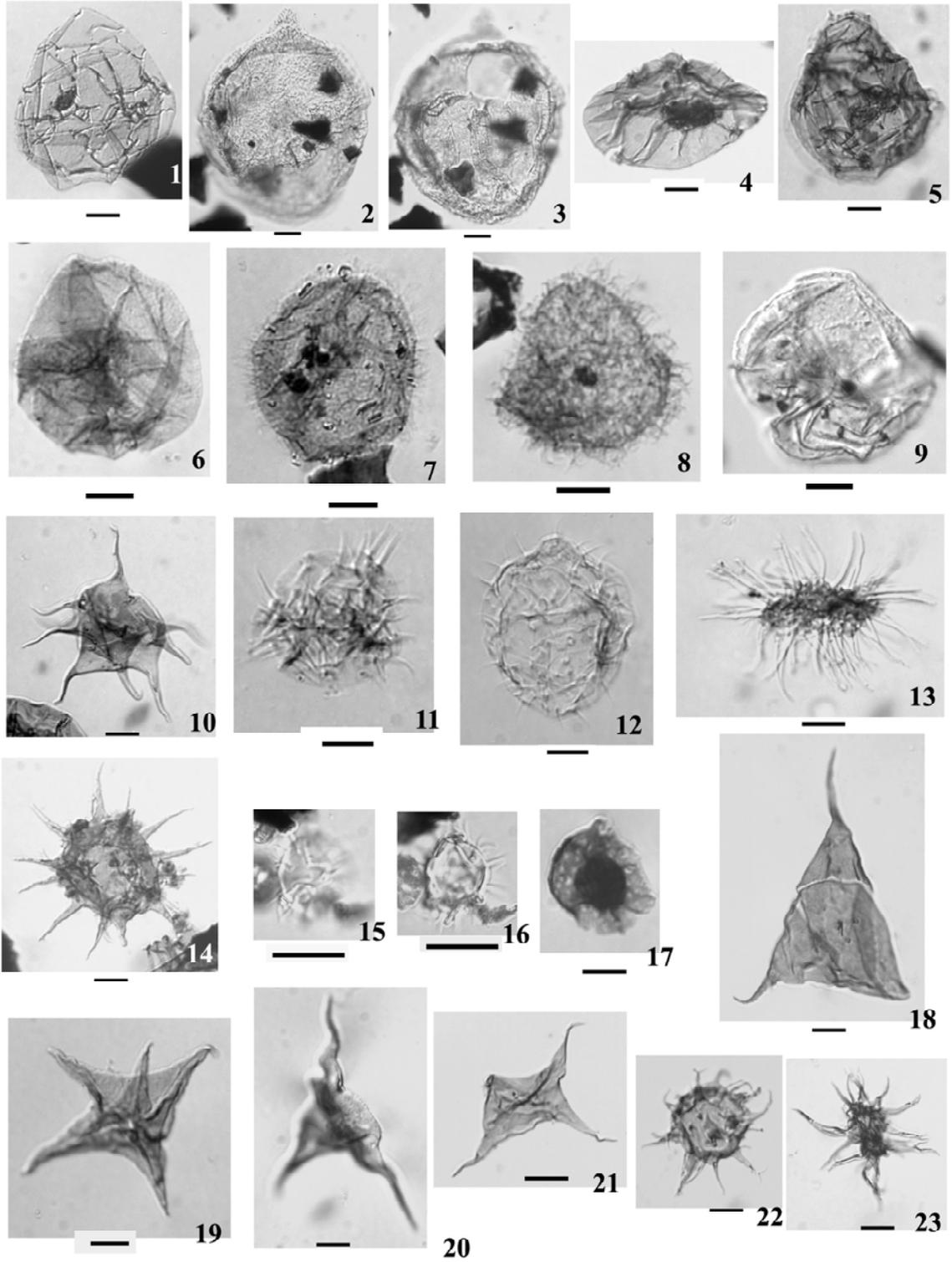


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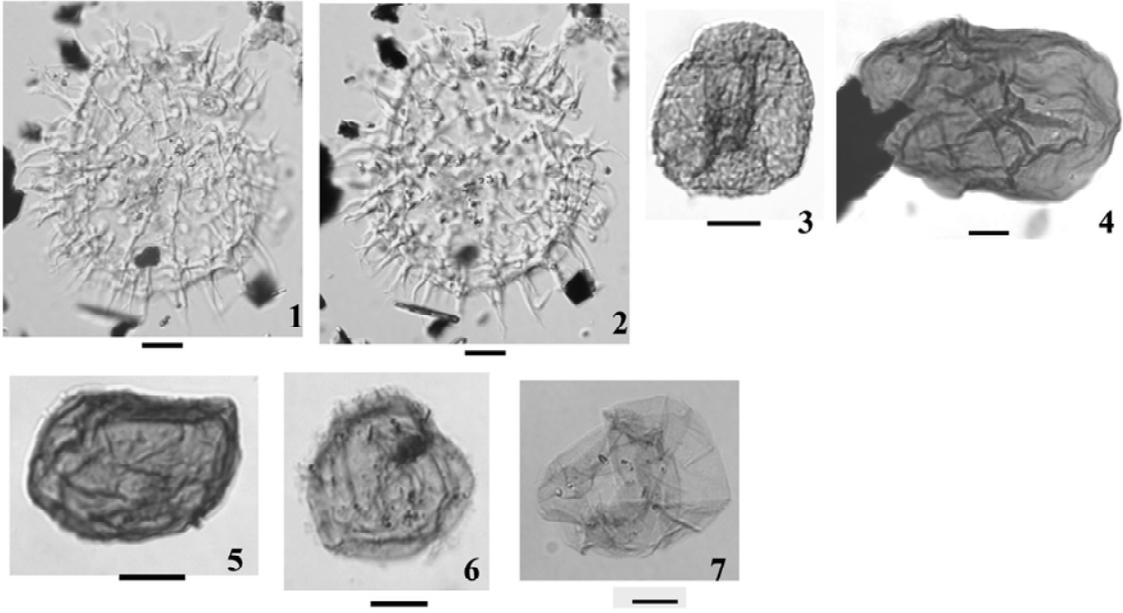


Plate 28

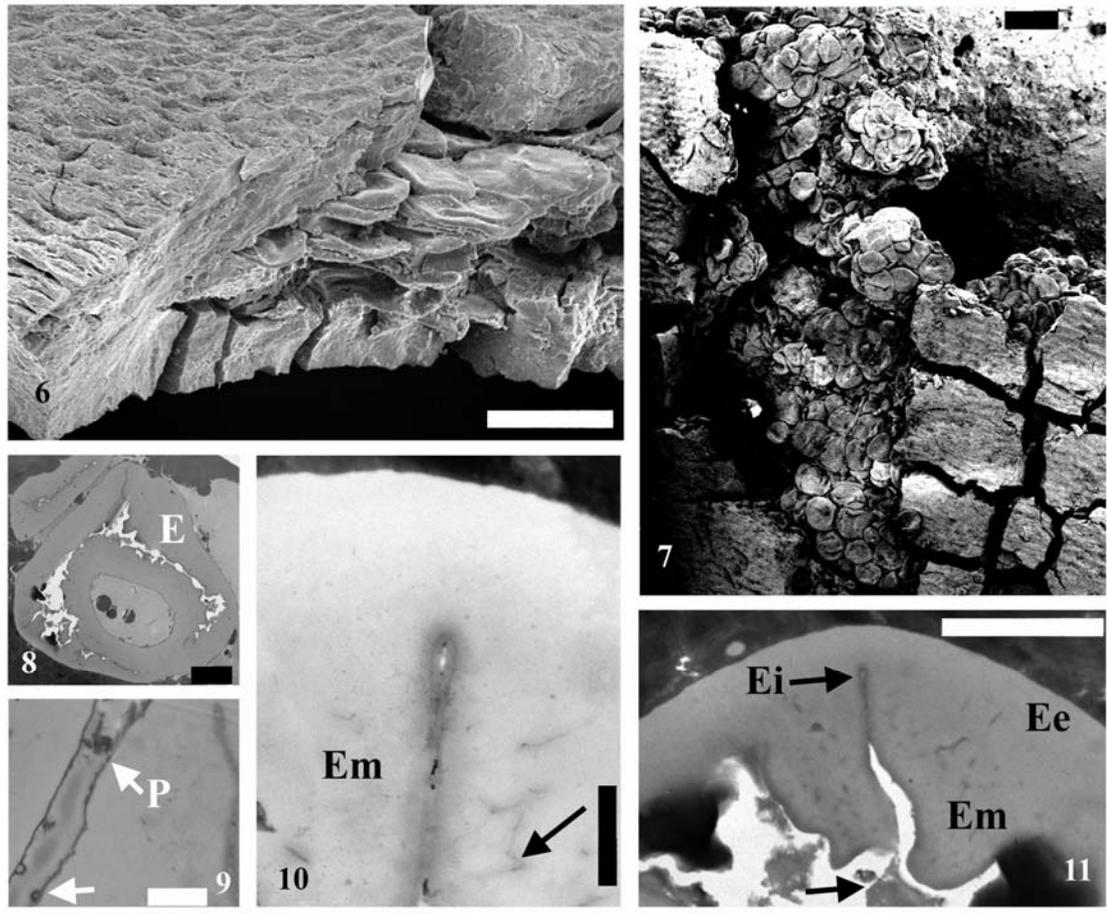
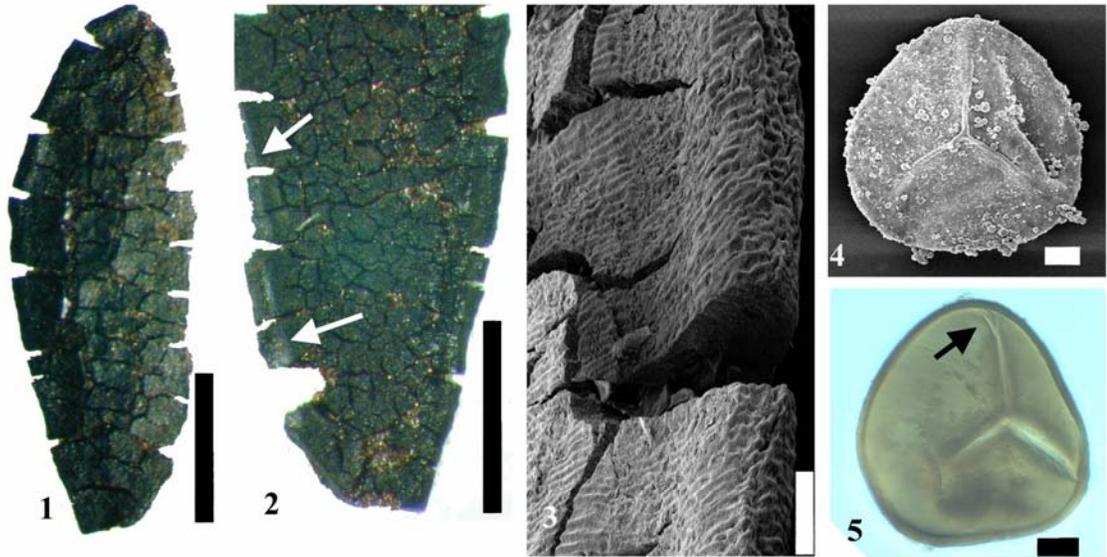
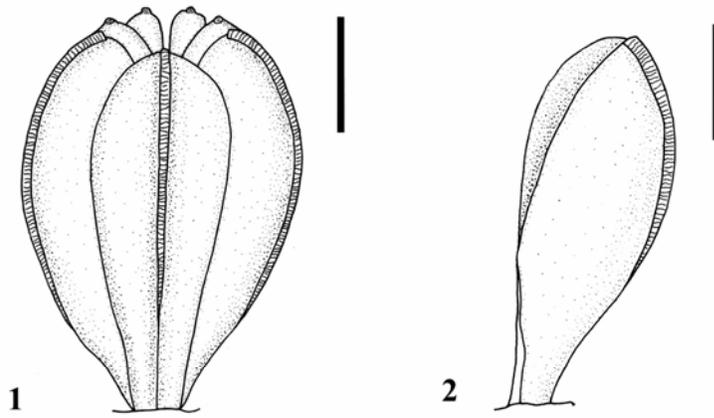


Plate 29



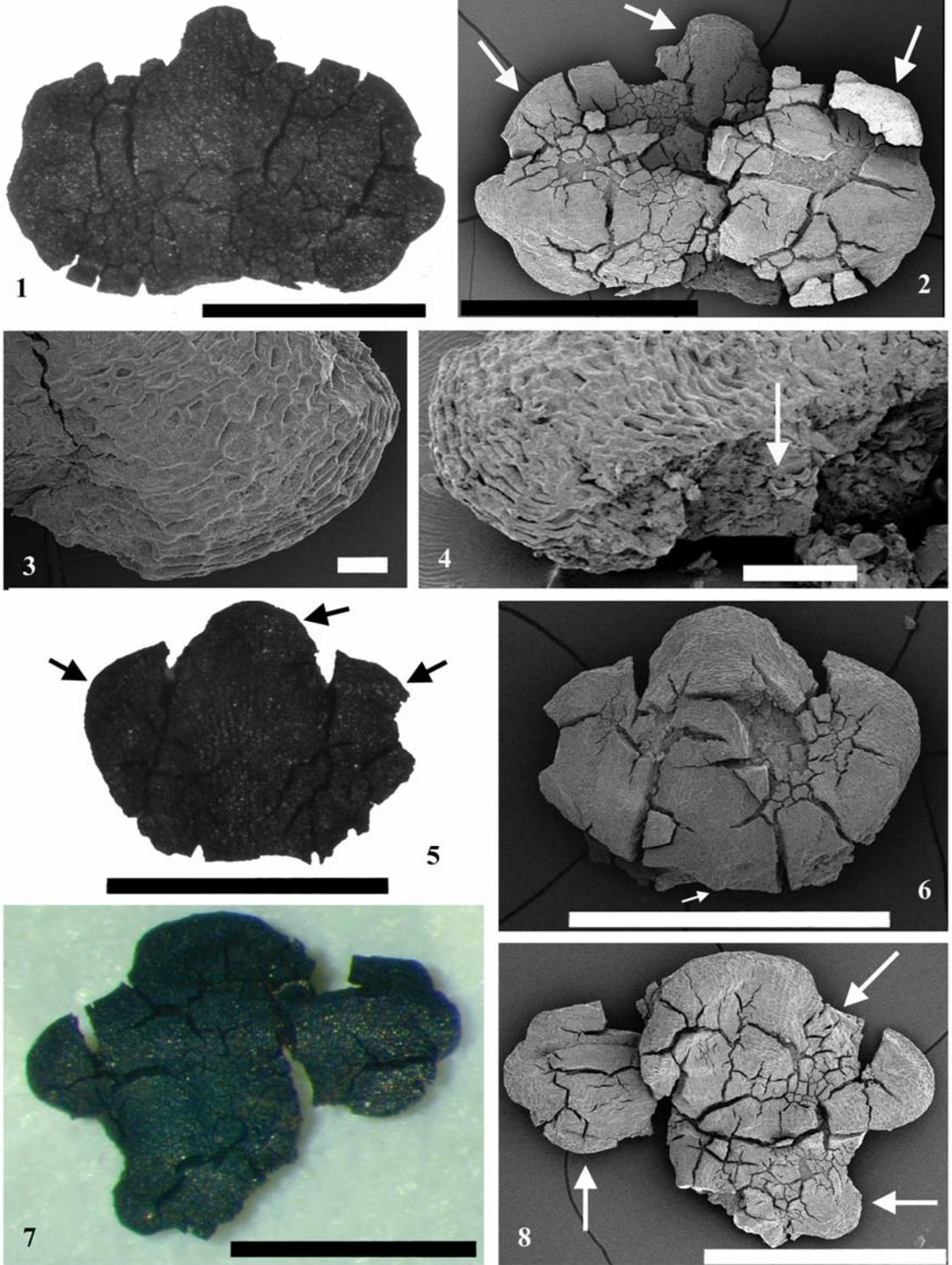


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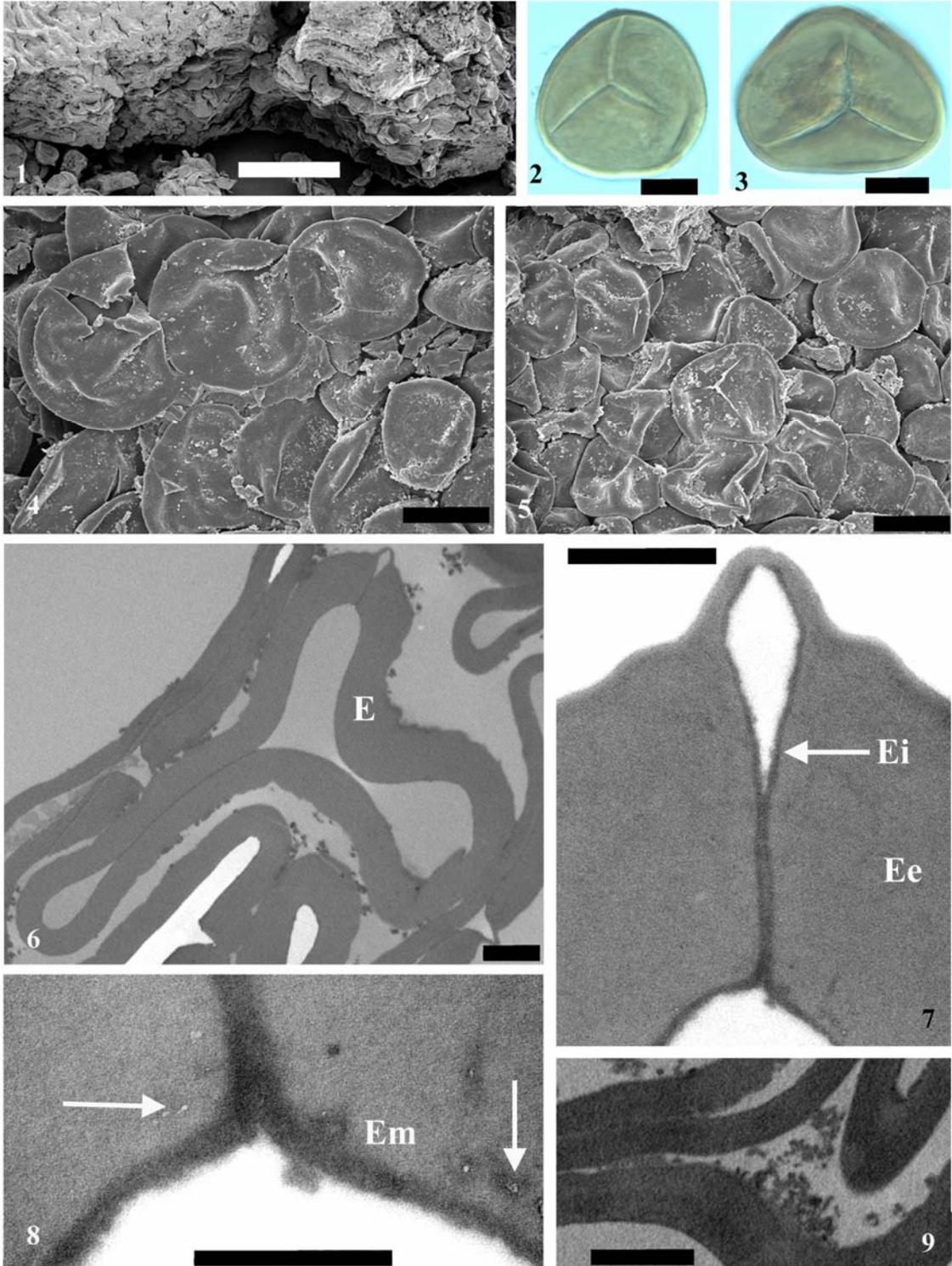


Plate 32

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BIOGRAPHICAL SKETCH

Shusheng Hu was born on July 18, 1965, in Shanxi, China. He obtained a Bachelor of Engineering degree in geology from Shanxi Mining College in 1985. He received a Master of Engineering degree in geology from Beijing Graduate School, China University of Mining and Technology in 1991. In August of 2000 he began his studies toward the degree of Doctor of Philosophy at the University of Florida, Gainesville, Florida, USA.